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Choosing the Right Instrument:

The Role of Public Revenues for Environmental Policy

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Abstract

This paper analyses the optimal choice of second-best optimal environmental policies. Using a partial equilibrium model, the paper first reconfirms the well-known result that the existence of a double dividend (in its weak definition) favours environmental policy instruments which maximise tax revenues for a given improvement in environmental quality. Additional revenues can be used to reduce the distortion of existing taxes such as taxes on labour and capital income. Without uncertainty, environmental taxes and auctioned permits are equally appropriate. In the presence of uncertainty, however, the optimal choice of taxes or tradable permits depends on the relative magnitudes of the marginal environmental damage and the marginal benefit from consuming a polluting good. In the second part, the paper, therefore, analyses how the revenue capacity affects the optimal choice of environmental policy instruments in the presence of uncertainty. The paper shows that the first-best choice rule between price and quantity regulation (Weitzman 1974) remains valid in a second-best world with distortionary taxation.

JEL-classification: H23, Q28

1. Introduction

When, in the early seventies, 'environmental protection' started to climb up the political agenda, economists were already prepared to offer a wide variety of efficient instruments to control pollution. On the one hand, many economists are in favour of different types of price-regulating mechanisms. It is well known that environmental taxes can, if set properly, link the market prices of polluting goods to their marginal social costs. On the other hand, some economists favour quantity-regulating mechanisms. Distributing tradable permits allows markets for pollution rights to develop. These markets then generate market prices equal to the marginal social costs.

In recent years, the claim that environmental taxes yield a second dividend was put forward in favour of a tax solution. According to the so-called weak form of the double-dividend hypothesis,[1] 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. Classifying all the environmental policy instruments according to their *revenue capacity* shows, however, that this is not a particular feature of environmental taxes. Auctioned permits will, in principle, yield the same amount of public revenues, while tradable permits distributed free of charge (so-called grandfathering schemes) are equivalent to tax/subsidy solutions which yield zero tax revenues.

If lump-sum taxes are not available in the economy, the government has to raise revenues via distortionary taxes. In order to choose the best environmental policy instrument, we therefore have to take account of the welfare effects the additional public revenues from green taxes or pollution permits may have. Using a partial equilibrium model, it will be shown that the choice of second-best optimal environmental policy actually depends on both the marginal environmental damage *and* the revenue capacity of the particular environmental policy instruments applied. Additional public revenues from environmental policies can be

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[1] For a definition of the weak form of the double-dividend hypothesis cf. e.g. Goulder (1995).

used to reduce the distortion of existing taxes and thereby increase welfare. Pure tax schemes and auctioned permits turn out to be more efficient than either tax/subsidy schemes or grandfathered permits. Hence, environmental policy should be based on instruments which yield the highest public revenues.

Though this result is widely accepted in the recent literature with respect to green taxes, the fact that auctioned permit schemes have, in principle, the same revenue capacity as a pure tax solution has been largely neglected. This may be justified as long as we are looking at environmental problems in a world without uncertainty. There, both regulating mechanisms are equivalent.

In the presence of uncertainty, however, the choice of taxes or tradable permits depends on the relative magnitudes of the marginal environmental damage and the marginal benefit from consuming a polluting good. The main focus of this paper therefore is to analyse the impact the revenue capacity effect has on the choice between price and quantity regulation in the presence of uncertainty. Two main results are derived. Firstly, if there is uncertainty about the marginal environmental damage, price and quantity regulations lead to the same result because the price-quantity relation is determined by the marginal benefit of consuming a polluting good. Secondly, in the case of uncertainty about the marginal benefit of pollution, the revenue capacity effect generates additional welfare effects which one has to take into account. It turns out that the second-best analysis reconfirms the results of the first-best analysis of Weitzman (1974) and others. The first-best choice rule between price and quantity regulation remains valid in a world with distortionary taxation.

Section 2 offers a brief classification of environmental policy instruments with respect to their revenue capacity. Section 3 presents a partial equilibrium model which analyses environmental policy in a second-best world without uncertainty. Section 4 then extends the analysis to the case of uncertainty and derives conditions under which a pure tax solution is preferable to auctioned permits and vice versa. Section 5 concludes.

2. Environmental policies and tax revenues

When considering efficient instruments for controlling pollution, we can distinguish between price-regulating mechanisms and quantity-regulating mechanisms. The idea of a price-regulating mechanism is to charge the polluter an amount that, at the margin, completely covers the external costs of the pollution. The optimal tax on emissions, known as Pigovian tax, has to be set equal to the marginal environmental damage (*MED*).

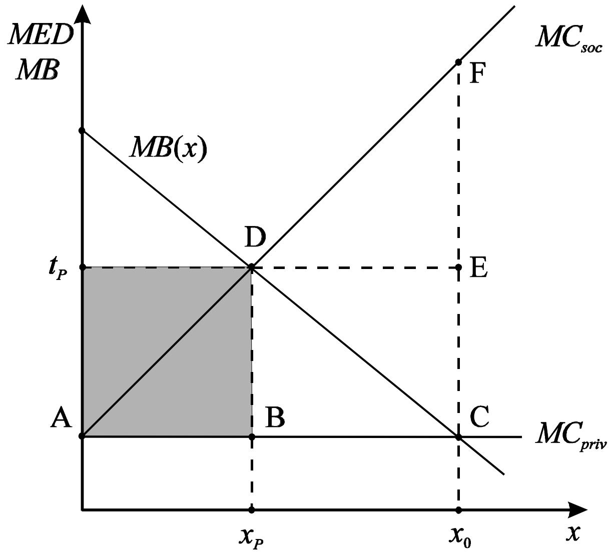

Figure 1: *Optimal environmental policies*

In figure 1, we consider the case of a polluting consumption good *x*. *MB* describes the marginal benefit of consumption, MC_{priv} the private marginal cost, and MC_{soc} the social marginal cost curve, respectively. Without regulation, competitive markets equalises private marginal costs and private marginal benefits. Hence, the market equilibrium is at x_0. This imposes a welfare loss equal to the area CDF. Introducing a tax t_P guarantees Pareto efficiency: Marginal social cost MC_{soc}, i.e. marginal private cost MC_{priv} plus the external cost *MED*, has to be equal to the marginal benefit of consumption *MB*. This tax leads to tax revenues equal to the area shaded in grey. As is well known, such a first-best tax ensures both static (cf. e.g. Baumol and Oates 1988) and dynamic efficiency (cf. e.g. Spulber 1985).

Other types of price-regulating mechanisms are tax/subsidy schemes. If the laissez-faire emissions are x_0 the government could implement a subsidy which equals t_P. This induces polluters to reduce their consumption to x_p where the marginal cost of emission reduction equals the subsidy. This ensures static efficiency. Such a subsidy scheme, however, can be interpreted as a tax solution with a *lump-sum subsidy*. The subsidy is equal to $t_P \cdot x_0$. The remaining emissions x_p are taxed at the Pigovian tax level. In this case, tax revenues are equal to minus the area DBCE. Alternatively, the lump-sum subsidy can be equal to $t_P \cdot x_P$, with zero total tax revenues. If the subsidy is granted independently of any entry or exit decisions of the polluters, such a tax/subsidy scheme can also ensure dynamic efficiency.[2]

Dales (1968) proposes introducing tradable permits for pollution instead of imposing taxes. His idea is to give - at least to some extent - the property rights to pollute to the polluters and to allow them to trade these rights. In terms of our analysis, we can distinguish three different schemes for the initial distribution of such property rights:

1. *Auction*: The government decides to auction the optimal amount of emissions E^* by restricting consumption of x to x_p. In a competitive market the auction price will be equal to the Pigovian tax t_P. The revenues from the auction then equal the tax revenues of a Pigovian tax solution (The shaded area in figure 1).

2. *Grandfathering:* The government can, e.g., based on historical levels of emissions, distribute tradable emission rights x_p to polluters without charging them. Each polluter then can either use the emission rights to pollute himself or he can sell these rights to someone else whose marginal benefit of pollution is higher than his in a market for permit. In a competitive market, the equilibrium market price is t_P. Government revenues are zero.

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[2] Mumy (1980) was the first to interpret a subsidy as a tax/subsidy scheme. Dewees and Sims (1976, p. 330) interpret such a subsidy as a compensation for the loss of the property right to pollute. This implies that only existing firms can obtain such subsidies.

3. Finally, the government can implement a tradable permit scheme where it grandfathers a quantity larger than x_P, e.g., x_0 emission rights, and repurchases (x_0 - x_P) emission rights. This will guarantee the optimal emission level x_P. Note that the initial distribution must be independent of the exit or entry decisions of polluters.

Regulation by	*Share of pollution rights going to the polluters free of charge*		
	0%	$\frac{x_P}{x_0} \cdot 100\%$	100%
Price	**Pigovian tax** subsidy = 0	**tax/subsidy** subsidy = $t_P \cdot x_P$	**tax/subsidy** subsidy = $t_P \cdot x_0$
Quantity	**permits** auctioned	**permits** Grandfathered permits up to the amount of x_P	**permits** Grandfathered permits up to the amount of x_0. Sold back: (x_0 - x_P)
Tax revenues	$R = t_P \cdot x_P$	$R = 0$	$R = -t_P(x_0 - x_P)$

Table 1: *Efficient environmental policies and their revenue capacity*

Table 1, based on Pezzey (1992, p. 987), summarises the different policies by distinguishing the policies according to both price regulation by quantity or price and to their capacity to raise tax revenues. Both the Pigovian tax and auctioned permits imply that the property rights for the environment are completely nationalised. This maximises tax revenues of a first-best efficient environmental policy. The intermediate solution, shown in the middle column, illustrates the two possible regulation mechanisms where polluters obtain the right to pollute at the efficient level without being charged. Tax revenues are zero in this case. The solution in the right-hand column gives all property rights to the environment to the polluters. In this case they have to be compensated for any reduction of their emissions. Hence, tax revenues are negative.

In a first-best world without uncertainty and with lump-sum taxes and lump-sum subsidies available, tax revenues do not matter, and neither does the decision to regulate by prices or quantities (cf. Montgomery 1972). All solutions described in table 1 lead to a Pareto efficient use of the environment. However, if environmental policy takes place in world with distortionary taxes, tax revenues do matter. This will be shown in the next section.

3. Second-best optimal environmental levies

Nichols (1984) and Lee and Misiolek (1986) analyse optimal environmental levies in the presence of distortionary taxes, using partial equilibrium models. A modified form of their models will be adopted for the following analysis.[3]

Consider, e.g., the tax on gasoline consumption, which is equivalent to an emission tax as long as emissions increase proportionately to consumption. The gross benefit of gasoline consumption is $B(x)$ with $B'(x) = MB(x) > 0$ and $B''(x) < 0$. In a small open economy, the world market price q, and therefore marginal private cost, are constant. The environmental damage function is given by $e(x)$ with $e'(x) = MED > 0$ and $e''(x) \geq 0$.

Assume, for simplicity, that the excess burden of all other taxes increases proportionately to total tax revenues: The *marginal excess burden* δ is thus constant, too. Given a fixed tax revenue requirement, the total amount of gasoline tax revenues, $R(x) = t(x) \cdot x$, determines the amount by which tax revenues from taxes other than gasoline taxes can be reduced. The welfare gain due to the reduction of distortionary taxes then is: $\delta \cdot R(x)$.

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[3] Sandmo (1975) and more recently the double-dividend literature (cf. e.g. Bovenberg and de Mooij 1994 or Bovenberg and van der Ploeg 1994) derive optimal environmental taxes within general equilibrium models. It turns out that the results of the partial equilibrium model are consistent with the result derived from optimal taxation models (cf. Schöb 1994 or Goulder 1995). Only the partial equilibrium model, however, allows us to derive analytical results in the presence of uncertainty. Note that Lee and Misiolek (1986) in their paper focus on the optimal tax rate in the presence of distortionary taxes while Nichols (1984) focuses on the potential welfare gains.

The government maximises the following social welfare function which takes into account the environment as well as the inefficiency of the tax system:

$$W = B(x) - q \cdot x - e(x) + \delta \cdot R(x)\,. \tag{1}$$

The consumer price *p* is given by the world market price plus the gasoline tax *t:* $p = q + t$. The total burden of the tax is borne by the consumers. The government can determine *p* and, therefore, total consumption of gasoline by varying the tax rate, i.e., the government acts like a monopolist. However, the objective function is different from the objective function of a private monopolist. While the latter maximises private profits, the former maximises social surplus. Maximising equation (1) with respect to the tax rate *t* yields the following first-order condition:

$$\frac{\partial W}{\partial t} = \left(MB - q - MED + \delta \cdot R' \right) \frac{\partial x}{\partial t} = 0\,. \tag{2}$$

It is assumed that all cross-price effects between taxed goods are identically zero. In addition, feedback effects of changing emissions on the consumption of taxed goods are neglected. Rearranging equation (2) yields:

$$MB = q + MED - \delta \cdot R' = q + MED - \delta \cdot \left(t + x \cdot \frac{\partial t(x)}{\partial x} \right). \tag{3}$$

In the optimum, the marginal benefit of gasoline consumption *MB* has to be equal to the sum of private marginal cost *q* plus the marginal environmental damage *MED* minus the efficiency gain from reducing other distortionary taxes by refunding marginal revenues, $\delta R'$.

The *tax elasticity* is defined as

$$\tau = -\frac{\partial x}{\partial t} \cdot \frac{t}{x} = -\frac{t}{p} \frac{\partial x}{\partial p} \cdot \frac{p}{x} = \frac{t}{p} \varepsilon\,,$$

with ε being the price elasticity. The tax elasticity indicates the percentage at which the demand of gasoline will be reduced if the tax rate is increased by one per cent. Inserting the tax elasticity into equation (3), using the first order condition of household maximisation, $MB = q + t$, and solving for the optimal tax rate t^*, we obtain:[4]

$$t^* = \frac{MED}{1 + \delta \cdot \left(1 - \frac{1}{\tau}\right)}. \tag{4}$$

This is the second-best tax rate derived by Nichols (1984, p. 36).[5] It turns out that the optimal tax is a function of the marginal environmental damage, the marginal excess burden of the rest of the tax system, and the tax elasticity. The optimal tax rate is therefore different from the Pigovian tax, which was completely determined by the marginal environmental damage:

$$t_P = MED. \tag{5}$$

The Pigovian tax turns out to be optimal in two circumstances, only. First, the Pigovian tax is optimal if there is no distortion of the tax system, i.e., $\delta = 0$. This is the case if either there are no other distortionary taxes present, e.g., the government uses lump-sum taxes, or the revenues from gasoline taxation are equal to the tax revenues required (cf. Sandmo 1975).

Second, the Pigovian tax may be optimal even in the presence of other distortionary taxes. This is the case when, at the optimum, the tax elasticity is equal to unity. A tax elasticity of one implies that marginal tax revenues are equal to zero. There is no possibility of reducing other taxes. Hence, the only benefit from the tax results from the reduction in pollution. Any deviation from the Pigovian tax reduces welfare. A non-zero tax elasticity, however, changes the optimality conditions and hence the optimal tax rate.

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[4] From $p = q + t$ we have: $\partial x / \partial t = \partial x / \partial p$.

[5] Nichols minimises social costs instead of maximising welfare. He thereby disregards the consumer surplus of gasoline consumption. Being aware of this inconsistency, Nichols states that the excess burden of gasoline taxation also has to be taken into account (Nichols 1984, p. 37), if the optimal tax rate if different from the Pigovian tax. In the approach adopted here, the consumer surplus is already considered. Increasing the Pigovian tax at the margin, the loss of reducing the benefits of gasoline consumption is completely compensated by the improved environment, i.e. $MB = MED$. Hence, the only additional effect here is the welfare gain from using the marginal tax revenues.

3.1 Positive marginal revenues of the Pigovian tax

If the tax elasticity for the Pigovian tax is smaller than one, a marginal increase in the Pigovian tax yields positive marginal tax revenues. As these tax revenues can be used to reduce distortionary taxes, such an increase is welfare improving.

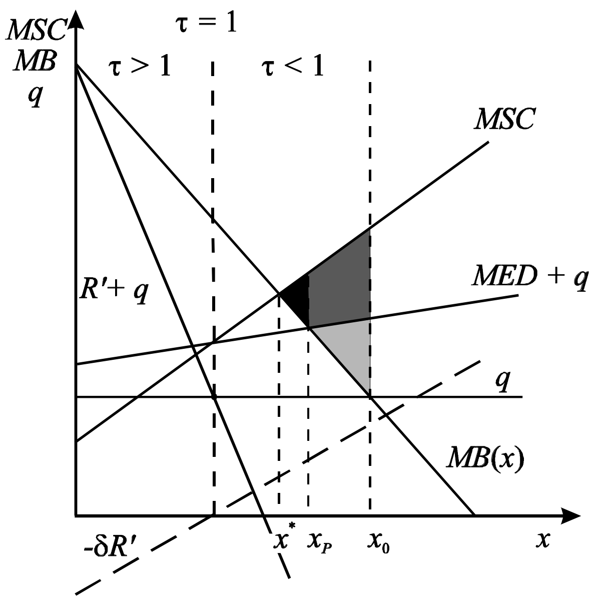

Figure 2: *Positive marginal revenues*

To see this, consider figure 2. There, the marginal benefit curve *MB* denotes the demand for gasoline. From this curve, we can derive the marginal revenue curve. Marginal revenues consist of the private marginal revenues q and the marginal tax revenues R'. Where the marginal revenue curve intersects the private marginal cost curve, marginal tax revenues are zero. This implies $\tau = 1$. For linear demand functions, we have $\tau > 1$ to the left and $\tau < 1$ to the right.

If the marginal tax revenues $R'(x)$ are positive, the *consumption of gasoline* has a positive external effect for society as additional consumption leads to additional tax revenues. These can be used to reduce other distortionary taxes. The marginal benefit of tax revenues is $\delta \in R'$. Taking the negative value, we obtain an additional 'external' cost component for gasoline consumption (the dotted line at the bottom). Adding this cost to the private cost curve q and the marginal environmental damage *MED*, we obtain the second best marginal social cost $MSC = MED + q - \delta R'$.

Negative marginal tax revenues $R' < 0$ imply that increasing gasoline taxes increases tax revenues. This indicates the Laffer-efficient part of the tax revenue curve. From figure 2, we can see that, where $\tau < 1$, the second-best marginal social cost curve lies above the first-best marginal social cost curve. At x_p, the first-best optimum, marginal social costs are still higher than the marginal benefits. Therefore, it is welfare improving to further reduce consumption of gasoline by increasing gasoline taxes.

To analyse the welfare effect, we first fix the tax at the Pigovian level. The area shaded in light grey shows the total welfare gain from improving the environment. This will be called the *environmental effect* of a Pigovian tax. If the total tax revenues are used to reduce other taxes, there is another positive welfare effect. The area between the second-best marginal social cost curve *MSC* and the first-best marginal social cost curve, shaded in dark grey, shows the welfare gain from improving the efficiency of the rest of the tax system. This will be called the *revenue effect* of a Pigovian tax.

Looking at these two effects only, we can conclude that environmental policies which yield tax revenues are superior to policies which do not. Hence, policies listed on the left-hand side of table 1 are preferable to environmental policies which do not generate tax revenues, i.e., policies listed on the right-hand side of table 1.

However, there are additional welfare gains possible from increasing the tax beyond the Pigovian tax. The additional welfare gains from adjusting the tax rate optimally will be called the *adjustment effect* of a second-best optimal tax. This effect is shown as the black triangle in figure 2. Using these definitions, we have three effects at work. Two effects defined for the Pigovian tax and one which describes the effect of deviating from the Pigovian tax.

3.2 Negative marginal revenues of a Pigovian tax

There is no reason, why we should restrict gasoline taxation to the Laffer-efficient side of the tax revenue curve. If the environmental damage is quite severe, the internalisation of the external effect may justify taxation even in the Laffer-inefficient area. We therefore also have to analyse the case of a tax elasticity larger than one.

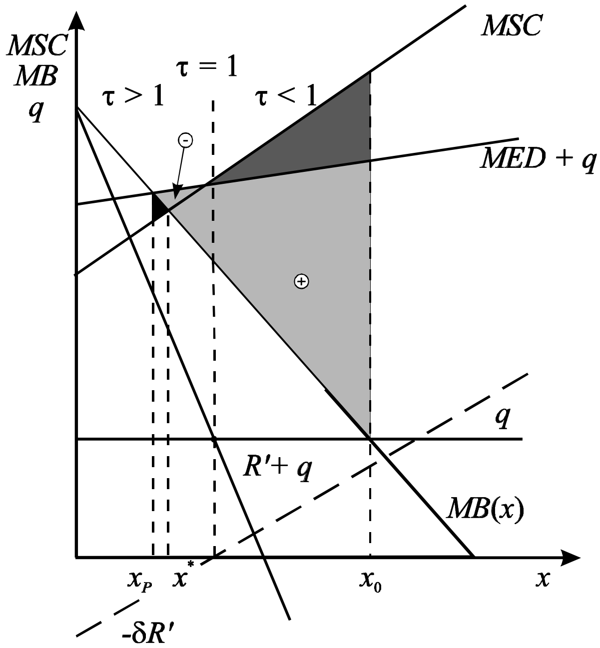

Figure 3: *Negative marginal revenues*

The consequences for optimal tax policies can be analysed in figure 3. At the first-best optimum x_P the second-best marginal social cost curve *MSC* lies below the first-best marginal social cost curve. Changing the Pigovian tax at the margin makes the marginal benefit of gasoline consumption completely outweigh the marginal environmental damage. For $\tau > 1$, cutting the tax below the Pigovian tax will increase tax revenues and will therefore yield an additional benefit to society. The total welfare effect of such a tax reform is equal to – $\delta R'$ (> 0). Hence, optimal second-best policies require the green tax to be reduced below the Pigovian level if implementing a Pigovian tax implies taxing in the Laffer-inefficient area.

At x_P the environmental effect is equivalent to the area shaded in light grey. The revenue effect corresponds to the area shaded in dark grey, minus the small area denoted with (-) and minus the black triangle.[6] The latter denotes the adjustment effect, which in the Laffer-inefficient area is rather small.

4. Prices vs. quantities reconsidered

The previous analysis is valid only in the case without uncertainty. Normally, however, the government has only little information about the marginal benefit curves and the marginal environmental damage curves. Optimal environmental policies therefore have to be designed under uncertainty. Weitzman (1974) was the first to analyse within a first-best framework how price and quantity regulations may lead to different expected welfare gains in the case of uncertainty.[7] With respect to pollution control, we have to distinguish

i) the case where the government does not know the actual position of the marginal environmental damage curve and

ii) the case where the government does not know the actual position of the marginal benefit curve - which can be interpreted as the marginal abatement cost curve.

4.1 First-best analysis

In the first case, where there is uncertainty about the marginal environmental damage, it makes no difference whether the government reduces pollution by imposing a tax or introduces tradable permits. The polluters, whose decisions determine the level of pollution,

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[6] Note that the first two effects are defined for the case where the tax is equal to the Pigovian tax. However, the definitions are chosen to make the three effects add up to 100 per cent of total welfare gains.

[7] Also see Roberts and Spence (1976). A graphical illustration is given in Adar and Griffin (1976) and Fishelson (1976). To model uncertainty, they assume that the government has knowledge about the slope but not about the position of the curve.

maximise utility by making their marginal benefit of consumption equal to the consumer price of the good (in the case of taxation) or to the consumer price for the polluting good plus the price of the permits (in the case of quantity regulation). Hence, if the marginal benefit curve is known to the government, it can determine the quantity by setting the price and vice versa.

Things are different if there is uncertainty about the marginal benefit curve. Figure 4 illustrates the analysis for in the relevant area linear curvatures.[8] If the expected marginal benefit curve MB_{exp} is known, the tax which maximises the expected welfare for the tax solution is given by t_P^e. For the permit system, fixing the consumption at x^e maximises expected welfare.

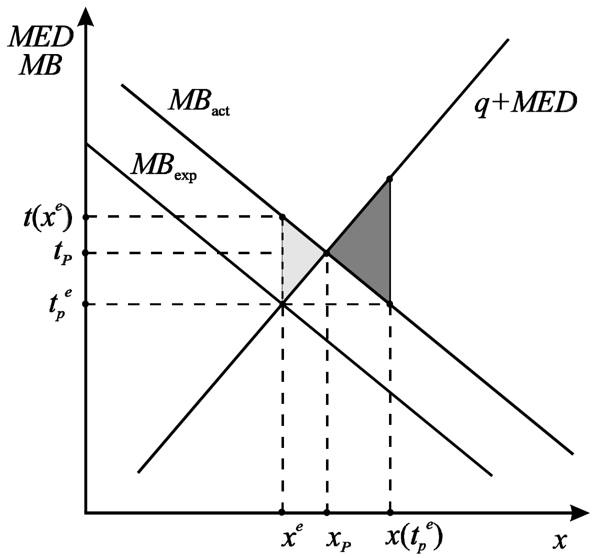

Figure 4: *Prices vs. quantities: first-best analysis*

If it turns out that the actual marginal benefit curve MB_{act} lies above the expected one, it would have been optimal to ex post set x_P or t_P, respectively. With the permit system, however, the quantity is fixed at x^e and the price will increase beyond t_P to $t(x^e)$. This will lead to a welfare loss equal to the area shaded in light grey. With the tax solution the

[8] Cf. Weitzman (1974, p. 485) and Adar and Griffin (1976, p. 188). Crandell (1983, p. 65f) extends the analysis to the case where both curves are unknown to the government.

government has fixed the price at t_P^e. As a consequence, the consumption will be higher than expected: $x(t^e) > x_P$. The resulting welfare loss for the tax solution is indicated by the area shaded in dark grey. In figure 4, the slope of the (first-best) social cost curve is assumed to be larger (in absolute terms) than the slope of the marginal benefit curve. The welfare loss of the tax solution is higher than the welfare loss of the permit system.

Fixing quantities determines the level of emissions but generates uncertainty about the marginal benefit of consumption. Fixing prices determines marginal benefits of consumption but generates uncertainty about the level of emissions (cf. Spence and Weitzman 1978, p. 208). In figure 4, a steeper social marginal social cost implies that any deviation from the optimum causes additional environmental damages greater than the additional benefits to the consumer of the polluting good, while a steeper marginal benefit curve implies that any deviation from the optimum causes more harm to the consumers than to the pollutees. To summarise the result of the first-best analysis:

- In the case of uncertainty about the marginal benefit curve, price regulation and quantity regulation will yield the same expected welfare if the marginal benefit curve and the marginal environmental curve have the same absolute slope.
- Permits achieve a lower (higher) expected welfare loss than the tax solution in the case where the actual curve deviates from the expected marginal benefit curve if the marginal benefit curve is flatter (steeper) than the marginal environmental damage curve.

Hence, the equivalence of price and quantity regulation is no longer valid in the case of uncertainty. The choice of optimal environmental policies in first-best worlds (cf. table 1) depends on the slopes of the relevant curves. The question arises of whether or not these results apply in the case of distortionary taxation, where the second-best marginal social cost curve is different from the first-best marginal social cost curve.

4.2 Prices vs. quantities reconsidered: the role of public revenues

As we have seen from section 3, environmental policy instruments which maximise tax revenues are superior to instruments which do not. The question arises of whether, in the case of uncertainty, the revenue effect has any implications for the choice of price or quantity regulating instruments. To answer this question we first have to modify the model in section 3.

Modelling uncertainty

The risk-neutral central planner knows with certainty the location of the marginal environmental damage curve, given by the intercept a, and the slope b:

$$MED(x) = a + bx. \qquad (6)$$

With respect to the marginal benefit curve the government knows the slope v. However, there is uncertainty with respect to the location of the curve: The intercept is given by w and a random variable u. The expected value of the random variable is zero, i.e. $E(u) = 0$. The marginal benefit of consuming x therefore is given by:

$$MB(x,u) = w - vx + u. \qquad (7)$$

From equation (7) we can easily derive the marginal revenues of taxing the polluting good x:

$$R'(x,u) = w - q - 2vx + u. \qquad (8)$$

The knowledge of the expected marginal tax revenues allows the second-best marginal social cost curve to be calculated. It is given by the private marginal cost q plus the marginal environmental damage [equation (6)] minus the expected marginal tax revenues [equation (8)] weighted with the (constant) marginal excess burden of the rest of the tax system δ:

$$MSC(x,u) = \tilde{a} + (b + 2\delta v)x - \delta u, \qquad (9)$$

whereby $\tilde{a} \equiv a + q - \delta(w - q)$. Contrary to the first-best analysis, the marginal social cost curve is stochastic as the marginal tax revenues are dependent on the location of the stochastic marginal benefit curve. Note that the social marginal cost curve is increasing in *x* while the marginal benefit is decreasing in *x*. Hence, the second order conditions for the welfare maximisation problem are guaranteed to hold.

Maximising expected welfare

We start by deriving the optimal quantity of consumption which maximises expected welfare for the permit system. For a risk-neutral government, the first order condition for the optimal environmental standard is given where expected social marginal cost is equal to the expected marginal benefit of consuming the polluting good:

$$\mathrm{E}\left[MSC(x,u)\right] = \mathrm{E}\left[MB(x,u)\right]. \tag{10}$$

For E(u) = 0 the optimal quantity of the polluting good is therefore given by:

$$x^e = \frac{w - \tilde{a}}{(1+2\delta)v + b}. \tag{11}$$

Now consider the case of a price regulation. Households maximise utility. This implies that the marginal benefit of consumption is equal to the marginal private cost plus the commodity tax. From equation (7) we can therefore derive the quantity consumed for a given tax on *x*:

$$x(t,u) = -\frac{(q + t - w - u)}{v}. \tag{12}$$

Pareto efficiency requires

$$\mathrm{E}\left[MSC\left(x(t,u)\right)\right] = \mathrm{E}\left[MB\left(x(t,u)\right)\right]. \tag{13}$$

The government has to choose the optimal tax rate which equalises the expected marginal social cost and the expected marginal benefit. Both values thereby depend on the actual tax rate chosen. From the first-order condition we can derive the optimal tax rate t^e which maximises expected welfare:

$$t^e = -\frac{(w-\tilde{a})v}{(1+2\delta)v+b} + w - q. \tag{14}$$

Substituting equation (14) in equation (12), we can see that, for E(u) = 0, the expected emissions of the tax solution are exactly the same as the fixed emissions which maximise expected welfare in the permit system [cf. equation (11)].

Comparing expected welfare

The fact that the expected emissions are the same in both systems does not, however, imply that the expected welfare is also the same. We have to calculate the expected welfare for both systems to see whether the expected welfare level of an optimal tax system differs from the expected welfare level of the permit system.

For the permit system the expected welfare is given by

$$\mathrm{E}W(x^e) = \mathrm{E}\left[\int_0^{x^e} \left(MB(x,u) - MSC(x)\right)\mathrm{d}x\right]. \tag{15}$$

Substituting equations (7) and (9) into (15) and integrating, we obtain the following expression for the expected welfare level of the permit system:

$$\mathrm{E}W(x^e) = (w-\tilde{a})x^e - 0{,}5\left((1+2\delta)v+b\right)x^{e2} + (1+\delta)\mathrm{E}(u)x^e, \tag{16}$$

whereby the last term is identical zero.

For the tax system the expected welfare level is given by

$$\mathrm{E}W(t^e) = \mathrm{E}\left[\int_0^{x(t^e,u)} \left(MB\left(x(t^e,u)\right) - MSC\left(x(t^e,u)\right)\right)\mathrm{d}x\right]. \tag{17}$$

Substituting in equations (7) and (9), and using equation (12), the expected welfare of the tax system is given by:

$$\mathrm{E}W(t^e) = (w-\tilde{a})\mathrm{E}\left[x(t^e,u)\right] - 0{,}5\left((1+2\delta)v+b\right)\mathrm{E}\left[x(t^e,u)^2\right] + \mathrm{E}\left[(1+\delta)ux(t^e,u)\right]. \tag{18}$$

The quantity of the polluting good consumed can be derived by using equations (11), (12) and (14):

$$x(t^e, u) = x^e + \frac{u}{v}. \tag{19}$$

Substituting in equation (18) yields:

$$\mathrm{E}W(t^e) = \mathrm{E}W(x^e) - 0{,}5\big((1+2\delta)v + b\big)\frac{\mathrm{E}[u^2]}{v^2} + (1+\delta)\frac{\mathrm{E}[u^2]}{v}. \tag{20}$$

Comparison of the permit system and tax system

Some simple transformations show that the difference in the expected welfare level is independent of the marginal excess burden δ. What determines the difference of the expected welfare level is the difference between the slope of the marginal benefit curve (*v*) and the slope of the marginal environmental damage curve (*b*):

$$\mathrm{E}W(t^e) = \mathrm{E}W(x^e) + \left(\frac{v-b}{2v^2}\right)\mathrm{var}\, u. \tag{21}$$

The difference between the expected welfare levels is higher the larger the variance of *u*. Whether the expected welfare is larger for the tax system, however, is determined by the relative size of the slopes of the marginal benefit curve and the marginal environmental damage curve, respectively. If the marginal benefit of consumption decreases at a lower rate than the marginal environmental damage increases, the tax system is to be preferred and vice versa. In general, we obtain:

$$\mathrm{E}W(t^e) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \mathrm{E}W(x^e) \quad \Leftrightarrow \quad v \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} b. \tag{22}$$

This result corresponds to the result derived by Adar and Griffin (1976) for the first-best case. For, in the relevant area, linear curvatures and a constant marginal excess burden, the second-best analysis reconfirms the first-best analysis.[9] In the presence of uncertainty, the slope of the second-best social marginal cost curve is irrelevant for the choice between regulating the environment by prices or by quantity.

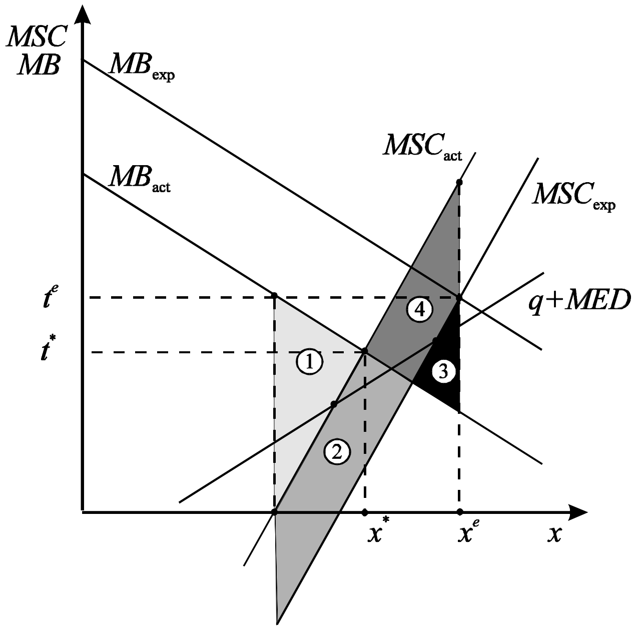

Figure 5: *Prices vs. quantities: Second-best analysis*

For an interpretation, consider figure 5 which shows the case where both the first-best marginal social cost curve (q + *MED*) and the marginal benefit curve have the same absolute slope, i.e. $v = b$. This implies a steeper second-best marginal social cost curve *MSC*. At first glance, one may argue that this indicates that the permit solution is optimal. However, the change of the slope is not the only effect at work.

Assume that the actual marginal benefit curve MB_{act} lies below the expected marginal benefit curve MB_{exp}. This has an impact on the social marginal cost curve as a lower marginal benefit curve lowers both total and marginal revenues. This implies lower additional benefits. As tax revenues are stochastic both curves become stochastic.

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9 The result is critically dependent on this assumption. However, a constant marginal excess burden is a reasonable approximation where environmental tax revenues are small compared to total tax revenues.

The second dividend provides two effects which work into opposite directions. On the one hand, the social marginal cost curve becomes steeper. Disregarding all other effects, areas 1 and 2 would indicate the welfare loss of choosing the tax solution. A permit solution would yield a welfare loss given by area 3. Hence, the permit system seems to lead to lower welfare losses than the tax system.

However, the result changes if we consider the second effect. Due to the lower MB_{act}-curve we have lower marginal revenues and hence a lower second dividend. The lower the MB_{act}-curve, the lower the ability to reduce other distortionary taxes. The social marginal cost increases and the *SMC*-curve shifts upwards. As the shift of the *SMC*-curve always follows the direction of the shift of the *MB*-curve, the deviation of the optimal level of gasoline consumption x^* from x^e becomes larger. Because of the second effect, the welfare loss of the permit solution increases by area 4. By contrast, the ex post optimal consumption x^* is now closer to $x(t^e)$. The welfare loss of the tax solution reduces by the area 2.

As the comparison of equations (20) and (21) shows, these two effects exactly outweigh one another. This is because the expected tax revenues turn out to be the same for both systems. Therefore, only the slopes of the marginal benefit curve and the marginal environmental damage curve matter. The policy recommendations drawn from the first-best analysis remain valid in a second-best setting:

- Price regulation and quality regulation are equally appropriate for regulating the environment if there is uncertainty about the marginal environmental damage.

- In the case of uncertainty about the marginal benefit curve, price regulation and quantity regulation will yield the same expected welfare if the marginal benefit curve and the marginal environmental curve have the same absolute slope.

- Permits achieve a lower (higher) expected welfare loss than the tax solution if the slope of the marginal benefit curve (v) is flatter (steeper) than the slope of the marginal environmental damage curve (b).

The choice between a tax system and a permit system must be made from case to case. As a rule of thumb, a price regulation is advantageous if the marginal environmental damage increases slowly with pollution while the permit system is favourable in the case of thresholds or irreversible consequences. However, there is only little empirical evidence of threshold effects for most pollutants (cf. Crandell 1983, p. 65). For the greenhouse effect, recent estimates of the costs and benefits of reducing CO_2-emissions show that the marginal abatement cost curve, which is equivalent to the marginal benefit curve *MB,* seems to be relatively steeper than the marginal environmental damage curve of CO_2-emissions (cf. e.g. Nordhaus 1991 or Boyd, Krutilla and Viscusi 1995). Similar results are derived for the cost and benefits of emitting sulphur dioxide which is made responsible for the acid rain (cf. e.g. Newbery 1992).

5. Conclusion

In a first-best world tax revenues do not matter. However, they do matter in the presence of distortionary taxes in the economy as tax revenues from green taxes can be used to reduce other distortionary taxes. This is the core of the double dividend argument put forward in favour of tax solutions.

Having chosen the environmental policies which maximises tax revenues for any given environmental quality, one also has to implement them properly. Optimal green taxes do not only depend on the environmental damage, they also depend on the magnitude of the distortion of existing taxes. If Pigovian taxes yield positive marginal revenues an even higher environmental quality can be obtained by optimally adjusting environmental policies. If, however, Pigovian taxes yield negative marginal tax revenues, then second-best environmental quality will be lower.

Imposing taxes is not the only means of raising public revenues, auctioning permits raises revenues too. For the question of whether to choose price regulation or quantity regulation, it is seen that, in the presence of distortionary taxes, considering tax revenues does not alter the results obtained from the first-best analysis. First-best results normally do not remain valid within second-best models. However they do with respect to the optimal instrument choice in the presence of uncertainty. One advantage of this is that no further information is needed to decide whether an optimal environmental policy implies price regulation or quantity regulation.

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