# THE DOUBLE DIVIDEND HYPOTHESIS OF ENVIRONMENTAL TAXES: A SURVEY

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## 1. INTRODUCTION

In the early seventies, environmental awareness grew and environmental protection started to climb up the political agenda. Right from the beginning of the greening of politics, the idea of taxing polluting activities dating back to Pigou (1920) has been taken up in the political discussion. It was widely accepted that environmental taxes are an efficient instrument to protect the environment, superior to the classical environmental policy instruments of command and control.

The enthusiasm for environmental taxes gained momentum with the double dividend hypothesis. Tax revenues from environmental or green taxes can be used to cut other taxes. This can reap a second dividend as it reduces the distortion due to other taxes. The weak form of this hypothesis states that tax revenues from a revenue-neutral green tax reform can be used to cut distorting taxes thus lowering the efficiency cost of the green tax reform. The strong form of the double dividend asserts that a green tax reform does not only improve the environment but also increases non-environmental welfare. If the latter holds, a green tax reform would be "a so-called 'no-regret' option: even if the environmental benefits are in doubt, an environmental tax reform may be desirable" (Bovenberg 1999, p. 421).[1]

The weak form of the double dividend hypothesis is widely accepted among economists. As a consequence, green tax reforms are nowadays preferred to other environmental tax instruments that – although they are efficient in regulating the environmental – do not raise public revenues.

The question as to whether the strong form holds, however, heavily depends on the structure of the economy. While a green tax reform is likely to fail to increase non-environmental welfare in economies with functioning labour markets, it may succeed in economies suffering from involuntary unemployment.

This survey focuses on this distinction in reviewing the literature on the double dividend hypothesis and its recent extensions. The next section first provides a brief sketch of the classical concept of environmental taxation. Then a model is presented that allows us to (i) restate the main results of the double dividend literature derived in the nineties and (ii) discuss two important extensions made in the recent literature and how they affect the standard results. The first extension focuses on an apparently technical point that, however, turns out to

[1] The distinction between the weak and the strong form of the double dividend hypothesis is due to Goulder (1995) who surveys the early literature. Recent surveys on the double dividend hypothesis are Bovenberg (1995, 1998, 1999), Schöb (1995), Bosello, Carraro and Galeotti (2001) and Kirchgässner (1998).

be of importance if it comes to sound policy recommendations: if environmental problems are severe, we can expect individuals to protect themselves from the consequences of pollution by e.g. buying defensive goods. Severe pollution may also affect labour supply negatively thus reducing employment. If this is the case, relaxing the assumption of separability between pollution and consumption is an important issue. Furthermore, as the political debate about the introduction of green taxes demonstrated, distributional considerations cannot be separated from efficiency considerations. Section 2 therefore also studies how optimal tax formulae have to be adjusted, taking equity considerations into account.

The main purpose of the third section is then to point out the importance of the labour market for the determination of optimal environmental taxation or – adopting a more moderate approach – for welfare improving green tax reform. While the analysis of Section 2 assumes perfect labour markets and thus may be a good approximation for the US economy, it certainly fails to provide an appropriate framework for analysing green tax reforms in European countries. Section 3 therefore considers the double-dividend hypothesis for imperfect labour markets. This section will analyse under which conditions environmental taxes on polluting inputs in production and on polluting consumption goods reap a second dividend in the form of an employment dividend and discuss the welfare implication. The aim of this section is to point out the differences in the tax incidence for countries with perfect labour markets and countries facing labour market imperfections.

Section 4 turns to the international aspects of environmental taxation. A first important question about international environmental problems is whether countries should introduce environmental taxes unilaterally or should try to harmonise environmental taxes. This question will be addressed by looking at the competitiveness of an economy. Therefore Section 4 will use a graphical model for the two models developed in Section 2 and Section 3, respectively. Another question concerns the international distribution of the rents environmental taxation can generate. Here we stress the fact that environmental problems are normally tied to the use of exhaustible resources. Depending on the time path of an environmental tax, the extraction rate of natural resources varies and hence the time path of pollution. The design of environmental taxes in the long run may not only affect the intertemporal allocation but will have severe consequences on the international distribution of wealth as they affect the distribution of resource rents. A final section concludes.

## 2. THE DOUBLE-DIVIDEND HYPOTHESIS: RECENT EXTENSIONS

In the classical contribution about environmental taxation, Pigou (1920) has shown that an optimal tax on emissions has to be set equal to the marginal environmental damage (*MED*). Such a 'Pigovian tax' can ensure that polluters pay for the marginal social cost of their consumption of polluting goods completely. The concept of Pigovian taxation can be seen from Figure 2.1, which can be found in every textbook on environmental economics.

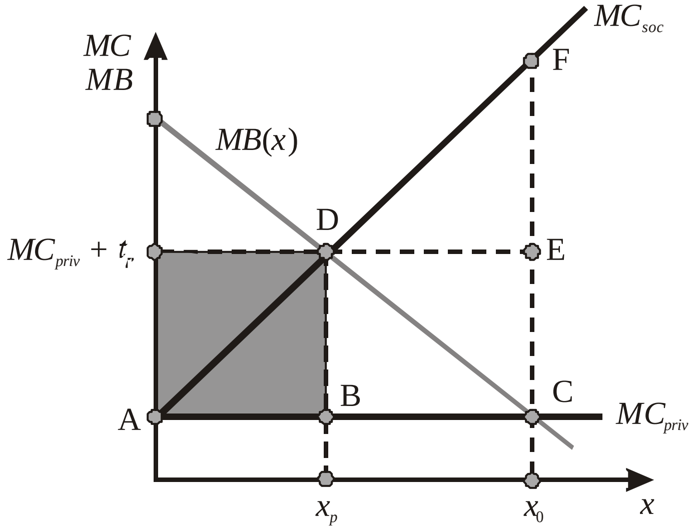


**Figure 2.1:** *Pigovian tax*

In Figure 2.1 we consider the case of a polluting consumption good $x$. $MB(x)$ describes the marginal benefit of consumption, $MC_{priv}$ the private marginal cost, and $MC_{soc}$ the social marginal cost, respectively. Without environmental regulation, the competitive market outcome leads to an equalisation of private marginal costs and private marginal benefits. The market equilibrium is $x_0$. The welfare loss in the equilibrium is equal to the area CDF as the marginal social cost $MC_{soc}$ exceeds the marginal benefit of consumption $MB$ for all units consumed in excess of $x_P$. Piecemeal extension of the dirty good consumption from zero to $x_P$ however, increases welfare. Pareto optimality is achieved where the marginal private cost $MC_{priv}$ plus the external cost $MED$ equal the marginal benefit. [cf. e.g. Baumol and Oates (1988)].

The Pigovian tax $t_P$ can sustain the Pareto-efficient outcome. This tax leads to tax revenues equal to the area shaded in grey. These tax revenues may be used to reduce the excess burden of other taxes. According to the so-called weak form of the double-dividend hypothesis,[2] environmental taxes are expected not only to improve the quality of the environment but also to reduce the distortions of existing taxes on e.g. labour and capital income. This idea was first mentioned by Tullock (1967) and has been supported by partial equilibrium models in the eighties, developed by Nichols (1984), Terkla (1984) and Lee and Misiolek (1986).

Based on the seminal paper by Sandmo (1975), however, this view has been questioned by several papers e.g. Bovenberg and de Mooij (1994), Bovenberg and van der Ploeg (1994a,b,c) and Goulder (1995) by looking at a somewhat different definition of a second dividend. According to their interpretation, a positive second dividend only exists if the excess burden of the total tax system – including the excess burden of the environmental tax – declines. E.g. Bovenberg and de Mooij (1994) conclude “that environmental taxes typically exacerbate, rather than alleviate, pre-existing distortions – even if revenues are employed to cut pre-existing distortionary taxes”. (p. 1085). Increasing a narrow-based green tax and reducing a broad-based tax like a tax on labour income will typically increase the overall distortion of the tax system. Hence, the second dividend is negative and the double-dividend hypothesis fails.

This section will present a model (Section 2.1) which allows us both to replicate the standard results of the double dividend literature and to show the validity of both interpretations (Section 2.2). The model is set up in more general way in order to analyse two important extensions recently made in the literature. Most of the standard results have been derived under the assumption that there is separability between consumption and the environment. As FitzRoy (1996) points out convincingly, environmental problems have to be considered as important when we observe people to protect themselves from the consequences of pollution. If this is the case, separability between consumption and environmental quality is too strong an assumption. It is necessary to explicitly take account of the interaction between pollution and consumption. As will be shown in Section 2.3, lower environmental taxes increase pollution and induce a higher level of the consumption of taxed defensive goods and therefore lower the welfare loss from taxation.

Secondly, although already analysed in Sandmo (1975), the double dividend literature has somehow been neglecting redistributional objectives in determining optimal

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[2] For a definition of the weak and strong form of the double-dividend hypothesis cf. Goulder (1995).

environmental taxation.[3] It has been frequently pointed out that equity considerations may change the structure of optimal taxes significantly. In particular, it has been shown that differentiated commodity taxes should be used to supplement the income tax as a redistributive device [cf. Atkinson and Stiglitz (1980)]. In an economy with externalities, distributional considerations may affect the optimal environmental tax in two ways. As some empirical studies indicate, environmental taxes may have a regressive nature because some environmentally harmful goods are largely consumed by low-income persons. In this case, the presence of redistributional objectives might lower the level of taxes on environmentally harmful commodities. Secondly, distributional considerations also influence the valuation of environmental damage. While the physical incidence of pollution is typically higher in the low-income groups, e.g. due to badly situated housing, well-off people tend to put a higher value on environmental quality [cf. Smith (1992), Harrison 1994)].

Section 2.4 analyses the consequences of taking account of redistributional objectives. The individual willingness to pay for environmental quality, summed up to derive the environmental damage, has to be weighted by the social weight given to the individuals in the social welfare function. The stronger society's inequality aversion, the more heavily weighted are the valuations of the poor and, ceteris paribus, environmental taxes should therefore be larger the more pollution affects the poor. Following Pirttilä and Schöb (1999), this section derives the many-person Ramsey tax rule by allowing for environmental externalities, which arise from the consumption of an environmentally harmful good and discuss how environmental externalities influence the condition for the optimal tax structure.

### *2.1 THE MODEL*

We consider a closed economy with $H$ households with identical preferences but different income earning abilities. There are two private consumption goods $c$ and $d$, a public good $G$ and labour $\ell$. The private consumption good $c$ is clean, i.e. its consumption has no external effect, whereas the private good $d$ is dirty, i.e. its consumption creates negative external effects that cause the environmental quality $E$ to deteriorate. The quantities demanded or supplied by household $h$ are denoted by $x_i^h$, $i = c, d, \ell$, the aggregate quantities of the consumption goods are denoted by $X_c$ and $X_d$, respectively.

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[3] Exceptions are Johansson (1994) Mayeres and Proost (2001), Schöb (1995), Pirttilä and Schöb (1999) and Bulckaen and Stampini (2001).

There is a linear technology for the production of the private goods and the public good, with labour being the only input. Assuming perfect competition, we can choose units for all goods such that all producer prices are equal to one. As labour productivity differs between households, we denote the marginal productivity of each household's labour by $p_\ell^h$. For the normalisation chosen, $p_\ell^h$ also represents the wage rate for household *h*. The production possibilities are described by

$$\sum_h p_\ell^h x_\ell^h = X_c + X_d + G \,. \tag{2.1}$$

The government provides the public good *G* and grants each household a uniform lump-sum subsidy *T* (which might be negative). To finance its expenditures for a given amount of the public good, the government can levy taxes on the private commodities. The government's budget constraint is therefore given by

$$G + HT = t_\ell \sum_h p_\ell^h x_\ell^h + t_c X_c + t_d X_d \,, \tag{2.2}$$

where $t_c$ and $t_d$ denote the commodity taxes on the clean good and the dirty good, respectively, and $t_\ell$ denotes the labour tax rate. As all private demands are homogeneous of degree zero in consumer prices, we are free to normalise one consumer price to unity, i.e. we can normalise one tax rate to zero. In what follows we will make use of different normalisations in order to derive and compare the standard results from the double dividend literature.

Environmental quality *E* deteriorates due to polluting production or consumption. As the main emphasis of this paper is on the interaction of optimal environmental taxes with other forms of taxation, we restrict our analysis to the case of environmental externalities that are proportional to the quantity of a polluting commodity produced or consumed. The environmental quality is thus a decreasing function of the aggregate quantity of the dirty good $X_d$ produced and consumed, i.e.

$$E = e(X_d), \; e' = de/dX_d < 0 \,. \tag{2.3}$$

The preferences of household *h* with respect to both the clean and dirty commodity, leisure $x_0^h$, the public good *G*, and the environmental quality *E*, can be represented by a twice continuously differentiable, strictly quasi-concave utility function

$$(2.4) \qquad U^h = u(x_0^h, x_c^h, x_d^h, G, E),$$

with $u_i > 0$, $i = 0, c, d, G, E$, denoting the marginal utility of good *i*. The time endowment is normalised to one, hence $x_0^h + x_\ell^h = 1$. The budget constraint of the household is given by

$$(2.5) \qquad (1+t_c)x_c^h + (1+t_d)x_d^h = (1-t_\ell)p_\ell^h x_\ell^h + T\ .$$

As households differ in their earning abilities, represented by differences in the wage rate, households will also differ in their consumption patterns. When consuming the dirty good, the single household does not take account of the negative effect of its consumption on the environmental quality.

The benevolent government maximises social welfare, represented by a Bergson-Samuelson welfare function

$$(2.6) \qquad W = W(v^1(t_\ell, t_c, t_d, T, G, E), v^2(t_\ell, t_c, t_d, T, G, E), ..., v^H(t_\ell, t_c, t_d, T, G, E)),$$

subject to its budget constraint (2.2). The term $v^h$ refers to the indirect utility function of household *h*. The government can influence private utility, and hence social welfare by (i) varying the lump-sum transfer, (ii) imposing commodity taxes in general and (iii) determining the environmental quality *E* by imposing a particular environmental tax on the dirty good.[4]

The Lagrangean of the government's maximisation problem is therefore

$$(2.7) \qquad \mathcal{L} = W(v^1, v^2, ..., v^H) + \mu\left[t_\ell X_\ell + t_c X_c + t_d X_d - G - HT\right].$$

Denoting the private marginal valuation of income (the Lagrange multiplier of the individual household's optimisation problem) by $\lambda^h$, and using Roy's identity, the first-order conditions are as follows (using the notation $X_\ell = \sum_h p_\ell^h x_\ell^h$):

$$(2.8) \qquad \frac{\partial \mathcal{L}}{\partial t_\ell} = -\sum_h \frac{\partial W}{\partial v^h}\lambda^h p_\ell^h x_\ell^h + \sum_h \frac{\partial W}{\partial v^h}\frac{\partial v^h}{\partial E}\frac{\partial E}{\partial t_\ell} + \mu\left[X_\ell + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial t_\ell} + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial t_\ell}\right] = 0,$$

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[4] The more general case where the government also maximises with respect to the public good provision is analysed in Schöb (1995) and Pirttilä (1998).

(2.9) $$\frac{\partial L}{\partial t_c} = -\sum_h \frac{\partial W}{\partial v^h}\lambda^h x_c^h + \sum_h \frac{\partial W}{\partial v^h}\frac{\partial v^h}{\partial E}\frac{\partial E}{\partial t_c} + \mu\left[X_c + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial t_c} + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial t_c}\right] = 0,$$

(2.10) $$\frac{\partial L}{\partial t_d} = -\sum_h \frac{\partial W}{\partial v^h}\lambda^h x_d^h + \sum_h \frac{\partial W}{\partial v^h}\frac{\partial v^h}{\partial E}\frac{\partial E}{\partial t_d} + \mu\left[X_d + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial t_d} + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial t_d}\right] = 0,$$

(2.11) $$\frac{\partial L}{\partial T} = \sum_h \frac{\partial W}{\partial v^h}\lambda^h + \sum_h \frac{\partial W}{\partial v^h}\frac{\partial v^h}{\partial E}\frac{\partial E}{\partial T} + \mu\left[-H + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial T} + \sum_{i=\ell,c,d} t_i \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial T}\right] = 0.$$

The derivative of $E$ with respect to a parameter $Z, Z = t_\ell, t_c, t_d, T$, can be calculated by total differentiation of equation (2.3):

(2.12) $$\frac{dE}{dZ} = \frac{e'\sum_h \frac{\partial x_d^h}{\partial Z}}{1 - e'\sum_h \frac{\partial x_d^h}{\partial E}} \equiv \varphi e' \sum_h \frac{\partial x_d^h}{\partial Z},$$

where $\varphi(>0)$ denotes the *environmental feedback* effect. The environmental feedback effect takes account of the fact that the quality of the environment may influence the demand for the dirty good. If a cleaner environment increases the consumption of the dirty good, $\varphi$ becomes smaller than unity. Peak load pricing e.g. will reduce traffic jams during the rush hour. Less traffic, however, will encourage more traffic.[5]

*2.2 OPTIMAL ENVIRONMENTAL TAX WITHOUT DISTRIBUTIONAL CONSIDERATIONS*

In this section we focus on the case with homogenous households and assume separability between private consumption and the environment *E*, and private consumption and the public good *G*, respectively. Thus, all marginal rates of substitution between private goods are independent of *E* and *G*. There are *H* identical households whose preferences are represented by the same indirect utility function and the welfare function simplifies to

(2.6a) $$W = Hv(t_\ell, t_c, t_d, T, G, E).$$

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5 Stability is guaranteed as long as the denominator of equation (2.12) is positive (cf. Schöb 1995, p. 118).

Welfare is maximised with respect to the government's budget constraint (normalising $p=1$)

(2.2a) $$G + HT = H\left(t_\ell x_\ell + t_c x_c + t_d x_d\right).$$

The first-order conditions (2.8) to (2.11) have to be adjusted accordingly. If the government has unlimited access to lump-sum taxes $T<0$, the conditions $\lambda=\mu$ and $t_\ell = t_c = 0$ establish a first-best solution where the government sets the environmental tax equal to the marginal environmental damage (using $\lambda = \partial u/\partial c$):

(2.13) $$t_d \equiv t_P = -\frac{H\dfrac{\partial u}{\partial E}e'}{\dfrac{\partial u}{\partial c}}.$$

In a first-best world the government will set the optimal environmental tax equal to the Pigovian tax and will not apply any other distorting taxes.

*A LABOUR TAX SYSTEM*

If lump-sum taxation is not available, the government has to rely on distortive taxes to raise revenues. The second-best solution can be derived from the equation system (2.8) and (2.10) or the equation system (2.9) and (2.10), depending on the normalisation chosen. Following Schöb (1997) we describe the normalisation $t_c = 0$ as a labour tax system. For this normalisation and, following Bovenberg and de Mooij (1994), the assumptions that the utility function is (i) separable between environmental quality, public good, leisure and consumption goods and (ii) homothetic in consumption goods, it would be optimal to have a labour tax but no commodity tax in the absence of environmental externalities. In the presence of external effects however, there will be an environmental tax in addition to the labour tax (see Appendix 1 for the relevant calculations for this section):

(2.14) $$t_d = \frac{\lambda}{\mu} t_P.$$

For the case of an upward sloping labour supply curve, Bovenberg and de Mooij (1994) show that the second-best optimal environmental tax is lower than the first-best Pigovian tax. The intuition behind this result is, that increasing a narrow-based green tax and reducing a broad-based tax like a tax on labour income will typically increase the overall distortion of the tax system. To see this, consider the whole consumption bundle and its consumption price index. It is obvious that a reduction in the labour tax and a revenue-neutral increase of $t_d$ will not affect the real after-tax wage, if the household does not alter the composition of its consumption basket. However, if it substitutes the clean good for the dirty good, there will be a negative tax-base effect. Revenue-neutrality requires that the consumer price index will increase at a higher rate than the net-of-tax wage. As a consequence the real after-tax wage actually falls. Labour supply falls and welfare decreases. Since the Pigovian tax completely internalises the marginal environmental damage, the only effect of a marginal increase of the Pigovian tax is a higher marginal cost of public funds, i.e. a negative second dividend occurs.

*A COMMODITY TAX SYSTEM*

Things look different, however, if we normalise the net wage rate to unity, i.e. $t_\ell = 0$. Using the same assumptions made above, this would yield a commodity tax system with equiproportional tax rates in the absence of environmental externalities. In the presence of external effects, however, the tax on the dirty tax must be adjusted,

$$t_d = \frac{\mu - \lambda}{\mu} t_d^R + \frac{\lambda}{\mu} t_P \,, \tag{2.15}$$

where $t_d^R$ denotes the Ramsey tax component, which relies on the efficiency of the tax system only. From equation (2.15) it is no longer clear whether the tax on the dirty good lies above or below the Pigovian tax, even if the marginal utility of the public good exceeds marginal utility of the clean good as before.

The two alternative optimal tax formulae (2.14) and (2.15) are the essence of an apparently ongoing controversy which has emerged in the literature about the magnitude of the second-best optimal tax on a polluting good: it seems to be unclear whether in second-best situations, characterised by distortionary taxes, optimal taxes on polluting goods should be higher or lower than the first-best Pigovian tax associated with the same allocation.[6]

As this analysis, which followed the analysis of Schöb (1997) [also see Fullerton (1997)], has shown, the difference in the results concerning the optimal tax rate on a polluting good is due to different normalisations of tax rates which lead to different definitions of what the tax on a polluting good actually is. The controversy can be settled by looking at a *second-*

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6 Cf. e.g. Jaeger (1999).

*best internalisation tax*.[7] In the presence of externalities, Pareto efficiency requires the equality of *social* and *private* marginal welfare of consuming a dirty good. In a first-best world, characterised by the feasibility of lump-sum taxes, this can be achieved by imposing a tax on a polluting good that equals the marginal environmental damage. Such a Pigovian tax fully *internalises* the external costs at the margin. In a second-best world we can apply the concept of *internalising externalities* in a similar way by looking for a tax rate $t_d^E$ on the dirty good which would exactly internalise the external effect of this dirty good.

To derive such a tax rate, let us assume that one of the $H$ households obtains an additional marginal unit of exogenous income $Y$. In the household optimum the household is indifferent to how to spend this additional income. Without loss of generality we can therefore assume that the household increases the consumption of $d$ only, i.e. by $1/(1+t_d^E)$ and that the government uses the additional tax revenues to increase the supply of the public good by $t_d^E/(1+t_d^E)$. The effect of a marginal increase in income for one household on social welfare is therefore:

(2.16)
$$\frac{dW}{dY} = \frac{\frac{\partial u}{\partial x_d} + H\frac{\partial u}{\partial E}e' + H\frac{\partial u}{\partial G}t_d^E}{1+t_d^E}.$$

The first term of the right-hand side denotes the increase in private utility while the second term denotes the external effect imposed on all households by the additional consumption of the dirty good $d$. The last term is the increase in all households' utility due to the additional provision of the public good $G$ which is financed by the internalisation tax imposed on the dirty good $d$.

Full internalisation requires that the *private marginal utility* of consuming the dirty good, which is $du/dY = \partial u/\partial x_d/(1+t_d^E)$, is equal to the *social marginal welfare* (2.16) of consuming the dirty good. From this identity, it follows that the external effect is exactly internalised if and only if the internalisation tax on the dirty good is

(2.17)
$$t_d^E \equiv -\frac{\frac{\partial u}{\partial E}e'}{\frac{\partial u}{\partial G}},$$

[7] See Orosel and Schöb (1996) for the following.

which is identical to the tax rate (2.13) and the second component of the tax rate (2.15). This is the tax component of the total tax on the dirty good *d* that the government has to impose in order to exactly internalise the external effect. An important property of *this second-best internalisation tax* $t_d^E$ as defined in (2.17), is that it depends only on the real variables $u_E$, $u_G$ and $e'$ and thus is itself a real variable. Therefore, although the tax rates themselves can be arbitrarily normalised, the second-best internalisation tax $t_d^E$ is given independently of the normalisation. It will not be affected by any change of this normalisation. Empirically, this component is smaller than the Pigovian tax. Parry (1995) estimates that it is only between 63% and 78% of the marginal environmental damage.

The concept of the second-best internalisation tax allows us to reinterpret the two tax formulae (2.14) and (2.15). From the labour tax system we can learn that the scope for environmental policy is smaller compared to the scope in a first-best world because, due to distortionary taxation, the environmental quality is already closer to the second-best optimum than the laissez-faire situation in a non-distorted economy. From adding the second-best internalisation tax in a commodity tax system we learn that the total tax borne by the dirty good (in units of leisure) can – and normally will – be higher than the Pigovian tax. As the total effective tax on the dirty good exceeds the Pigovian tax, one could expect that the environmental quality is better in a second-best than in a first-best world. Indeed, it is maybe the most important insight that environmental policies which raise public revenues are superior to policies that leave the rent created by restrictions on pollution in the private sector (cf. Schöb 1996). Achieving a given environmental level would impose the same effects on the consumption of taxed goods as the tax-interaction effect describes for achieving the goal by levying green taxes. However, the green taxes have, unlike e.g. grandfathered permits, the advantage of generating a revenue-recycling effect, which partly offset the tax-interaction effect. This result has been confirmed by a series of numerical general equilibrium models recently.[8] The conclusion of Parry, Williams and Goulder (1999) with respect to carbon abatement policies can easily be generalised: “Carbon taxes, as well as carbon quotas or tradable permits that are auctioned by the government, enjoy the revenue-recycling effect as long as the revenues obtained are used to finance cuts in marginal tax rates of distortionary taxes such as the income tax. In contrast, grandfathered (non-auctioned) carbon quotas and permits fail to raise revenues and thus cannot exploit the revenue-recycling effect. ... the inability to make use of the revenue-recycling effect can put the latter policies at a substantial efficiency disadvantage relative to the former policies" (p. 53).[9]

The literature also shows that in second-best economies the abatement cost exceeds the abatement cost economies would face in a first-best world. Assuming increasing marginal abatement cost, this suggests that the environmental quality in a second-best world is better than in a first-best world – a result confirmed recently by Metcalf (2003) who shows that increasing the public expenditure requirement improves the environment in most plausible cases.

The discussion about the normalisation is also very helpful to discuss the case where the dirty good may not be taxable at all. Fullerton and Wolverton (2003) argue that many types of pollution are difficult to monitor or, when measurement of pollution is possible, enforcing a green tax may not be feasible. For instance, emissions of cars cannot be measured directly and the impact of emissions may differ widely depending on whether the car emits pollutants in densely populated areas or on the country side or, with respect to noise, whether one drives during rush hour or during night time through town. Fullerton and Wolverton (2003) show that it taxation of the dirty good is restricted, $t_d = 0$, a two-part instrument that consists of a combination of a higher labour tax and a subsidy on the clean good can achieve the same allocation as either the labour tax system or the commodity tax system where we have a direct tax on the dirty good in effect.

### *2.3 HOMOGENOUS HOUSEHOLDS AND NON-SEPARABILITY*

As pointed out by FitzRoy (1996), severe environmental problems make it likely that a significant proportion of the consumption is spent on defensive goods, i.e. goods which are used to reduce the disutility derived from pollution. Thus, if we allow for such behavior and assume non-separability between consumption goods and environmental quality, the optimal tax formula of the dirty good for the case of a commodity tax system becomes (cf. Appendix 1):

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[8] Cf. Goulder, Parry and Burtraw (1997), Goulder, Parry, Williams and Burtraw (1999), Parry, Williams and Goulder (1999).

[9] Fullerton and Metcalf (2001) have pointed out, however, that it is not necessary that the government raises revenues from environmental policy. Essential is that the government can capture the rents generated by the environmental policy.

(2.15a)
$$t_d = \frac{\mu - \lambda}{\mu} t_d^R + \left( \frac{\lambda}{\mu} t_P - \sum_{i=c,d} t_i H \frac{\partial x_i}{\partial E} e' \right) \varphi .$$

In condition (2.15a) the reaction of household is reflected by an aggregate substitutability between the taxed commodities and the environmental quality, i.e. $\sum t_i H \partial x_i / \partial E > 0$. In this case, a higher tax on the dirty good will reduce both pollution and tax revenues as the need for taxed defensive goods will be reduced when environmental quality increases. Put it differently: in the presence of defensive goods which are taxed, the social cost of pollution is lower as the marginal environmental damage is partly compensated by higher tax revenues due to a higher demand for defensive goods.

If, for instance, the price elasticity of a defensive good is low, according to the Ramsey rule it should be taxed at a relatively high rate. If, by contrast, the elasticity with respect to pollution is high, a marginal increase of the environmental tax would lead to a large decrease in tax revenues. In this extreme case, it cannot be ruled out that the tax revenues decrease rather than increase as a consequence of an increase in the environmental tax.[10]

> PROPOSITION 2.1 (Optimal environmental tax and defensive goods): In the presence of defensive goods, in the sense that there is aggregate substitutability between taxed consumption goods and the environmental quality, the optimal tax on the dirty good should ceteris paribus be lower than in the case with separability between consumption goods and the environment.

Schwartz and Repetto (2000), by contrast, show that if labour supply is positively affected by an improvement of environmental quality, increasing rather than decreasing environmental quality will yield an additional positive tax-interaction effect. A positive tax interaction effect would lead to a higher tax on the dirty good.

### *2.4 HETEROGENEOUS HOUSEHOLDS*

To analyse the case of heterogenous households, we restrict the analysis to the case where the labour tax rate is normalised to zero and assume again separability between private consumption and the environment $E$, and private consumption and the public good $G$, respectively. This implies that the environmental quality has the same physical impact on all households, independently of their earning abilities and their consumption pattern. In this case, the environmental feed back effect $\varphi$ [cf. (2.12)], reduces to unity and the demand for the dirty good becomes independent of the environmental quality (cf. Pirttilä and Schöb (1999) for the following).

To derive optimal tax rules for heterogeneous households, it is convenient to introduce the definition of the *gross social marginal valuation* of household *h*'s income, measured in terms of government's revenue by

$$\beta^h \equiv \frac{\partial W}{\partial v^h}\frac{\lambda^h}{\mu}. \tag{2.18}$$

If the government is interested in redistributing income from high ability households to low ability households, the social welfare function (2.6) will be strictly quasi-concave, i.e. $\partial W/\partial v^h$ is larger the lower $v^h$ is. As private utility is also strictly quasi-concave, $\lambda^h$ decreases in utility. Hence, $\beta^h$ is negatively correlated with the earning ability and the household's utility level, respectively.

The individual evaluation of the additional environmental damage may differ between individuals as the marginal valuation of the environment normally does not change proportionately with the marginal utility of income $\lambda^h$. The marginal willingness to pay for environmental quality is therefore defined as

$$\omega^h \equiv \frac{\partial v^h/\partial E}{\lambda^h}. \tag{2.19}$$

Applying the separability assumption, and using the definitions (2.18) and (2.19) in the first-order conditions, and using Cramer's rule, we can solve equations (2.9) and (2.10) for the optimal commodity tax rate of the clean and the dirty good, respectively. Denoting the determinant of the Jacobian matrix for the case of heterogenous households as $|\hat{J}|$, the optimal tax formulae are:

$$t_c = \frac{1}{|\hat{J}|}\sum_h \left(\beta^h - 1\right)\left(x_c^h \frac{\partial X_d}{\partial t_d} - x_d^h \frac{\partial X_d}{\partial t_c}\right), \tag{2.20}$$

[10] Note that the existence of defensive goods would also reduce the marginal environmental damage.

$$t_d = \frac{1}{|\hat{J}|}\sum_h \left(\beta^h - 1\right)\left(x_d^h \frac{\partial X_c}{\partial t_c} - x_c^h \frac{\partial X_c}{\partial t_d}\right) - \sum_h \beta^h \omega^h e' . \tag{2.21}$$

Equations (2.20) and (2.21) show the result derived by Sandmo (1975). The external effect does not enter the optimal tax formula for the clean good even if distributional objectives are taken into account. It only enters the optimal tax formula for the dirty good additively. This environmental component of the optimal tax on the dirty good may be considered as the price the consumer of the dirty good has to pay in a second-best world in order to completely internalise the external effect.

To see this, consider the following thought experiment which is related to the interpretation of the *second-best internalisation tax* in the last section for the model with identical households. We abstract from all other taxes and focus on the environmental tax component alone which we define as $t_d^E$. Assume that a household $h$ receives an additional marginal unit of exogenous income $Y^h$. In the household optimum, the household's utility increases by $\lambda^h$, independently of how it spends the additional income. Hence, without loss of generality, we assume that the household increases the consumption of $d$ only, i.e. by $1/(1+t_d^E)$. The effect of a marginal increase in household $h$'s income on social welfare is therefore (measured in units of public revenues)

$$\frac{dW/dY^h}{\mu} = \frac{\partial W}{\partial v^h}\frac{\lambda^h}{\mu} + \sum_k \frac{1}{\mu}\frac{\partial W}{\partial v^k}\frac{\partial v^k}{\partial E} e' \frac{1}{1+t_d^E} + \frac{t_d^E}{1+t_d^E} = \beta^h + \left(\sum_k \beta^k \omega^k e' + t_d^E\right)\frac{1}{1+t_d^E} . \tag{2.22}$$

The first term of the right-hand side denotes the increase in the gross social marginal valuation of household $h$'s private utility $\beta^h$ [cf. equation (2.18)]. The second term denotes the social marginal external effect imposed on *all* households by the additional consumption of the dirty good $d$ [cf. equation (2.19)]. The last term shows the increase in public revenues from the internalisation tax imposed on the dirty good $d$. (It is assumed that additional tax revenues are used to increase public good provision.)

Full internalisation requires that, from the viewpoint of society, the *social marginal utility* of the private consumption of the dirty good, i.e. the gross social marginal valuation $\beta^h$, should be equal to *social marginal welfare* of consuming the dirty good:

$\beta^h = dW/dY^h/\mu$ . Hence, the external effect is exactly internalised if and only if the tax on the dirty good is equal to

(2.23)
$$t_d^E = -\sum_h \beta^h \omega^h e',$$

which forms the environmental component of $t_d$ in equation (2.21). The term $\omega^h e'$ denotes the marginal willingness to pay for a reduction in emissions times the amount of emissions caused by a marginal increase in the dirty good consumption. In order to derive the social evaluation of pollution, the household's marginal willingness to pay has to be weighted with the social weight $\beta^h$ given to the household.

*THE MANY-PERSON RAMSEY TAX RULE WITH EXTERNALITIES*

Diamond (1975) presents a procedure for interpreting commodity taxation rules when income can be taxed on a linear scale. This section refers to Diamond's approach to deriving a many-person Ramsey tax rule, and demonstrates how his model has to be modified to allow for the presence of externalities. Therefore, we first redefine the *net social marginal valuation* of household *h*'s income, denoted by $\gamma^h$, by taking into account the influence private consumption has on the external effect:

(2.24)
$$\gamma^h = \beta^h + \sum_{i=c,d} t_i \frac{\partial x_i^h}{\partial T} + \sum_k \beta^k \omega^k e' \frac{\partial x_d^h}{\partial T}.$$

Definition (2.24) is identical with Diamond's definition [see his equation (6)], except for the last term of the right-hand side. The *net* social marginal valuation of household *h*'s income includes, first of all, the *gross* marginal social valuation of income $\beta^h$ which represents the social evaluation of the marginal utility household *h* derives from a marginal increase in income. The social value of an extra income to household *h* also depends on the influence the additional income has on tax revenues. This effect is captured by the second term of the right-hand side of equation (2.24). If the extra income increases the demand for taxed goods by household *h*, tax revenues also increase and may be used e.g. to increase the provision of the public good. In this case, the net social marginal valuation exceeds the gross social valuation of income.

In the presence of externalities, the net social valuation of income also depends on the impact the additional income has on environmental quality. This effect is covered by the last term on the right-hand side. If the extra income increases the household *h*'s consumption of the dirty good, the value of the additional damage caused by it to all members of the economy has to be deducted from the social valuation of income. If the dirty good is a normal good, the externality-augmented net social valuation of income will therefore be lower than Diamond's (1975) definition suggests.

Using the definition of $\gamma^h$, the Slutsky decomposition $\partial x_i^h / \partial t_j = s_{ij}^h - x_j^h \cdot \partial x_i^h / \partial T$, where $s_i^h$ denotes the compensated (cross-) price effect, and Slutsky-symmetry, the first-order conditions for $t_j$, $j = c, d$ can be rewritten in the following way:

(2.25) $$\sum_h \sum_{i=c,d} t_i s_{ij}^h = \sum_h (\gamma^h - 1) x_j^h - \sum_h (\beta^h \omega^h e') \sum_h s_{dj}^h ,$$

with $j = c, d$. In the absence of externalities, i.e. for $e' = 0$, equation (2.25) restates Diamond's (1975) result [cf. his equation (7)]. The new second term on the right-hand side takes account of the externality. In order to interpret equation (2.25), however, we will further simplify this condition. Substituting definition (2.24) into the first-order condition for the lump-sum transfer, equation (2.11), we obtain:

(2.26) $$\sum_h \left( \beta^h + \sum_{i=c,d} t_i \frac{\partial x_i^h}{\partial T} + \sum_k \beta^k \omega^k e' \frac{\partial x_d^h}{\partial T} \right) = H \quad \Leftrightarrow \quad \bar{\gamma} = 1,$$

where $\bar{\gamma}$ denotes the average net social valuation of income over all households. Equation (2.26) states that in an optimum, the average valuation of a transfer of one unit of money should be equal to its cost, which is equal to unity.

Next, we define the normalised covariance between the net social evaluation of private income and the consumption of good *j*,

(2.27) $$\Phi_j \equiv \frac{\sum_h \gamma^h x_j^h}{\bar{\gamma} X_j} - 1$$

(cf. e.g. Atkinson and Stiglitz 1980). The first term of the right-hand side is known as the *distributional characteristic* of good *i* (cf. Feldstein 1972). If the government is indifferent to which household the extra income is given, all $\gamma^h$ are identical to $\bar{\gamma}$, and the normalised covariance expression reduces to zero. With inequality aversion, $\gamma^h$ is larger for low-income households, provided that the additional tax revenue and the externality term in definition of $\gamma^h$ [cf. (2.24)] do not have too strong countervailing effects.[11] This implies that the distributional characteristics of a good, of which low-income households demand a large proportion, takes a value greater than unity, because the relative consumption of that good by household *h* increases with $\gamma^h$. According to Rose and Wiegard (1983), the distributional characteristics of a good *i* can be interpreted as a measure of society's willingness to pay for a more equal distribution of income.

Substituting the definition of the normalised covariance (2.27) into equation (2.25) we obtain:

$$\text{(2.28)} \qquad \frac{\sum_h \sum_{i=c,d} t_i s_{ij}^h}{X_j} = \Phi_j - \frac{\sum_h (\beta^h \omega^h e')}{1+t_d} \sum_h \varepsilon_{jd}^h \frac{x_j^h}{X_j},$$

with $j = c,d$. The term $\varepsilon_{jd}^h$ denotes the compensated cross-price elasticity of good *j* with respect to the price of the dirty good *d*. The left-hand side equals the relative change of the compensated demand if all tax rates change proportionately. To see this, consider the total differential of the compensated demand function $x_j^h(t_c, t_d, \bar{u}), j = c,d$ for a small equiproportionate change of all tax rates, i.e. $dt_i = \alpha t_i,\ i = c,d$ :[12]

$$\text{(2.29)} \qquad dx_j^h\Big|_{\bar{u}} = \sum_{i=c,d} s_{ji}^h dt_i = \alpha \sum_{i=c,d} s_{ji}^h t_i .$$

Summing up over all households and dividing by the total demand, we obtain the relative change in aggregate demand

$$\text{(2.30)} \qquad \frac{\sum_h dx_j^h\Big|_{\bar{u}}}{X_j} = \alpha \frac{\sum_h \sum_{i=c,d} t_i s_{ij}^h}{X_j}.$$

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[11] The gross social valuation of income is always larger for low-income households than for well-off households. This need not be the case for the net measure, because additional income may lead to larger changes in the demand for the taxed commodities among the high-income households, in which case $\gamma^h$ would increase. It is also hard to deduce whether the magnitude of the externality-encompassing term is greater or smaller for worse-off households and, accordingly, in which direction the differences in the net social valuation move.

[12] Note that we have assumed separability between consumption and environmental quality.

The left-hand side of equation (2.28) therefore explains how the relative change in the demand of good $j$, due to a small equiproportionate change of all tax rates, is determined. To interpret the right-hand side carefully, consider first the case without external effects (i.e. $e' = 0$). In this case, the externality-based term disappears from the first-order condition and from the definition of $\gamma^h$, respectively. Optimal commodity taxation is determined by the normalised covariance alone.

If, on the other hand, redistribution is not an issue, and there are no external effects, the normalised covariance term vanishes. In this case, there would be no commodity taxation in the optimum. Tax revenues would be raised by imposing a uniform lump-sum tax $(T < 0)$ only. With inequality aversion, however, the aggregate compensated change in demand of good $j$ should be smaller, the lower the values of the normalized covariance $\Phi_j$ is. The normalised covariance rule therefore advises the government to subsidise the consumption of goods which are largely demanded by those people with a large net social marginal valuation of income, i.e. the poor people and discourage the consumption of luxury goods consumed by rich households with low $y^h$. In this way commodity taxation is used for redistributional purposes.

If external effects are present, but society is not interested in redistribution, the aggregate compensated change in the demand of taxed goods is determined solely by the externality term. This term depends on the compensated elasticity between the taxed good and the dirty good. The compensated own-price elasticity of the dirty good, and hence the aggregate compensated change in the demand for the dirty good, will be negative. This impact arises naturally from the fact that, as the consumption of good $d$ worsens the environmental quality, it is in the society's interest to reduce its consumption. For the clean good, the compensated change in demand should be smaller, the higher the compensated complementarity relationship between the taxed good and the dirty good is (the more negative the compensated elasticity is). Proposition 2.2 summarises.

PROPOSITION 2.2 (The many-person Ramsey tax rule in the presence of externalities): If commodity taxes and the uniform lump-sum transfer are set optimally, a small equiproportional increase in all tax rates will cause all compensated commodity demands to change according to their distributional characteristics. In addition, the decline (increase) in the compensated demand for the taxed good will be larger (smaller), the stronger the complementarity relationship between the taxed good and the dirty good is.[13]

It is important to note that, with an equiproportional change in all tax rates, we change the level of the Pigovian tax component by the same amount as the Ramsey tax component. Hence, the tax on the dirty good increases at a larger rate than the standard many-person Ramsey tax rule suggests in the absence of externalities. Consequently, the demand for all complements will fall at a larger rate while the demand for substitutes will fall at a lower rate. This is the mechanism which makes the complementarity relationship between taxed goods and the dirty good enter the tax rule. A comparison with Sandmo's additivity property shows that Proposition 2.2 does not imply that goods which are complements to the dirty good should be taxed more strongly. Rather, the conclusion suggests that their consumption is reduced because of the indirect impact the relatively larger change of the tax on the dirty good has on their demand.

This result also shows that, apart from the redistributional characteristics of the particular commodity, the optimal tax rule also depends on redistributional concerns because of the social valuation of environmental damage. The private disutility of a marginal increase in pollution is weighted by the gross social valuation of household *h*'s income $\beta^h$. This means that the marginal willingness to pay for the environmental quality by a low-income household has a relatively high impact on the social valuation of the environment and on the externality-based term in the tax rules as well. Moreover, as the magnitude of $\beta^h$ decreases with the shadow price of public funds $\mu$, we can deduce that the externality-based part in the tax conditions decreases with rising $\mu$. The reason is that, as the burden of public funds rises, it becomes more and more expensive to internalise externalities.

In brief, the modified many-person Ramsey tax rule reveals that the influence of commodity taxation on the demand for taxed goods depends on both redistributional and environmental objectives. If the worse-off households have a relatively large demand for the environmentally harmful good, as some empirical studies suggest, then the optimal tax rule proposes that the income distribution part of taxation lowers the tax on the dirty good. This tax would otherwise be high in order to internalise the negative external impact. Therefore,

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[13] Pirttilä and Schöb (1999) derive another alternative many-person Ramsey tax rule in the presence of externalities not presented here: If commodity taxes and the lump-sum transfer are set optimally, a small

without any further restrictions on consumers' preferences, efficiency and equity considerations cannot be separated when making decisions concerning the level of environmental taxes. This confirms Sandmo's (2000) statement that the distributional concerns cannot be ignored in the study of externalities within public finance models.

This discussion can be connected to the double-dividend debate reviewed in Section 2.2. Although the formulation containing the change in the compensated demand does not provide an explicit tax rule, it still implies that if the harmful goods are in relatively great demand by the low-income households, the non-environmental tax component should be low – or even negative – because, in the absence of externalities, differentiated commodity taxation is only used to influence income distribution, and a reduction in the tax rate of a good is a direct way to increase its compensated demand.

## *2.5 CONCLUDING REMARKS*

This section reviewed the standard results of the double-dividend literature and discussed some of the more recent extensions. As has been shown, the question whether an environmental tax should be larger or smaller than a Pigovian tax is best be addressed by looking at the second-best internalisation tax. This tax component will fall short of the Pigovian tax if the government has to rely on distortionary taxes. Allowing for non-separability is a necessary extension which has to be made if environmental problems are or any significant relevance. Optimal environmental tax rates may be lower in the presence of defensive goods but higher, if improved environmental quality has e.g. a positive effect on labour supply. The government's concern of both efficiency and equity also requires some modifications of the optimal second-best tax system. The government should not only impose high taxes on goods that are largely consumed by well-off households. The many-person Ramsey tax rule in the presence of externalities shows that this rule has to be adjusted by imposing an additional environmental tax on the dirty good so that the compensated change in the demand of a taxed good due to a small equiproportional change in all tax rates is smaller, the higher the compensated complementarity between the taxed good and the dirty good is. This is because an increase of the environmental tax component reduces the demand for goods which are complements for the dirty good while it increases the demand for all goods which are substitutes.

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equiproportional increase in all Ramsey tax components will cause all compensated commodity demands to change according to their distributional characteristics.

## 3. EMPLOYMENT AND WELFARE EFFECTS IN THE PRESENCE OF UNEMPLOYMENT

Do green tax reforms boost employment? This question provoked the search for another second dividend of environmental tax reform: the employment dividend. Though the concept of an environmental dividend is meaningless for countries with functioning labour markets and hence full employment, it has become the most important concept in the political debate about green tax reforms in the European countries suffering from persistently high levels of unemployment.

One obvious way to reduce employment by raising environmental taxes is by recycling the resulting tax revenues through cuts in labour taxes. The high levels of taxes on labour income, combined with the high level of unemployment benefits, are often made responsible for unemployment since it distorts labour supply and increases wage pressure in labour markets (see OECD 1995). A green tax reform may alleviate the tax burden on labour and hence reduce the resulting disincentives.

To show this, one has to analyse the tax incidence of both the green tax and the labour tax in the presence of labour market imperfections. Indeed, many papers dealing with environmental tax reforms in the presence of involuntary unemployment discovered an environmental dividend. In a model with fixed net-of-tax wages, Bovenberg and van der Ploeg (1996, 1998a) show that if green taxes are low initially, employment may increase if substitution between labour and resources within the production sector is easy. Bovenberg and van der Ploeg (1998b), using a search theoretic framework, found a positive employment effect for a revenue-neutral green tax reform which both increases the tax on a polluting factor of production and succeeds in shifting the tax burden away from labour income to transfer income. In an efficiency wage model, Schneider (1997) also shows that employment may increase due to an increase in green taxes.[14] Koskela and Schöb (1999) apply a model with endogenous wage negotiations between trade unions and firms. Using the right-to-manage approach [cf. Nickell and Andrews (1983)], they elaborate different institutional settings and their importance for the employment effect. Their main finding is that if unemployment benefits are nominally fixed and are taxed at a lower rate than wage income, a revenue-neutral green tax reform which increases green taxes on the consumption of a polluting good alleviates unemployment. Holmlund and Kolm (2000) examine the role of an environmental

[14] Also see the comment by Scholz (1998).

tax reform for a small open economy with monopolistic competition. They show for a Cobb-Douglas technology and a two sector economy that a revenue-neutral green tax reform boosts employment if wages in the tradable sector are higher than in the non-traded sector. Koskela, Schöb and Sinn (1998) show that if the net-of-tax wage rate does not react to tax rate changes the environmental taxes in the production sector should exceed the labour tax rate. Their analysis suggests that a green tax reform can provide a free lunch even when there are no environmental externalities. In a bargaining model where the firm can invest in abatement technologies, Strand (1999) shows that rebating green tax revenues by either subsidising either firms' hiring or investments in abatement, pollution declines whilee employment may increase thus creating a double dividend.

Brunello (1996) and Carraro, Galeotti and Gallo (1996) are pessimistic about the long-run effects of a green tax reform. Modelling the outside option of the trade union as a weighted average of unemployment benefit payments and wage income from being employed elsewhere[cf. Layard, Nickell and Jackman [(1990, 1991)], they show that in the long run, the trade union succeeds in raising the net-of-tax wage rate at the same amount the labour tax rate is reduced, thus eliminating the short run employment dividend. Carraro, Galeotti and Gallo (1996) provide numerical simulations of the effects of a carbon tax reform in a bargaining model, which indicate some evidence in favour of a short-run employment dividend but not in the long-run.[15]

In this section the effects of green taxes in the production sector are analysed in a model related to the framework developed by Koskela, Schöb and Sinn (1998). In their model the wage is endogenously determined in a bargaining process between trade unions and a firm. The firm produces with two factors of production and faces a downward sloping demand for its good. The wage negotiations are analysed using a 'right-to-manage' model by allowing non-constant elasticities of factor demands. Trade unions and firms bargain over wages and firms then choose the employment level that maximises profits. While the focus of Koskela, Schöb and Sinn (1998) was on tax reform, the focus here is on optimal tax formulae, in order to provide a comparison with the analysis of Section 2.

Section 3.1 sets up the model. Section 3.2 provides the main intuition why a green tax reform can reap a second employment dividend. Section 3.3 then derives the optimal tax

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[15] See Bosello, Carraro and Galeotti (2001) for further references.

formulae and discusses how they depend on the magnitude of the labour market distortion and the availability of non-distorting profit taxes. Section 3.4 summarises this section.

### *3.1 THE MODEL*

We consider a small open economy that satisfies the usual resource constraint

$$I = C + G + pY - M \,, \tag{3.1}$$

where $I, C, G, Y$ and $M$ denote domestic income, private consumption, public consumption, exports, and imports. The price of export goods $Y$ in terms of a produced import good which serves for public and private consumption is denoted by $p$, which we will identify with the economy's "terms of trade". The other import good $R$, a natural resource, called "energy", is available at a given price $q$, again defined in terms of the imported consumption good, so that $M = C + G + qR$.

Domestic production is represented by a single monopolistic firm which produces good $Y$ with energy $R$ and labour $L$ as inputs. While energy $R$ is imported, labour $L$ is internationally immobile. Technology is assumed to be linear-homogeneous and is represented by a constant elasticity of substitution production function $Y = f(L, R)$. The monopolistic firm faces world output demand $D(p)$, which is decreasing in the output price $p$ and is assumed to be iso-elastic, i.e. $Y = D(p) = p^{-\varepsilon}$, with $\varepsilon \equiv -\left(D(p)/\partial p\right) \cdot p/Y$ denoting the output demand elasticity. The closer substitutes for good $Y$ on the world market are, the more elastic output demand becomes.

The firm maximises profits, which are given by $\pi = p(Y)Y - \tilde{q}R - \tilde{w}L$, where the firm considers the gross energy price $\tilde{q}$ and the gross wage rate $\tilde{w}$ as given. The gross wage is the net-of-tax wage, which is negotiated between a trade union and the firm, plus the labour tax, modelled as a payroll tax: $\tilde{w} = (1 + t_w)w$. The energy price is the foreign resource price plus a green tax levied on the use of energy in production: $\tilde{q} = (1 + t_q)q$. To guarantee a profit maximum, the output demand elasticity must exceed unity, i.e. $\varepsilon > 1$, in which case profit maximisation implies that the firm will set a price which exceeds the constant marginal cost $c(\tilde{w}, \tilde{q})$ by a constant mark-up factor $\varepsilon/(\varepsilon - 1) > 1$.

All $N$ workers of the economy are represented by a single trade union which maximises its $N$ members' net-of-tax income.[16] Each member of the trade union supplies one unit of labour if employed, or zero labour if unemployed. The earning of a member thus equals the net-of-tax wage rate $w$ if employed. If he is unemployed the trade union member has an outside option $b$ which depends on the utility derived from leisure and the unemployment benefit transfers from the government. The objective function of the trade union is hence given by

$$V^* = wL + b(N - L)\,. \tag{3.2}$$

The wage rate is determined in a bargaining process between the trade union and the firm. After the net-of-tax wage rate is fixed, the firm then unilaterally determines employment. This is modelled by using a 'right-to manage' model which represents the outcome of the bargaining by an asymmetric Nash bargaining. The fall-back position of the trade union is given by $V^0 = bN$, i.e. if the negotiations break down, all members receive their reservation wage equal to the outside option. The fall-back position of the firm is given by zero profits, i.e. $\pi^0 = 0$. Using $V \equiv V^* - V^0$, the Nash bargaining maximand can be written as

$$\Omega = V^{\beta}\pi^{1-\beta}, \tag{3.3}$$

with $\beta$ representing the bargaining power of the trade union. Using a CES production technology we will apply the explicit formulation of the wage elasticity of labour demand, $\eta_{L,\tilde{w}} \equiv L_{\tilde{w}}\tilde{w}/L = -\sigma + s(\sigma - \varepsilon)$, with $\sigma$ being the elasticity of substitution between labour and energy and $s = \tilde{w}L/cY$ being the cost share of labour (cf. Koskela and Schöb 2002b). The first-order condition with respect to the net-of-tax wage rate is

$$\Omega_w = 0 \Leftrightarrow (w - b)\big(\beta\eta_{L,\tilde{w}} + (1-\beta)s(1-\varepsilon)\big) + w\beta = 0\,. \tag{3.4}$$

Equation (3.4) implicitly determines the negotiated net-of-tax wage from Nash bargaining as a function of the tax policy parameters $t_w$ and $t_q$ so that we have $w = w(t_w, t_q)$.

To derive the optimal tax formulae for an economy where the nominal wage is determined in wage negotiations, we have first to know how wage negotiations are affected by the tax system. The effect of a change in the labour tax rate on the net-of-tax wage rate is

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[16] Note that although we assume a single trade union in the economy it behaves like a small trade union as its

$$w_{t_w} = -\frac{\Omega_{wt_w}}{\Omega_{ww}} = -\frac{(w-b)zw}{y+(w-b)z(1+t_w)}, \tag{3.5}$$

with $y = \beta(1+\eta_{L,\tilde{w}}) + (1-\beta)(1-\varepsilon)s$ and $z = [\beta(\sigma-\varepsilon)+(1-\beta)(1-\varepsilon)]s_{\tilde{w}}$. As the second-order condition is assumed to hold throughout, i.e. $\Omega_{ww} = y + (w-b)z(1+t_w) < 0$, we can infer that $\text{sign}\,(w_{t_w}) = \text{sign}\,(z) = \text{sign}\,(-s_{\tilde{w}})$ if labour and energy are price complements $\sigma < \varepsilon$, as we will assume in what follows. (Note that $\varepsilon > 1$). For a CES production technology, the partial derivative of the cost share of labour with respect to the gross wage rate is given by

$$s_{\tilde{w}} = \frac{s}{\tilde{w}}(1-s)(1-\sigma)\begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0 \Leftrightarrow \sigma \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 1,$$

so that

$$w_{t_w} \begin{cases} < 0 & \text{as} \quad \sigma < 1 \\ = 0 & \text{as} \quad \sigma = 1. \\ > 0 & \text{as} \quad \sigma > 1 \end{cases} \tag{3.6}$$

If the elasticity of substitution $\sigma$ is less than one, an increase in the labour tax rate will lead to an increase in the cost share of labour $s$. A larger share $s$ implies that the wage elasticity of labour demand is higher in absolute terms. Hence, the trade union benefits less from demanding higher wages and the net-of-tax wage rate falls. By contrast, when the elasticity of substitution exceeds one, the cost share of labour $s$ decreases due to higher labour taxes, so that the wage elasticity of labour demand is lower in absolute terms. The trade union benefits more from demanding higher wages and the net-of-tax wage increases. In the case of Cobb-Douglas production function with the elasticity of substitution being one, the wage elasticity is constant so that factor taxes will have no effect on the negotiated net-of-tax wage.

An exogenous increase in the green tax rate has an effect on the cost share of labour opposite to that of the increase in the labour tax rate. Hence, depending on the elasticity of substitution, the total effect of an increase in $t_q$ is:

$$w_{t_q} \begin{cases} > 0 & \text{as} \quad \sigma < 1 \\ = 0 & \text{as} \quad \sigma = 1. \\ < 0 & \text{as} \quad \sigma > 1 \end{cases} \tag{3.7}$$

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policy cannot affect the consumer price level.

The interpretation of (3.7) is analogous to that presented for the labour tax rate.

Finally, the government requires a fixed amount of tax revenues to finance the public good $G$.[17] The government levies the labour tax $t_w$ on wage income and a source-based tax on energy input $t_q$. In addition there is might be a profit tax $t_\pi$ on domestic profits so that the government budget constraint is given by

(3.8) $$t_w wL + t_q qR + t_\pi \pi = G .$$

To focus on efficiency aspects of the optimal tax structure only, we assume linear preferences and thereby consider the total surplus as an appropriate social planner's objective function [cf. Summers, Gruber and Vergara (1993)]. The total surplus consists of the wage income equal to $wL$, which accrues to workers, $b(N-L)$, the money metric-utility unemployed derive from leisure, and the net-of-tax profit income $(1-t_\pi)\pi$. As we keep $G$ constant throughout the analysis, we can suppress the term $G$ in the welfare function. As all energy is imported, private income from energy sales does not appear in the welfare function. All domestic profits go to domestic capitalists. Finally, the monetarised value of the environment is given by $E(R)$, with $E_R < 0$, which enters the welfare function separately. Hence, the welfare function is given by

(3.9) $$S = wL + b(N-L) + (1-t_\pi)\pi + E(R) .$$

### *3.2 LABOUR TAX SYSTEM VS GREEN TAX SYSTEM*

Let us begin our analysis by asking whether there might be a reason for introducing a "green tax system", characterised by relatively high tax rates on energy and relatively low labour taxes, which yields the same output as the existing "labour tax system" where the labour tax rate exceeds the energy tax rate, but generates a higher level of employment.[18] For the sake of the argument we keep the net-of-tax wage $w$ constant.

Such a green tax system must satisfy several conditions. Profit maximisation requires that the same output $f(L,R) = Y_0$, where the output level $Y_0$ is *ceteris paribus* determined by

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[17] For the sake of the argument, we assume that there are no unemployment benefit payments paid by the government. This assumption does not affect the qualitative results so it does affect the magnitude of the actual optimal tax formulae.

[18] This section replicates a thought experiment by Koskela, Schöb and Sinn (1998).

the initial tax rates $t_w^A$ and $t_q^A$, is produced with minimum cost. The first-order condition for cost-minimisation can be represented by $\tilde{w}f_R(L,R)-\tilde{q}f_L(L,R)=0$, where $f_i$ denotes the partial derivative of $f(L,R)$ with respect to $i=L,R$ (e.g. $f_R=\partial f/\partial R$). Furthermore, the marginal cost must be equal in the two systems, for otherwise the firm would not sell the same output in equilibrium as before. With linear-homogenous technologies this implies constant total cost, $\tilde{w}L+\tilde{q}R=C_0$. Finally, the government budget constraint (3.8) must be met.

These conditions provide an equation system which can be solved with respect to the optimal inputs and the necessary tax rates, respectively. Instead of solving the system analytically, the solution is represented in Figure 3.1. In the profit maximum, the slope of the isoquant $Y_0$ equals the negative of the ratio of the tax-inclusive factor prices $-\tilde{q}/\tilde{w}$. In the initial equilibrium A we observe the factor price ratio $-(1+t_q^A)q/(1+t_w^A)w$ with $t_w^A>t_q^A$. Since A is a point of tangency between the isocost and the isoquant, it characterises a cost minimum. Given $q$, $w$, $t_q^A$, $t_w^A$, there are many such cost minima on a ray from the origin through A all of which have the same unit production cost, but because of the endogeneity of the output price, there is only one point that maximises profits: point A that shall indicate the initial labour tax system $(t_w^A,t_q^A)$.

The isocost through A reflects the factor cost including the burden of factor taxes. Figure 3.1 also shows the corresponding net-of-tax isocost curve. This curve is defined as the geometrical locus of factor combinations that would be attainable at a given expense if there were no taxes. The net-of-tax isocost curve is steeper than the tax-inclusive isocost through A because $t_w^A>t_q^A$ and it is lying in a more outward position because $t_w^A$, $t_q^A>0$.

The horizontal distance between A and the net-of-tax isocost equals the government's tax revenue in terms of *R*. The broken parallel to the net-of-tax isocost through A thus defines the geometrical locus of all potential equilibria, where tax revenue and net-of-tax factor expenses are the same as in the labour-tax regime A.

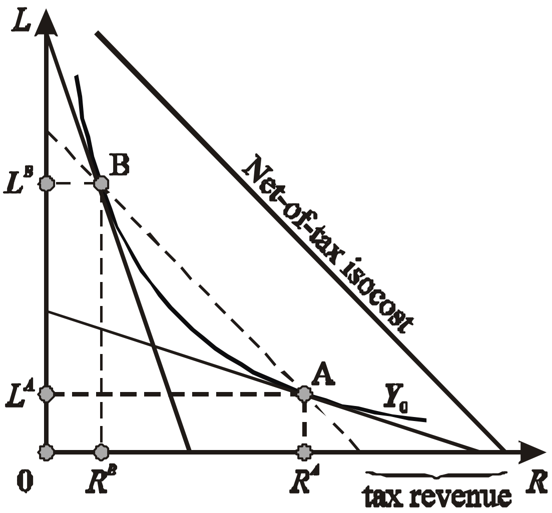


**Figure 3.1:** *Labour tax system versus green tax system*

It is now possible, with an appropriate choice of the tax rates $t_w$ and $t_q$, to transpose the economy from A to B, keeping output, tax-inclusive factor expenses and unit production cost constant while preserving the conditions for a cost minimum. Since neither the unit production cost nor the output price alter with this transposition, B is an equilibrium. Point B indicates a green tax system $(t_w^B, t_q^B)$ with $t_q^B > t_w^B$ that yields the same output at the same total cost. Moving from A to B will instantaneously increase employment, $L^B > L^A$, without imposing any additional cost on either firm or government. In addition, less energy will be used, $R^B < R^A$, and, consequently, the environment will improve (remember: $E_R < 0$).

This thought experiment shows that with given net-of-tax factor prices and a linear-homogenous production technology, there exists a *green tax system* with higher tax rates on energy than on labour which yields both the same output level and same tax revenues as the existing *labour tax system* where the labour tax rate exceeds the energy tax rate. The green tax system generates both a higher level of employment and a cleaner environment thus reaping a double dividend. As profits are unchanged, and welfare is increasing in both employment and environmental quality, welfare will be higher in the green tax system than in the labour tax system.

*3.3 WELFARE MAXIMISATION: THE OPTIMAL TAX FORMULAE*

Now we turn to the welfare maximisation problem where the government chooses tax rates first and the labour organisations then determine the wage rate in a wage negotiation, taking the tax rates as given. Hence, the government maximises the total surplus (3.9) subject to the budget constraint of the government (3.8), the outcome of the wage negotiation, which is implicitly given by the first-order condition of the Nash bargaining (3.5), and an additional constraint on the profit tax rate (3.10) that might or might not be binding.

$$\underbrace{\max}_{t_w, t_r, t_\pi, w} \; S = wL + b(N - L) + (1 - t_\pi)\pi + E(R) \,,$$

s.t.

(3.8) $$t_w wL + t_q qR + t_\pi \pi = G \,.$$

(3.5) $$\Omega_w = 0 \Leftrightarrow (w - b)\left(\beta\eta_{L,\tilde{w}} + (1-\beta)s(1-\varepsilon)\right) + w\beta = 0 \,.$$

(3.10) $$t_\pi \le \bar{t}_\pi$$

The Lagrangian for the welfare maximisation is

(3.11) $$\mathsf{L} = wL + b(N - L) + (1 - t_\pi)\pi + E(R) - \lambda\left(G - t_w wL - t_q qR - t_\pi \pi\right) - \mu\Omega_w + \varphi(\bar{t}_\pi - t_\pi) \,,$$

where $\lambda$, $\mu$ and $\varphi$ describe the shadow prices of the three constraints. Using the following additional expressions of the factor demand elasticities: $\eta_{R,\tilde{w}} = R_{\tilde{w}}\tilde{w}/R = s(\sigma - \varepsilon)$, $\eta_{L,\tilde{q}} = L_{\tilde{q}}\tilde{q}/L = (1-s)(\sigma - \varepsilon)$ and $\eta_{R,\tilde{q}} = -\sigma + (1-s)(\sigma - \varepsilon)$ the first-order conditions with respect to the profit tax rate, the two factor tax rates and the net-of-tax wage rate can be expressed (after some manipulations) as follows:

(3.12) $$\mathsf{L}_{t_\pi} = 0 \quad \Leftrightarrow \quad \pi(\lambda - 1) = \varphi \,,$$

(3.13) $$\mathsf{L}_{t_w} = \left[w - b + \lambda t_w w\right]L\eta_{L,\tilde{w}} + (E_R + \lambda t_q q)R\eta_{R,\tilde{w}} + (\lambda - 1)(1 - t_\pi)\tilde{w}L - \mu\Omega_{wt_w}(1 + t_w) = 0 \,,$$

(3.14) $$\mathsf{L}_{t_q} = \left(w - b + \lambda t_w w\right)L\eta_{L,\tilde{q}} + (E_R + \lambda t_q q)R\eta_{R,\tilde{q}} + (\lambda - 1)(1 - t_\pi)\tilde{q}R - \mu\Omega_{wt_q}(1 + t_q) = 0 \,,$$

(3.15) $$\mathsf{L}_w = \left(w - b + \lambda t_w w\right)L\eta_{L,\tilde{w}} + (E_R + \lambda t_q q)R\eta_{R,\tilde{w}} - (\lambda - 1)\left(t_\pi - t_w/(1 + t_w)\right)\tilde{w}L - \mu\Omega_{ww}w = 0 \,.$$

Given the complementary slackness condition $\bar{t}_\pi - t_\pi \ge 0$, $\varphi \ge 0$, $\varphi\left(\bar{t}_\pi - t_\pi\right) = 0$, we can distinguish two cases. If $\varphi = 0$, the profit tax constraint is not binding and the government can choose the profit tax rate as a lump-sum tax optimally. If the government is restricted in using profit taxes, the profit tax constraint is binding, i.e. $\varphi > 0$. We will discuss these two cases separately.

*3.3.1 WELFARE MAXIMISATION WITH OPTIMAL PROFIT TAXATION*

We first consider the case, where the government does not have to rely on distortionary taxation. If $\varphi = 0$, the first-order condition with respect to the profit tax rate (3.12) reduces to $\lambda = 1$. The shadow price $\lambda$ represents the marginal cost of public funds and is equal to one. This indicates that the government can raise taxes to meet its revenue requirement without imposing any cost on society that exceeds tax revenues. Thus we have an economy without tax distortions but it is left with labour market distortions. To analyse how these labour market distortions affect welfare, we subtract (3.15) from (3.13), using $\lambda = 1$. This yields

$$-\mu\Omega_{ww}w\left[-\frac{\Omega_{wt_w}(1+t_w)}{\Omega_{ww}w}+1\right]=0. \tag{3.16}$$

As we know from the second-order condition, $\Omega_{ww}w < 0$, the shadow price $\mu$ must be equal to zero if the terms in brackets are non-zero. The first term in brackets represents the net-of-tax wage elasticity with respect to the labour tax. As long as an increase in the labour tax rate increases the gross wage rate however, the absolute value of the elasticity is below one (cf. Koskela and Schöb (2002a) for a proof), which is also in conformity with empirical studies [cf. e.g. Lockwood and Manning (1993) and Holm, Honkapohja and Koskela (1994)]. Therefore, the term in brackets must always be positive and condition (3.16) holds only if the shadow price $\mu = 0$.

This result suggests that if the government can use profit taxation without any restriction, i.e. apply non-distortionary taxation, the Nash bargaining constraint is not binding. This has two consequences. First of all, it is optimal for the government to levy a Pigovian tax on energy. Solving the equation system (3.13) and (3.14) with respect to the factor tax rates and making use of $\varphi = 0$, $\lambda = 1$ and $\mu = 0$, we obtain:

$$t_q = -\frac{E_R}{q} > 0. \tag{3.17}$$

Furthermore, the government is able to fully offset the labour market distortions. Whatever net-of-tax wage rate is fixed in the wage negotiation between the trade union and the firm, the government can choose an appropriate wage tax or subsidy to obtain the gross wage which optimises social welfare:

$$t_w = -\left(\frac{w-b}{w}\right) < 0 . \tag{3.18}$$

These two tax rates ensure that both gross factor prices equal their social opportunity cost. The marginal productivity of energy equals the net-of-tax energy price the country has to pay for importing energy plus the marginal environmental damage energy input in domestic production causes. From substituting the definition of the gross wage rate into equation (3.18) we can see that $\tilde{w} = b$. Thus, the gross wage equals the disutility of labour, which in turn equals the social cost of labour. The wage subsidy is equal to the mark-up between the net-of-tax wage rate and the marginal revenue product of labour the wage negotiation yields, given this subsidy. This establishes full employment in the sense that there is no involuntary unemployment anymore. These findings can be summarised as a proposition:

> PROPOSITION 3.1: If the government can set the profit tax optimally, it should levy a Pigovian tax on polluting inputs and it should levy a wage subsidy which completely offsets the mark-up between gross and net-of-tax wage rate as determined in the wage negotiations.

Proposition 3.1 establishes a first-best solution as it shows that the government can fully internalise the environmental externality and can control the labour market imperfection. It thus confirms for a unionised labour market the result by Guesnerie and Laffont (1978) according to which, in a first-best world, the output of a price maker should be subsidised such that the market price equals the marginal cost [also see Boeters and Schneider (1999)].

### *3.3.2 WELFARE MAXIMIZATION WITH RESTRICTED PROFIT TAXATION*

So far we have focused on unrestricted profits. In practice, however, tax authorities may have difficulties in distinguishing between pure profits and return to capital investments or they face institutional or legal constraints. Hence, the more relevant case is where $\varphi > 0$, i.e. the profit tax constraint is binding and the profit tax rate is set at the upper bound for the profit tax rate $\bar{t}_\pi$.

As profits are always positive, we can infer directly from equation (3.12) that $\lambda > 1$, i.e. the marginal cost of public funds exceeds unity. Thus, the government has to apply distortionary taxes to raise revenues. But this is not the only distortion the economy faces. Now the labour market constraint also becomes binding because, intuitively, the government has to apply distortionary taxes to finance the wage subsidy. Allowing for marginal mark-up due to wage negotiations to remain in effect has only a negative second-order effect on welfare, but the lower tax revenue requirement generates a first-order welfare gain. This is a standard second-best result according to which, in the presence of more than one distortion, it is not optimal to establish the first-best solution in only one sector. Formally, the shadow price $\mu$, which represents the social cost of labour market imperfection, can be signed by subtracting (3.15) from (3.13):

(3.19) $$\mu\Omega_{ww} w\left[-\frac{\Omega_{wt_w}(1+t_w)}{\Omega_{ww} w}+1\right] = -(\lambda-1)wL < 0\,.$$

The term in brackets on the left-hand side is positive (cf. Appendix 2). Hence, condition (3.19) can hold only if $\mu > 0$, i.e. reducing the labour market distortion due to wage negotiations is always welfare improving. The lower the net-of-tax wage rate as a result of the wage negotiation, the lower the welfare loss of distorting taxes will be. This will be true irrespective of the question of whether the net-of-tax wage rate changes as a consequence of a tax rate change.

*3.3.3 OPTIMAL TAX FORMULAE WHEN THE NET-OF-TAX WAGE RATE CHANGES*

Now we turn to the more general case where the elasticity of substitution between factors of production differs from one. In this case the outcome of the wage negotiation is affected by changes in factor taxation as we showed in Section 3. Solving the system of equations (3.13)-(3.14) for the CES production function case with respect to the tax rates and making use of $\lambda > 1$ and $\mu > 0$, we obtain the general optimal factor tax formulae (cf. Appendix 2)

(3.20) $$\left(\frac{t_q}{1+t_q}\right) = -\frac{1}{\lambda}\frac{E_R}{\tilde{q}} + \frac{1}{\varepsilon}\left(1-\frac{1}{\lambda}\right)(1-\bar{t}_\pi) + \frac{\mu}{\lambda}\left(\frac{\Omega_{wt_w}(1+t_w)}{(1-s)cY\sigma}\right),$$

(3.21) $$\left(\frac{t_w}{1+t_w}\right) = -\frac{1}{\lambda}\left(\frac{w-b}{\tilde{w}}\right) + \frac{1}{\varepsilon}\left(1-\frac{1}{\lambda}\right)(1-\bar{t}_\pi) - \frac{\mu}{\lambda}\left(\frac{\Omega_{wt_w}(1+t_w)}{scY\sigma}\right),$$

where

(3.22) $$\Omega_{wt_w} = (w-b)\left(\frac{s}{1+t_w}\right)(1-s)(1-\sigma)[\beta\sigma-\varepsilon+1-\beta]\begin{Bmatrix}>\\=\\<\end{Bmatrix}0 \Leftrightarrow \sigma\begin{Bmatrix}>\\=\\<\end{Bmatrix}1 .$$

To interpret the result, we first consider a Cobb-Douglas production function where the elasticity of substitution is unity and the net-of-tax wage rate is independent of the tax rates. The optimal factor tax formulae for this case are

(3.20a) $$\left(\frac{t_q}{1+t_q}\right)_{\sigma=1} = -\frac{1}{\lambda}\frac{E_R}{\tilde{q}}+\frac{1}{\varepsilon}\left(1-\frac{1}{\lambda}\right)(1-\bar{t}_\pi),$$

(3.21a) $$\left(\frac{t_w}{1+t_w}\right)_{\sigma=1} = -\frac{1}{\lambda}\left(\frac{w-b}{\tilde{w}}\right)+\frac{1}{\varepsilon}\left(1-\frac{1}{\lambda}\right)(1-\bar{t}_\pi).$$

Equation (3.20a) shows that when the price elasticity of output demand $\varepsilon$ is less than infinite the energy tax should be imposed for two reasons. First, it should be taxed to internalise the external effects caused by using polluting inputs in the production. As taxation becomes distortionary, however, it becomes more costly to provide the public good "environmental quality", thus the environmental tax component is smaller than the Pigovian tax. The reason is the same as in the case with perfect labour markets as discussed in Section 2 so that we do not have to interpret the result again.

Second, energy should be taxed to raise revenues. The positive second component of the energy tax – which might be once again called the Ramsey component – results from the restricted profit taxation that forces the government to rely on distortionary taxation. The energy tax rate is higher, the lower the feasible profit tax rate $\bar{t}_\pi$ is and the higher the marginal cost of public funds $\lambda$.[19]

A comparison of equation (3.21a) with the optimal labour tax formula for unrestricted profit taxation, equation (3.18), shows that the labour tax rate is now higher. The first term on the right-hand side represents the subsidy component of the tax rate and is increasing in the marginal cost of public funds $\lambda$. The subsidy has to be financed by distortionary taxes and

[19] For a thorough analysis of the role profit taxation plays for the determination of optimal tax formulae see Boeters (2001).

becomes more costly with higher $\lambda$. The second positive term, which one might refer to as the Ramsey component of the labour tax rate, represents the optimal tax one should levy on labour to minimise the excess burden of taxation. The wage subsidy, which becomes smaller as taxation becomes more costly, is at least partially offset by this Ramsey component. Hence, in the case of Nash wage bargaining with restricted profit taxation, a positive labour tax is possible as a part of the optimal tax treatment of factors of production. These results can be summarised in

> PROPOSITION 3.2: If profit taxation is restricted and factor taxes have no effect on wage negotiations, the government should use the energy tax to both internalise the external effect and to raise revenues. As the Ramsey tax component is the same for both taxes, the environmental tax always exceeds the labour tax rate.

A consequence of Proposition 3.2 is that introducing green taxes to about the level of the labour tax rate guarantees that welfare will improve – irrespectively of the magnitude of the environmental damage. This confirms the result derived by Koskela, Schöb and Sinn (1998) in a tax reform model.

If the net-of-tax wage rate is affected, there is an additional term in each tax formula – the second and third terms on the right-hand side in (3.20) and (3.21) respectively. These terms capture the effect that changes in the net-of-tax wage rate will have on the optimal factor taxes. Since we have already discussed the other terms, we will focus on these new terms only. From equation (3.20) we can deduce

> PROPOSITION 3.3: If profit taxation is restricted and factor taxes affect the wage negotiation, the optimal energy tax should be adjusted downwards (upwards) if the elasticity of substitution between energy and labour is smaller (greater) than one.

This result has a natural interpretation. If the elasticity of substitution between energy and labour is less than one, a fall in the energy tax rate – compared to the case where the wage negotiations are not affected by tax rate changes – decreases the net-of-tax wage rate so that the labour market distortion due to the difference between the net-of-tax wage $w$ and the social marginal cost of labour becomes smaller. On the contrary, if the elasticity of substitution exceeds one, a rise in the energy tax rate will decrease the net-of-tax wage rate and thereby reduce the labour market distortion. The optimal labour tax rate has to be adjusted by going in the opposite direction. With the elasticity of substitution being less than one, a rise in the labour tax rate decreases the net-of-tax wage rate so that the labour market distortion becomes smaller and vice versa. Then the labour market distortion can be decreased by raising the labour tax rate.

While the energy tax rate is always higher than the labour tax rate if $\sigma \geq 1$, the result becomes ambiguous for $\sigma < 1$. If $\sigma$ is less than one, it is optimal to increase the labour tax rate and decrease the energy tax rate to alleviate the labour market distortion. Hence, in this case, knowledge about the magnitude of both the elasticity of substitution and the marginal environmental damage is required to determine the relative size of the tax rates. If the elasticity of substitution is not too far below one, and if the marginal environmental damage is considered to be significant, it is still very likely that the energy tax rate should exceed the labour tax rate.

### *3.4 CONCLUDING REMARKS*

Let us conclude the section with three remarks. First, as was mentioned before, Brunello (1996) and Carraro, Galeotti and Gallo (1996) show that the employment dividend may vanish in the long run. This result, however, crucially depends on the assumption of a constant replacement ratio that implies that the outside option in the Layard, Nickell and Jackman (1991) framework becomes proportional to the wage rate in the long run. This assumption may be questionable. Blanchard and Katz (1999) argue that the income of the unemployed does not consist of unemployment benefit payments only but also non-market income. They therefore assume that the replacement ratio is homogeneous of degree zero in the wage rate and non-market income. If the latter remains constant due to tax rate changes, the replacement ratio would decline and, consequently, the long-run employment dividend would continue to be positive, even though the quantitative effect would be smaller in the long run. This can be seen by splitting the income of the unemployed into two components. The first is proportional to the net-of-tax wage rate while the second is a constant one. Furthermore, it should be noted that although unemployment benefits are often paid in proportion to the wage rate (cf. MISSOC 1998) other additional welfare transfers are often cut if other income components rise. In particular for low-qualified workers the assumption of a constant unemployment income is more realistic than the assumption of a constant replacement ratio. The employment effect may therefore be still positive.

Second, as the result derived above shows, it is very likely that a green tax reform may yield an ‘environmental dividend’. However, it may not be as clear that the green tax reform may also yield an environmental dividend. Bayindir-Upmann and Raith (2003) show that a revenue-neutral green tax reform may actually worsen rather than improve the environment as the income effect due to higher employment may overcompensate the substitution effect due to higher taxes on polluting goods. Although the deterioration of the environment may be consistent with welfare maximisation, this is an important aspect to take into consideration if governments commit to meet certain environmental standards.

Third, the analysis presented here is a special case of the more general case of how to optimally tax factor incomes at source if factors are internationally mobile and there is involuntary unemployment. The standard result in the optimal taxation literature that a small open economy would be worse off if it substitutes a tax on a mobile factor such as energy for a labour income tax [cf. e.g. Bucovetsky and Wilson (1991), Razin and Sadka (1991)] does not hold for economies suffering from involuntary unemployment in the economy. While the effect of a green tax reform does not yield a second dividend in the standard model, it yields a welfare improving employment effect in the latter.[20] We will come back to this comparison in the next section.

In conclusion, this section shows that there exists a second dividend of environmental taxes in the form of an employment dividend. Using green tax revenues to reduce labour taxes will reduce unemployment and therefore raise welfare. The existence of other market distortions therefore provide another rationale for the introduction of environmental taxes.

## 4. INTERNATIONAL ASPECTS OF ENVIRONMENTAL TAXATION

Competitiveness is a rather vague concept of a economic policy objective. However, as it is very present in the political debate about green tax reform, pure economic theory should be applied to that concept. In this section, we will consider the impact green taxes may have on the competitiveness of a small open country first for countries with functioning labour markets (Section 4.1) and then for countries suffering from unemployment (Section 4.2).

Before proceeding, we first have to find an appropriate definition of the competitiveness of an economy. Competitiveness is not an end in itself but is a useful notion for understanding the reaction to a country's policy moves. In line with Alesina and Perotti (1997), we measure competitiveness by the negative of the unit production cost of its exports.

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[20] The analysis of papers dealing with taxing mobile capital at source in the presence of labour market imperfections can easily be adopted to the case of taxing polluting resource inputs [cf. Koskela and Schöb (2002a, 2002b), Richter and Schneider (2001)]

In general the production cost is a function of the gross-of-tax factor prices and the output level, $C(\tilde{w},\tilde{q},Y)$. For the linear-homogeneous production function used in Section 3, we have

$$C(\tilde{w},\tilde{q},Y) = c(\tilde{w},\tilde{q})Y . \tag{4.1}$$

where $c$ is the unit production cost. The lower $c$ is, the more the country can sell in the world market for $Y$, and the higher its competitiveness is.

*4.1 GREEN TAXES AND COMPETITIVENESS: CLEARING LABOUR MARKETS*

Does a green tax on internationally mobile energy resources weaken the competitiveness of a small open economy? Looking at economies with functioning labour markets, this question can be answered by looking at the related literature on taxing mobile capital at source (cf. Richter and Schneider 2001). MacDougall (1960) was the first who pointed out that taxing a perfectly mobile factor at source would always decrease the welfare of a country. In the nineties, this question was discussed again with a particular focus on tax competition between countries [cf. Razin and Sadka (1991) and Bucovetsky and Wilson (1991)].

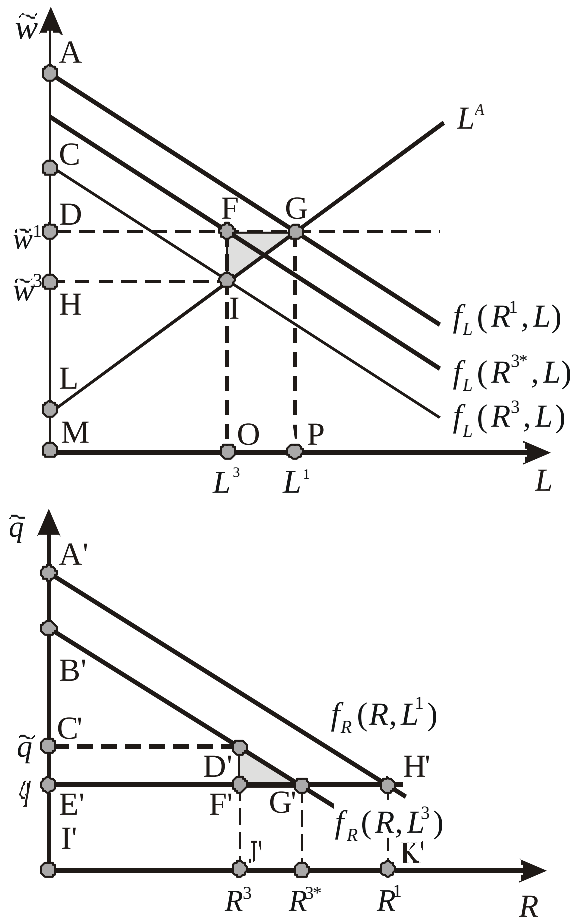


**Figure 4.1:** *Energy taxation and competitive labour markets*

The way a green tax reform can affect the competitiveness can be shown graphically. In Figure 4.1, the upper part shows the labour market, in which the initial equilibrium is characterised by the gross wage rate $\tilde{w}^1$ and the employment level $L^1$. The lower part shows the energy market. Without green taxes, the firm will increase energy input up to the point where the marginal productivity of energy equals the producer price $q$. Given the employment level $L^1$, the country will import the amount of energy $R^1$ and has to pay the resource owners E'H'K'I'. This area is equivalent the triangle AGD in the labour market diagram. On the other hand, the triangle A'H'E' in the energy market diagram equals the gross wage income, represented by the rectangle DGPM in the labour market diagram.[21]

Note that by assuming a linear-homogenous production technology and perfect competition in the output market, the gross wage rate is completely determined by the energy price $q$ and the world output price $p$. Now assume that the government unilaterally imposes an energy tax $t_q$. As the whole burden falls on the firm, energy input must become more productive. This can be achieved by reducing energy input for any level of employment. As *ceteris paribus* a higher resource price increases marginal cost [cf. equation (4.1)], the gross wage rate has to fall in order to keep marginal cost constant. This induces a reduction in employment as the workers will work less if the wage rate falls.

The new equilibrium will be achieved with the gross wage rate $\tilde{w}^3$ that ensures that marginal cost of production remain constant. The new equilibrium employment level is $L^3$, the new equilibrium energy input level is $R^3$ and the new domestic gross energy price is $\tilde{q} = q(1+t_q)$. Wage income falls to HIOM (in the labour market diagram), the energy costs are E'F'J'I' (in the energy market diagram) with C'D'F'E' being the energy tax revenues.

Competitiveness in the definition chosen has not changed as long as the world output market determines the marginal cost. Nevertheless, the decision whether or not to introduce energy taxes unilaterally has severe consequences for domestic welfare. Consequences which become important if a country has to decide whether it should meet e.g. the Kyoto protocol requirements of reducing $CO_2$ emissions.

To see the welfare effect, assume that the government has introduced a labour tax instead of an energy tax which also ensures an equilibrium employment level $L^3$. As the

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[21] A linear-homogeneous production technology imply convex marginal productivity curves which do not intersect with the axis. For didactical purposes Figure 4.1 uses linear curves only. As a consequence, the corresponding areas in the labour market and the energy are not necessarily of the same size.

whole tax burden falls on the worker, the gross wage is not affected but the net-of-tax wage rate falls to $\tilde{w}^3$. The labour tax rate thus equals the distance DH = $\tilde{w}^1 - \tilde{w}^3$. The new marginal labour productivity curve intersects with the gross wage curve at F. The energy input necessary to sustain this equilibrium can be found by the intersection of the marginal energy productivity curve $f_R(R, L^3)$ with the gross energy price curve $q$. It turns out that the energy input $R^{3*}$ is larger than in the case where the introduction of the energy tax leads to an employment level $L^3$.

The welfare loss due to the introduction of the labour tax equals the area FGI shaded in grey which is associated with the tax revenues of DFIH. The total loss in workers' net-of-tax wage income can also be seen in the energy market diagram. Here the loss is given by the area A'H'G'B'.

Now, assume that the government replaces the labour tax and levies an energy tax which ensures the same employment level $L^3$. Such a reform further reduces domestic income which consists of the net-of-tax wage income plus tax revenues from the triangle B'G'E' in the energy market to B'D'C' + C'D'F'E' = B'D'F'E'. The additional loss equals the triangle B'G'E' shaded in grey. As the net-of-tax wage rate remains the same, $\tilde{w}^3$, the total income loss equals the loss in tax revenues that is equal to C'D'E'F'.

The energy tax thus has two negative welfare effects. First, there is the welfare loss resulting from a fall in the net-of-tax wage rate from $\tilde{w}^1$ to $\tilde{w}^3$ as the fall in the labour rent DGIH is only partly compensated by the tax revenues DFIH. Second, obtaining the same labour rent with an energy tax instead of a labour tax would result in lower tax revenues by the amount of (D'G'F'). The total welfare loss thus is FGI + D'G'F'. Figure 4.1 illustrates that a small open economy can maximise tax revenues for any given employment level by setting the green tax equal to zero. By contrast, one can infer from the analysis that for any given level of public expenditures, employment and energy input is maximised. As the labour rent is increasing with employment, welfare is maximised as well.

As both inputs are maximised if there is no energy tax, output is maximised as well. So far, we have assumed a constant world market price for the output good. If the output demand is downward sloping – as assumed in Section 3 – the output maximum is also a unit cost minimum. Hence, raising the energy tax weakens the competitiveness of economies facing downward sloping demand curves for their products. Whether welfare or competitiveness is the policy objective, the conclusion that energy taxes are harmful is the same. If energy is perfectly mobile, there is no reason other than improving the environment for imposing green taxes. For economies with functioning labour markets, this analysis confirms Bovenberg's (1999) conclusion that "the case for environmental taxes should be made primarily on environmental grounds... green taxes are worthwhile as long as the environmental benefits are non-negative" (p. 441) . Proposition 4.1 summarises.

> PROPOSITION 4.1: If the labour market is competitive, a small open economy should not levy an energy tax for other reasons than to improve domestic environmental quality. The competitiveness of the economy is not affected by the energy tax, though.

The next section shows that this conclusion does not hold for economies suffering from involuntary unemployment.

*4.2 GREEN TAXES AND COMPETITIVENESS: IMPERFECT LABOUR MARKETS*

In Section 3.2 we have shown (cf. Figure 3.1) that in the presence of involuntary unemployment, there exists a green-tax equilibrium with higher tax rates on energy than on labour which yields the same level of output and same tax revenue as, but a higher level of employment than, the existing labour-tax equilibrium. As firms face the same unit cost of production in the green tax system as in the labour tax system, the move from the labour-tax equilibrium to a green-tax equilibrium maintains the economy's international competitiveness in the sense of our definition of keeping the unit production cost and the terms of trade constant.

More, however, can be said if we analyse a marginal revenue-neutral green tax reform as we can then allow for a change in the output level that goes along with changes in unit cost of production, and hence the competitiveness of the country. To analyse the change in the competitiveness of the economy, we thus have to calculate the effect, a marginal revenue-neutral green tax reform has on the unit cost of production (cf. Appendix 3):

(4.2) $$sign\left(\left.\frac{dc}{dt_q}\right|_{dG=0}\right) = sign\left(t_q - t_w\right).$$

Recalling our definition of competitiveness and assuming that involuntary unemployment is not completely eliminated, the following proposition summarises.

PROPOSITION 4.2: As long as the labour tax rate exceeds the energy tax rate, a marginal revenue-neutral green-tax reform will increase both the international competitiveness and the output of an economy with involuntary unemployment due to too high net-of-tax wages. Competitiveness is maximised when the energy tax rate equals the labour tax rate.

To interpret and understand these results it is useful to consider Figure 4.2, which is constructed in the same way as Figure 3.1. Figure 4.2 shows two conceivable paths of consecutive marginal tax reforms starting in the labour tax system A and ending in the green tax system B. Up to points C or C' where $t_w = t_q$, output will increase. A further increase in $t_q$ will result in marginal output reductions.

Up to point C or C' employment will increase. However, an increase of $t_q$ sufficiently far beyond the point where $t_q = t_w$ will not necessarily increase employment further because there is a countervailing output effect. A green tax reform will definitely create the incentive to substitute employment for energy consumption. However, the output decline such a reform induces in the range where $t_q > t_w$ will, in itself, reduce the factor demands. If $t_q$ is sufficiently far above $t_w$, the output effect may dominate the substitution effect such that employment declines at the margin.

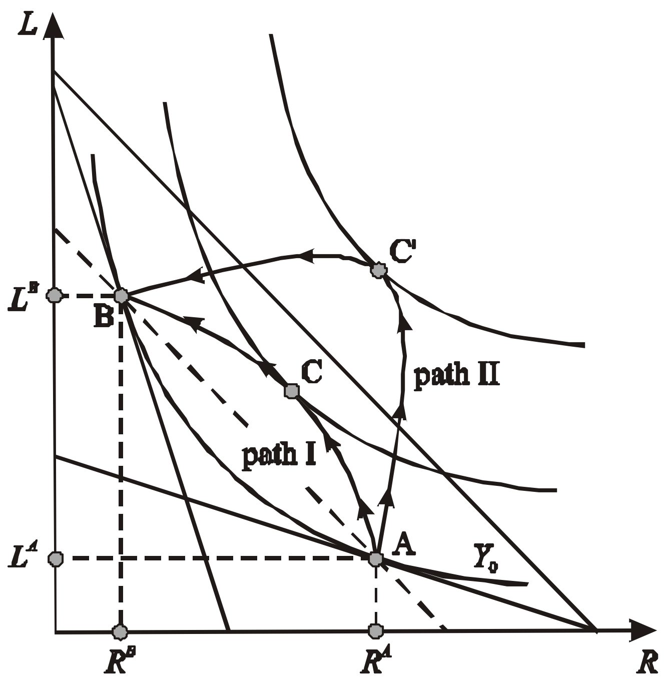


**Figure 4.2:** *Marginal green tax reforms*

With paths I and II, Figure 4.2 distinguishes two different possibilities that depend on the price elasticity of the demand curve for the economy's products. If the demand elasticity is small, the initial rise and subsequent fall in output will be small and the substitution effect will dominate the output effect. This case is represented by path I. Moving from C to B further increases employment while output is falling. If output demand is very price elastic, as represented by path II, there will be an interval on the path II from C' to B where output and employment are falling simultaneously.[22]

The ambiguity with respect to output translates to the country's international competitiveness. Since equation (4.2) says that the terms of trade are a declining function of output, the economy's competitiveness increases with a marginal green tax reform as long as $t_q < t_w$ (right of C and C') and declines when $t_q > t_w$ (left of C and C'). Hence, initial green tax reforms do not only improve the environment and raise employment, as long as output effect is positive, they also increase the competitiveness of an economy.

The standard result in the optimal taxation literature – applied to green taxation in Section 4.1 – is that a small open economy would be worse off if it substitutes a tax on a mobile factor such as energy for a labour income tax [cf. e.g. Bucovetsky and Wilson (1991)]. By contrast, we have to conclude that when there is involuntary unemployment in the economy, the effects of such a green tax reform are favourable. A green tax reform will induce a technical substitution in the production process that replaces energy use with employment. Since energy is priced at its true national opportunity cost, but the price of labour is above its opportunity cost, there is a strong presumption that the reform will boost employment and bring about an increase in the competitiveness of a country.

### *4.3 ENVIRONMENTAL TAXES ARE RESOURCE TAXES*

Since environmental issues are typically tied to the use of exhaustible resources, a comprehensive analysis of environmental tax incidence should take into account the impact of green taxes on the world producer prices of exhaustible resources such as gas and oil products as these affect the time path of extraction. The literature on environmental taxation has, until recently, not recognised this important relation in evaluating the impact of co-ordinated attempts to reduce greenhouse gas emissions.

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[22] For the same reason, moving from A to C' increases resource demand. This confirms the analysis by Bayindir-Upmann and Raith (2003).

Resource prices are principally determined by the user cost of the resource, i.e. the rent the resource owner can obtain from extracting the resource. An excise tax, introduced by a sole country with a negligible share in global energy demand, does not affect the world energy price. It is therefore optimal for such a small country to impose a green tax which leads the country to meet its own environmental standards or to meet international environmental agreements like the Kyoto Protocol. For the welfare analysis it is not necessary to incorporate the reactions on the world resource markets. By contrast, however, if all countries introduce environmental taxes the burden of the green tax will partly be borne by today's resource consumer and partly by the resource-extracting country. The welfare effects are then twofold and should be considered separately.

The main underlying idea can be described graphically. For simplicity assume first that the whole resource stock can be used in one period only. If we abstract from extraction costs, this implies that consumers face a fixed supply $R_0$. In the absence of pollution, it is optimal to use up the whole stock if the marginal willingness to pay at $R_0$, $MWP(R_0)$ is positive.

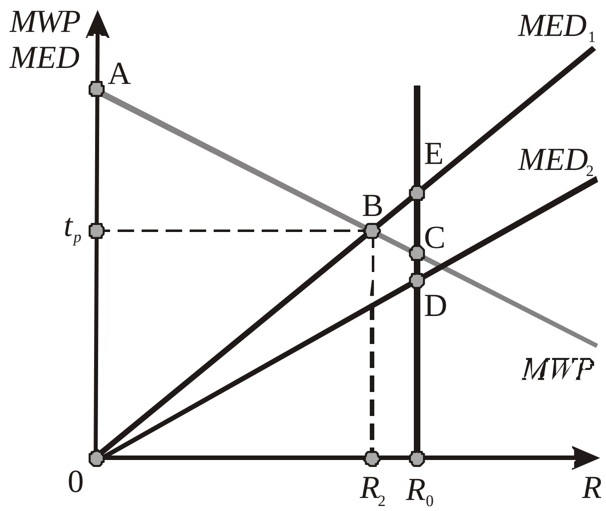


**Figure 4.3**: *The one-period model*

In Figure 4.3, total surplus is maximised at $R_0$, yielding a surplus of AC$R_0$O. In the presence of externalities, indicated by the marginal environmental damage curve $MED_i$, $i = 1,2$, it remains optimal to consume the whole stock as long as $MWP(R_0) - MED(R_0) > 0$, i.e. if the marginal net rent of consuming the last unit of the resource is still positive. The existence of a resource rent then completely compensates for the externality. In this case would be no need for environmental policy measures. A tax smaller than $MWP(R_0)$, however, would not alter the allocation, but affect the distribution of rents as the entire tax burden falls on the supplier.

If the environmental damage is more severe, as indicated by the $MED_1$ curve, it becomes optimal to reduce extraction from $R_0$ to $R_2$. In this case, a Pigovian tax $t_P = MED_1(R_2)$ maximises welfare, given by ABO. The welfare gain, compared to the laissez-faire solution equals BEC.

Now consider the case where a fixed resource stock can be consumed in two periods. This is illustrated in Figure 4.4 where the total resource stock is plotted on the horizontal axis and the period demands on the vertical axes. In the absence of pollution, the social benefit from resource consumption can be represented by the aggregate marginal willingness-to-pay curve $MWP_i$. In the presence of externalities, however, we have to subtract the marginal environmental damage, caused by the consumption of the natural resource, from the marginal willingness to pay in order to derive total welfare. This yields the marginal social benefit curve $MSB_i$. For period 2 the marginal cost and benefit are discounted by the interest rate $r$ which, in the case of perfect capital markets, equals the social discount rate.

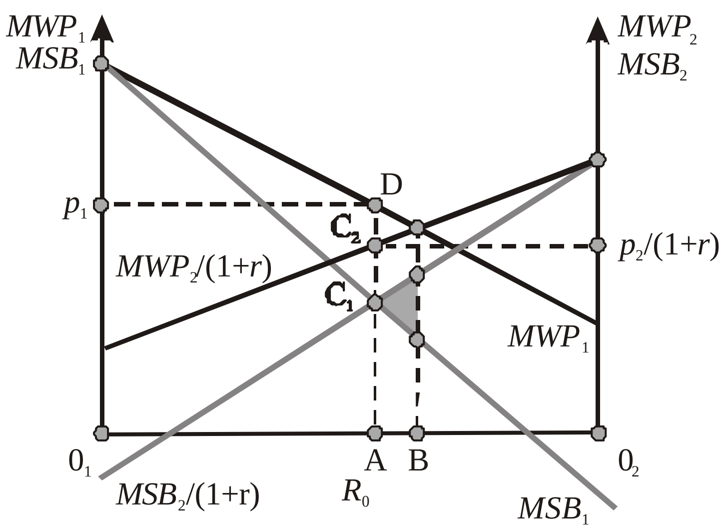


**Figure 4.4:** *A two-period model of exhaustible resource consumption*

Without internalising externalities the market equilibrium equalises the present value of the marginal willingness to pay, i.e. $MWP_1 = MWP_2 / (1+r)$, which maximises the present value of the consumer surplus. In Figure 4.4. the curves for the first period are plotted from left to right, the curves for the second period are plotted from right to left. Thus, the distance $O_1B$ denotes the consumption in the first period and $O_2B$ the consumption in the second period, respectively. However, due to the presence of externalities, a reduction of the first period's consumption, accompanied by an increase of second period's consumption enhances welfare. This can be achieved by e.g. introducing a Pigovian tax $t_P$ equal to $C_1D$ in the first period and $C_2D \cdot (1+r)$ in the second period, respectively. Such a combination of taxes equalises the present value of the marginal social benefit i.e. $MSB_1 = MSB_2 / (1+r)$. The resulting welfare gain – compared to the laissez-faire situartion – is shown by the shaded area.

The implications of this simple model can easily be generalised. As resource consumption falls, marginal environmental damage decreases, and so should the Pigovian tax. Ulph and Ulph (1994) and Farzin (1996) therefore emphasise that what matters is the time path of the environmental tax rather than its level. To delay extraction, the initial environmental tax should be high and then fall over time.[23] In the two-period model, however, the natural resource will not necessarily be exhausted. If the $MSB_1$-curve intersects the $MSB_2/(1+r)$-curve at negative prices, it would be optimal to consume a smaller amount such that $MSB_t = 0$ is ensured in each period. Such an outcome does not carry over to model with an infinite time horizon problem: if there is a minimum fixed amount of the resource consumed in each period, determined by $MSB_t = 0$, exhaustion of the whole resource stock would be beneficial to society – despite the existence of pollution.

The implication of this model are not only important with respect to the determination of the optimal time path of environmental taxes. The results with respect to international distribution are also striking. If resource-owning countries have optimised the time path of extraction and if all resource-importing countries introduce environmental taxes, total demand will fall in each period if the producer price remains constant. This cannot be an equilibrium, as the total resource stock would not be exhausted and a price taker would have an incentive to increase sales in some periods. As a consequence, both the producer price and the resource rent obtained by the resource-extracting country falls. Since the marginal environmental damage is an increasing function of resource consumption, a shift from present consumption towards future consumption is welfare enhancing. A delay in consumption reduces both the absolute amount of emissions and the present value of the environmental damage. One could therefore take the view that if consumption of the natural resource is not taxed, resource-consuming countries actually subsidise the resource-extracting country, by an amount equal to the value of the environmental damage that the households inflict upon themselves. In this sense, it is not the polluter who pays for the internalisation of the externality, but the producer of the non-renewable resource damage [cf. Amundsen and Schöb (1999)].

These distributional implications provide incentives for co-ordinating environmental policies in order to capture resource rents even if there are no transboundary or global pollution problems present, which are normally considered as the reason to co-ordinate environmental policies [e.g. Hoel (1992)]. For instance, the Kyoto Protocol may be exploited by resource-consuming countries by using a carbon tax as a new form of tariff which allows these countries to capture some of the resource rents. If, for example, all resource-consuming countries agree to introduce a carbon tax that increases with the real interest rate, we know from the literature on optimal resource taxation that such a co-ordinated per-unit resource tax would leave the time path of extraction and hence resource consumption completely unaffected. This follows directly from the Hotelling rule [cf. e.g. Dasgupta and Heal (1979), Sinn (1982)]. Such a tax would have no effect at all on the environment and would thus be a pure rent-capturing tax.[24]

If the resource-owning country can exercise market power, by contrast, they may attempt to raise the initial resource price, because this would reduce the environmental tax and allow the resource-owner to capture some of the tax revenues that the resource-consuming countries would otherwise collect [cf. Wirl (1994)]. The resource-consuming countries then fail to *completely* extract rents. Nevertheless, co-ordination would always allow the resource-consuming countries to capture *some* of the resource rent (and the monopoly rent). Indeed, as was shown by Karp and Newbery (1991), in the absence of externalities, the buyer's market power exceeds that of the sellers, as they succeed in reducing the initial producer price.

If the OPEC countries commit to raising oil prices, it might increase political pressure in resource-consuming countries to reduce the high taxes on fuel. This happened in the fall 2000 when French truck drivers forced the French government to reduce fuel taxes. A single country can actually reduce consumer prices by lowering the green tax. If all countries do,

[23] Also see Ploeg and Withagen (1991) and Kolstad and Krautkraemer (1993).

[24] Newbery (1976) and Bergstrom (1982) were the first to show that resource-consuming countries can secure the entire resource rent from the resource-owning country by co-ordinating their tariffs or their national excise tax policy. The theoretical findings are in line with the empirical. For example, in the countries of the European Union, tax rates on gasoline have increased substantially over time. Although these taxes were not primarily introduced to internalize national or global externalities, their effects are similar to those of environmental taxes. Hoeller and Coppel (1992) calculate the *implicit carbon tax* of fuel taxes and conclude that, at least for most European countries, the implicit carbon tax is considerably higher than the taxes suggested by energy tax reform proposals. Since the mid eighties the real producer price has fallen while the

however, the whole tax reduction would result in an increase in the producer price for the reason given above.

The lasting discussion of whether or not to implement a carbon tax may have adverse effects on the environment. Announcing the imposition of co-ordinated carbon taxes (even if the taxes are not intended to extract rents) acts like an expropriation threat to resource owners. As a consequence, the resource-owning countries have incentives to increase present extraction prior to the date the tax is introduced, so as to reduce future losses [cf. Long (1975), Konrad, Olsen and Schöb (1994)].

In summing up this section, the optimal environmental policy design requires a completely different time path for the environmental taxes if co-ordination of environmental policies is intended to internalise global environmental problems and if resource-consuming countries try to extract some of the resource rent from the resource owners. While it might be optimal for a single country to reduce its consumption of a natural resource in all periods, this may not be true for all resource-consuming countries altogether. If it is guaranteed that the use of at least one unit of the resource in a time period is beneficial, the whole resource stock should be used up in finite time. Hence, optimal environmental taxation must try to delay extraction of the resource rather than reduce resource consumption in every period. To delay extraction, however, an environmental tax is required which decreases over time.

## APPENDIX 1: SECOND-BEST OPTIMAL ENVIRONMENTAL TAX

Rewriting the equation system (2.9) and (2.10) for the case of homogenous households yields:

(A1.1)
$$\begin{vmatrix} \frac{\partial x_c}{\partial t_c}+\frac{\partial x_c}{\partial E}\frac{\partial E}{\partial t_c} & \frac{\partial x_d}{\partial t_c}+\frac{\partial x_d}{\partial E}\frac{\partial E}{\partial t_c} \\ \\ \frac{\partial x_c}{\partial t_d}+\frac{\partial x_c}{\partial E}\frac{\partial E}{\partial t_d} & \frac{\partial x_d}{\partial t_d}+\frac{\partial x_d}{\partial E}\frac{\partial E}{\partial t_d} \end{vmatrix} \begin{vmatrix} t_c \\ \\ t_d \end{vmatrix} = \begin{vmatrix} \frac{\lambda-\mu}{\mu}x_c - \frac{u_E}{\mu}\frac{\partial E}{\partial t_c} \\ \\ \frac{\lambda-\mu}{\mu}x_d - \frac{u_E}{\mu}\frac{\partial E}{\partial t_d} \end{vmatrix}.$$

The determinant $|D|$ is given by [using (2.12)]

(A1.2)
$$|D| = \varphi\left(\frac{\partial x_c}{\partial t_c}\frac{\partial x_d}{\partial t_d} - \frac{\partial x_c}{\partial t_d}\frac{\partial x_d}{\partial t_c}\right) \equiv \varphi|J|.$$

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real tax rate has increased steadily. These countervailing developments have left the consumer price more or less unaffected until the mid nineties evidence [cf. Amundsen and Schöb (1999)].

Applying Cramer’s rule for the clean good yields

$$t_c = \frac{\frac{\lambda-\mu}{\mu}\left(x_c\frac{\partial x_d}{\partial t_d} - x_d\frac{\partial x_d}{\partial t_c} + \frac{\partial x_d}{\partial E}\left(x_c\frac{\partial E}{\partial t_d} - x_d\frac{\partial E}{\partial t_c}\right)\right) + \frac{u_E}{\mu}\left(\frac{\partial E}{\partial t_d}\frac{\partial x_d}{\partial t_c} - \frac{\partial E}{\partial t_c}\frac{\partial x_d}{\partial t_d}\right)}{\varphi|J|}.$$

Applying the definition (2.12) shows that the last term of the numerator is zero. Furthermore, applying (2.12) again, we have

$$\left(x_c\frac{\partial x_d}{\partial t_d} - x_d\frac{\partial x_d}{\partial t_c} + \frac{\partial x_d}{\partial E}\left(x_c\frac{\partial E}{\partial t_d} - x_d\frac{\partial E}{\partial t_c}\right)\right)$$
$$= \left(1 + H\frac{\partial x_d}{\partial E}\varphi e'\right)\left(x_c\frac{\partial x_d}{\partial t_d} - x_d\frac{\partial x_d}{\partial t_c}\right) = \varphi\left(x_c\frac{\partial x_d}{\partial t_d} - x_d\frac{\partial x_d}{\partial t_c}\right).$$

Using the Slutzky equation, we finally obtain

(A1.3) $$t_c = \frac{\frac{\lambda-\mu}{\mu}\left(x_c\left(s_{dd} - x_d\frac{\partial x_d}{\partial T}\right) - x_d\left(s_{dc} - x_c\frac{\partial x_d}{\partial T}\right)\right)}{|J|} \equiv \frac{\mu-\lambda}{\mu}t_c^R.$$

For the dirty good, we have

$$t_d = \frac{\left(\frac{\partial x_c}{\partial t_c} + \frac{\partial x_c}{\partial E}\frac{\partial E}{\partial t_c}\right)\left(\frac{\lambda-\mu}{\mu}x_d - \frac{u_E}{\mu}\frac{\partial E}{\partial t_d}\right)}{\varphi|J|} - \frac{\left(\frac{\partial x_c}{\partial t_d} + \frac{\partial x_c}{\partial E}\frac{\partial E}{\partial t_d}\right)\left(\frac{\lambda-\mu}{\mu}x_c - \frac{u_E}{\mu}\frac{\partial E}{\partial t_c}\right)}{\varphi|J|}.$$

Multiplying through, using (2.12) and shortening yields:

(A1.4) $$t_d = \frac{\frac{\lambda-\mu}{\mu}\left(x_d\frac{\partial x_c}{\partial t_c} - x_c\frac{\partial x_c}{\partial t_d}\right) + \frac{\lambda-\mu}{\mu}H\frac{\partial x_c}{\partial E}\varphi e'\left(x_d\frac{\partial x_d}{\partial t_c} - x_c\frac{\partial x_d}{\partial t_d}\right)}{\varphi|J|} - \frac{Hu_E e'}{\mu}.$$

The first term can be rewritten (using the Slutzky decomposition) as follows:

(A1.5)

$$\frac{\frac{\lambda-\mu}{\mu}\left(x_d\frac{\partial x_c}{\partial t_c}-x_c\frac{\partial x_c}{\partial t_d}\right)}{\varphi|J|}=\frac{\frac{\lambda-\mu}{\mu}\left(x_d\left(s_{cc}-x_c\frac{\partial x_c}{\partial T}\right)-x_c\left(s_{cd}-x_d\frac{\partial x_c}{\partial T}\right)\right)}{\varphi|J|}$$

$$=\frac{\left(1-e'H\frac{\partial x_d}{\partial E}\right)\left(\frac{\lambda-\mu}{\mu}(x_d s_{cc}-x_c s_{cd})\right)}{|J|}=\frac{\mu-\lambda}{\mu}t_d^R-\frac{\mu-\lambda}{\mu}t_d^R H\frac{\partial x_d}{\partial E}e'.$$

Substituting in the tax on the clean good (A1.3) allows us to simplify the second term of (A1.4) as well. Finally, substituting (A1.4) in (A1.5) gives:

(A1.6)
$$t_d=\frac{\mu-\lambda}{\mu}t_d^R+\frac{\lambda}{\mu}t_P-\frac{\mu-\lambda}{\mu}\sum_{i=c,d}t_i^R H\frac{\partial x_i}{\partial E}e'.$$

Adding $-t_d e' H\,\partial x_d/\partial E$ on both sides, adding the two terms of the right-hand side with the Ramsey components of the dirty good together and substituting in equations (A1.3) and (2.12), this can be rewritten as:

(2.15a)
$$t_d=\frac{\mu-\lambda}{\mu}t_d^R+\left(\frac{\lambda}{\mu}t_P-\sum_{i=c,d}t_i H\frac{\partial x_i}{\partial E}e'\right)\varphi.$$

Applying the several restricting assumptions discussed in the main text give the respective optimal tax formulae (2.13) to (2.15).

## APPENDIX 2: RESTRICTED PROFIT TAXATION

Subtracting (3.15) from (3.13) implies that the following condition must hold:

(A2.1)
$$\mu\left[\Omega_{ww}w-\Omega_{wt_t}(1+t_w)\right]=-(\lambda-1)wL<0.$$

The left-hand side of (A3.1) must be negative. Rewriting the terms in brackets yields:

(A2.2)
$$\Omega_{ww}w-\Omega_{wt_w}(1+t_w)=\Omega_{ww}w\left[-\frac{\Omega_{wt_w}(1+t_w)}{\Omega_{ww}w}+1\right],$$

where the first term in brackets on the right-hand side is the net-of-tax wage elasticity with respect to the labour tax rate. As has been argued above, this elasticity is larger than $-1$. Hence (A2.2) is negative and the condition (A2.1) holds only if $\mu>0$.

Using this condition, we can derive the optimal tax formulae for the second case when the wage rate changes. For the case $\varphi > 0$ and hence $t_\pi = \bar{t}_\pi$ rearranging the equations (3.13) and (3.14) yields

$$\begin{vmatrix} wL\eta_{L,\tilde{w}} & qR\eta_{R,\tilde{w}} \\ wL\eta_{L,\tilde{q}} & qR\eta_{R,\tilde{q}} \end{vmatrix} \begin{vmatrix} \lambda t_w \\ \lambda t_q + \dfrac{E_R}{q} \end{vmatrix} = \begin{vmatrix} (1-\lambda)(1-\bar{t}_\pi)\tilde{w}L - \left(\dfrac{w-b}{w}\right) wL\eta_{L,\tilde{w}} + \mu\Omega_{wt_w}(1+t_w) \\ (1-\lambda)(1-\bar{t}_\pi)\tilde{q}R - \left(\dfrac{w-b}{w}\right) wL\eta_{L,\tilde{q}} - \mu\Omega_{wt_w}(1+t_w) \end{vmatrix},$$

with $\Omega_{wt_q} = -\Omega_{wt_w}(1+t_w)/(1+t_q)$ (cf. Koskela and Schöb 2002b). Applying Cramer's rule and using the fact that the determinant of the left-hand side matrix is equal to $\Delta = wLqR\sigma\varepsilon$ yields

(A2.4) $$\lambda t_w = -\left(\frac{w-b}{w}\right) + \frac{(1-\lambda)(1-\bar{t}_\pi)}{wL\sigma\varepsilon}\left[\tilde{w}L\eta_{R,\tilde{q}} - \tilde{q}R\eta_{R,\tilde{w}}\right] - \mu\frac{\Omega_{wt_w}(1+t_w)}{\tilde{w}L\eta_{R,\tilde{q}} - \tilde{q}R\eta_{R,\tilde{w}}},$$

(A2.5) $$\lambda t_q + \frac{E_R}{q} = +\frac{(1-\lambda)(1-\bar{t}_\pi)}{qR\sigma\varepsilon}\left[\tilde{q}R\eta_{L,\tilde{w}} - \tilde{w}L\eta_{L,\tilde{q}}\right] + \mu\frac{\Omega_{wt_w}(1+t_w)}{\tilde{q}R\eta_{L,\tilde{w}} - \tilde{w}L\eta_{L,\tilde{q}}}.$$

Using the explicit elasticity formulas, we have

(A2.6) $$\tilde{w}L\eta_{R,\tilde{q}} - \tilde{q}R\eta_{R,\tilde{w}} = cY\left(s\eta_{R,\tilde{q}} - (1-s)\eta_{R,\tilde{w}}\right) = -cY\sigma s,$$

(A2.7) $$\tilde{q}R\eta_{L,\tilde{w}} - \tilde{w}L\eta_{L,\tilde{q}} -= cY\left((1-s)\eta_{L,\tilde{w}} - s\eta_{L,\tilde{q}}\right) = -cY\sigma(1-s).$$

Substituting in (A2.6) and (A2.7) in (A2.4) and (A2.5) respectively, we obtain conditions (2.20) and (2.21).

## APPENDIX 3: COMPETITIVENESS

Without loss of generality, we assume that the profit tax is equal to zero. From the government budget condition (3.11) we then get

(A3.1) $$dG = \left[wL + t_w wL_{\tilde{w}}w + t_q qR_{\tilde{w}}w\right]dt_w + \left[qR + t_q qR_{\tilde{q}}q + t_w wL_{\tilde{q}}q\right]dt_q.$$

The elasticities of factor demands are given by $\eta_{R,\tilde{q}} \equiv R_{\tilde{q}}q/R = -\sigma + (1-s)(\sigma-\varepsilon)$, $\eta_{R,\tilde{w}} \equiv R_{\tilde{w}} \cdot \tilde{w}/R = s(\sigma-\varepsilon)$, $\eta_{L,\tilde{w}} \equiv L_{\tilde{w}}\tilde{w}/L = -\sigma + s(\sigma-\varepsilon)$, $\eta_{L,\tilde{q}} \equiv L_{\tilde{q}} \cdot \tilde{q}/L = (1-s)(\sigma-\varepsilon)$ where $s \equiv \tilde{w}L/cY$ denotes the cost share of labour and $(1-s) \equiv 1 - \tilde{w}L/cY = \tilde{q}R/cY$ denotes the cost share of energy and $\sigma$ denotes the constant elasticity of substitution as in Section 3. Substituting these in equation (A4.1) gives

$$dG = wL\left[1+\frac{t_w}{(1+t_w)}\eta_{L,\tilde{w}} + \frac{t_q}{(1+t_q)}\frac{(1-s)}{s}\eta_{R,\tilde{w}}\right]dt_w + qR\left[1+\frac{t_q}{(1+t_q)}\eta_{R,\tilde{q}} + \frac{t_w}{(1+t_w)}\frac{s}{(1-s)}\eta_{L,\tilde{q}}\right]dt_q .$$

Setting $dG = 0$ yields an expression that reveals how the labour tax rate changes due to a marginal increase of the tax on energy (using the fact that $\eta_{R,\tilde{w}} = s\eta_{L,\tilde{q}} / (1-s)$)

$$\text{(A3.2)} \qquad \left.\frac{dt_w}{dt_q}\right|_{dG=0} = -\frac{qR\left[1+\frac{t_q}{(1+t_q)}\eta_{R,\tilde{q}} + \frac{t_w}{(1+t_w)}\eta_{R,\tilde{w}}\right]}{wL\left[1+\frac{t_w}{(1+t_w)}\eta_{L,\tilde{w}} + \frac{t_q}{(1+t_q)}\eta_{L,\tilde{q}}\right]}.$$

To analyse the change in the competitiveness of the economy, we have to calculate the effect, a marginal revenue-neutral green tax reform has on the unit cost of production. The impact of a revenue-neutral green tax reform on the unit cost of production is given by $dc(\tilde{w},\tilde{q}) = c_{\tilde{w}}wdt_w + c_{\tilde{q}}qdt_q$. Applying Shephard's lemma $C_{\tilde{w}} = c_{\tilde{w}}Y = L$, $C_{\tilde{q}} = c_{\tilde{q}}Y = R$ and using equation (A4.2) allows us to determine the change in the unit cost of production:

$$\text{(A3.3)} \quad \left.\frac{dc}{dt_q}\right|_{dG=0} = c_{\tilde{w}}w\left.\frac{dt_w}{dt_q}\right|_{dG=0} + c_{\tilde{q}}q = \frac{qR\left[\frac{t_q(\eta_{L,\tilde{q}} - \eta_{R,\tilde{q}})}{(1+t_q)} + \frac{t_w(\eta_{L,\tilde{w}} - \eta_{R,\tilde{w}})}{(1+t_w)}\right]}{Y\left[1+\frac{t_w}{(1+t_w)}\eta_{L,\tilde{w}} + \frac{t_q}{(1+t_q)}\eta_{L,\tilde{q}}\right]}.$$

Assuming positive marginal tax revenues for the labour tax rate [cf. equation (A4.1)], the denominator is always positive. Substituting in the definitions of the (cross-)price elasticities of factor demands in the nominator of equation (A3.3) yields $\eta_{L,\tilde{q}} - \eta_{R,\tilde{q}} = \sigma$ and $\eta_{L,\tilde{w}} - \eta_{R,\tilde{w}} = -\sigma$. This gives us condition (4.2).

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