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Discussion paper

Atmospheric Externalities and Environmental Taxation

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Atmospheric Externalities and Environmental Taxation

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Abstract

The paper reviews the theory of environmental taxation under first best and second best conditions. It argues that negative environmental externalities lead to reductions of the provision of public goods, while investment in abatement increases the supply of public goods. Together with optimal tax rules, the paper therefore also derives conditions for the optimal use of resources on abatement. After brief discussions of the dimensions of time and uncertainty, tax reform and the double dividend, and taxes versus quotas, the optimal tax model is applied to the problem of global warming with a discussion of the particular incentive problems that arise in designing and implementing global climate policy.

JEL classification: D60, H41, H87

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1. Introduction.

When towards the end of the 1960s problems of public policy towards the environment began to be discussed in earnest, economists found that they were already equipped with a theoretical framework that allowed them to rise to the challenge of policy design in a new field. The foundations had been laid by Pigou (1920, 1928) who first introduced the idea of corrective taxation as a way of coping with negative environmental externalities. Although it took a long time for the analysis of Pigouvian taxes to achieve a prominent place in public economics, some contributions such as Meade (1952) helped to prepare the ground for the enormous expansion of the field of environmental economics during the 1970s and later. The purpose of this paper is first to review the basic theory of environmental taxation and second to show how it can be applied to the issue of climate change.

The general view adopted in the paper is that negative environmental externalities can be seen as reductions in the availability of public goods. Clean air and water, biological diversity and the global climate are all examples of public goods. Externalities related to the economic activities of consumers and firms lead to reduced provision of such goods, while abatement contributes to their restoration. The view of environmental externalities as generators of public “bads” and abatement as a public good fits well with Meade’s (1952) concept of “atmospheric externalities”, which will be discussed further in Section 7.

The plan of the paper is as follows. In Section 2 I construct a model of environmental public goods and externalities that is probably the simplest analytical framework that one can imagine for the discussion of the issues. I set out the conditions for a welfare optimum and compare them to the characterization of market equilibrium in the case where there is neither Pigouvian nor distortionary taxation. Comparing the welfare optimum with the market equilibrium one can derive the first best Pigouvian or green taxes. Section 3 extends the analysis to the more realistic setting of the second best where the government has to use distortionary taxes to finance spending on abatement; this leads to modifications both of the optimal tax rules and the characterization of optimal expenditure on abatement. Section 4 considers how the modelling framework could be interpreted to take account of the dimensions of time and uncertainty, while Section 5 discusses the distinction between tax design and tax reform. Section 6 considers the classical question of the choice between taxes and quotas, while in Section 7 we make the international dimensions of the problem more explicit. Section 8 briefly considers some insights from behavioural public economics before Section 9 concludes.

2. A simple model

In order to introduce the theoretical framework on which the general discussion will be based, I begin with a model that is stripped down to its barest essentials. To begin with, therefore, the global dimension is ignored and we consider the problem of optimal policy within the context of a nation state or single jurisdiction.

Society consists of a number n of identical consumers. Individual utility functions depend on the quantities consumed of four goods, three private goods (the first of which could be interpreted as leisure), and one public good:

$$u = u(x_0, x_1, x_2, G). \qquad (1)$$

The public good G is of the atmospheric kind, and I shall further interpret it as a good that represents the natural environment. In the context of a single country it could be interpreted as the extent of unspoilt coastline, the variety of the country's flora or fauna etc. The marginal utilities of all four goods are assumed to be positive. The amount of the public good is then determined negatively by the aggregate consumption of good *2* which is the good that generates emissions, and positively by the production of an abatement good, g. Using the simplest possible normalization assumption, the emission function can be written as

$$G = - nx_2 + g. \qquad (2)$$

The technology of production is represented by a linear production constraint with fixed producer prices. Taking commodity *0* as the *numéraire*, we may take the production coefficients of the other goods as equal to the producer prices, so that the production constraint can be written as[1]

[1] A possible interpretation of this constraint is that commodity *0* is leisure. Since leisure can be defined as time endowment minus labour, the production possibility curve shows private and public goods as being produced by labour.

$$nx_0 + p_1 nx_1 + p_2 nx_2 + p_g g = 0. \qquad (3)$$

The social welfare function is the utilitarian sum of utilities which in the world of identical individuals becomes simply

$$W = nu(x_0, x_1, x_2, G). \qquad (4)$$

Maximizing the social welfare function (4) subject to the constraints (2) and (3), we can characterize the optimal allocation of resources by the three conditions (where subscripts denote partial derivatives)

$$u_1/u_0 = p_1, \qquad (5)$$

$$u_2/u_0 - n(u_G/u_0) = p_2, \qquad (6)$$

$$n(u_G/u_0) = p_g. \qquad (7)$$

Equation (5) says that the marginal rate of substitution between good 1 and the *numéraire* should be equal to their marginal rate of transformation, while equation (6) requires that for good *2* the *social* marginal rate of substitution should be equal to the marginal rate of transformation. The social marginal rate of substitution consists of two parts. The first is the individual benefit of a unit increase of the consumption of good 1, given that the state of the environment is unaltered. The other is the negative social benefit of environmental degradation (global warming) that follows from an increase in consumption of this good. In other words, good 1 has both a private and public goods component; it provides an individual benefit while it also has a negative effect on the amount of the public good. Equation (7) is the Samuelson (1954) condition requiring equality between the sum of the marginal rates of substitution between the public good and the *numéraire* and the marginal rate of transformation; in this case it should be interpreted as the condition of optimal expenditure on abatement.

The first best optimality conditions (5)-(7) could also have been derived from a more explicit formulation of the problem as one of the optimal use of policy instruments from the point of view of the public sector. If the government could levy a commodity tax on good *2* this would generate tax revenue which together with the proceeds of a lump sum tax could be used to finance investment in abatement. The utility maximizing individual consumer would set his individual marginal rates of substitution equal to the consumer prices[2]. Denoting these by capital letters, optimal consumer choice would then be characterized by the conditions

$$u_1/u_0 = P_1, \qquad (8)$$

$$u_2/u_0 = P_2. \qquad (9)$$

Comparing these with conditions (5) and (6), it follows immediately that the market equilibrium conditions satisfy the social optimality requirements for the following structure of consumer prices:

$$P_1 = p_1. \qquad (10)$$

$$P_2 - p_2 = n(u_G/u_0) = t_2. \qquad (11)$$

Thus, for good *1* the consumer price should be equal to marginal cost, while for good *2* the price to consumers should exceed the marginal cost of production by an amount reflecting the marginal benefit of atmospheric improvement by a small reduction in consumption. This is the same measure of benefit that appears in the condition for optimal public goods supply. This excess of consumer price over marginal cost is the optimal first best Pigouvian tax on the polluting good.

A notable feature of the model is that if we combine the optimal tax formula (11) with the condition of optimal expenditure on abatement (7), we obtain

[2] "Individual marginal rates of substitution" should be interpreted in terms of the individual's choice of consumer goods when he or she takes the state of the environment as given. This is the standard assumption in the literature, and the argument is basically the same as one uses to defend the assumption of competitive behaviour: Each individual is of such small significance in relation to the market outcome that he has no incentive to take account of the relationship between his own behaviour and the market outcome, even when he realizes the nature of this relationship. The realism of the assumption will be further discussed in Section 8 below.

$$P_2 - p_2 = t_2 = p_g. \qquad (11')$$

At the optimum, the Pigouvian tax is equal to the marginal cost of abatement, a condition which in this model is an illustration of the “polluters pay” principle. Although the particular form that the condition takes here is obviously a reflection of the stylized assumption made about the emission function (2), it continues to hold in a modified form even with more general versions of this function. The more fundamental explanation for the link between the optimal tax and abatement rules is clearly that the crucial element in each of them is the social benefit of reduced emissions, and this is the same whether it has been achieved through a reduction of private consumption or an increase of expenditure on abatement.

Quite apart from the stylized nature of the model as a whole, an unrealistic feature of the analysis as a basis for policy advice is the assumption that the balance between on the one hand the public sector’s expenditure on abatement and on the other hand the revenue from the Pigouvian tax can be made up entirely by means of lump sum taxation. Although lump sum taxation is clearly a feasible option if one takes the assumption of identical individuals literally, it is not in general a practical instrument of tax policy. As an alternative, we ought therefore to investigate the case of finance via a tax on non-polluting commodities. This would lead the market allocation away from the first best but would on the other hand provide a more realistic setting for discussion of optimal environmental policy.

3. Second best taxes and public goods provision.

To study the second best problem we reformulate the model in dual terms. The demand functions for the three private goods can be written as

$$x_j = x_j(P_1, P_2, G), j = 0,\ldots,2. \qquad (12)$$

Hence the indirect utility function becomes

$$v = v(P_1, P_2, G). \qquad (13)$$

This has the partial derivatives

$v_1 = -\lambda x_1,\ \ v_1 = -\lambda x_1,\ \ v_G = u_G.$ (14)

At this point some remarks on the dependence of the demand functions on the state of the environment are in order. In some of the literature the assumption has been made that externalities are *separable.* In this case the utility function can be written as

$u = u(\varphi(x_0, x_1, x_2), G).$ (1')

With this assumption, the marginal rates of substitution between the three private goods are independent of G. This means that the demand for private consumption goods, including leisure, is independent of the state of the environment, so that the demand functions become simply

$x_j = x_j(P_1, P_2), j = 0,\ldots,2.$ (12')

In this case, people *suffer* from environmental deterioration in the sense that their utility is lower, but their *market behaviour is unaffected* by it. This is clearly unrealistic. One would hardly expect the allocation of consumer budgets between boats, fishing gear, swimsuits and other goods to be unaffected by the extent of unspoilt coastline. But since the extent of unspoilt coastline is itself a function of the pattern of consumption, it follows that a price increase has two conceptually separate effects on demand. First, there is the direct or partial effect which assumes that the state of the environment is constant. Second, there is the indirect or *environmental feedback effect* which takes account of the fact that the price increase, by changing the consumption of the externality-creating good and thereby the state of the environment has a secondary effect on demand. Taking the derivative of e.g. the demand function for good 2 with respect to the price P_2, we can write this, using (12), as

$$dx_2/dP_2 = (\partial x_2/\partial P_2) + (\partial x_2/\partial G)n\ (\partial x_2/\partial P_2) = (\partial x_2/\partial P_2)[1 + n(\partial x_2/\partial G)].$$

(15)

The left-hand derivative is the total price effect which adjusts the partial effect (the first factor on the right) by the environmental feedback effect (the term in brackets). While the partial effect is normally negative, its magnitude could become magnified or diminished depending on the sign of the feedback effect. In principle, the total and partial effects could even be of opposite signs, although a dynamic analysis (Sandmo 1980) indicates that the case of a negative environmental feedback effect corresponds to an unstable equilibrium.

To illustrate this, consider the case of another important instrument of environmental policy, viz. a traffic congestion charge. The extent of private automobile use depends on the charge and on the flow of traffic since this is crucial for the amount of time use. An increase of the congestion charge reduces car use on the expectation of a constant flow of traffic, but the reduction in traffic in turn provides every individual car owner with an increased incentive to use his car, thus counteracting the partial effect of the congestion charge. The existence of this type of feedback effect is essential for the understanding of a number of environmental problems.

Rewriting the social welfare function in terms of the indirect utility function, we can formulate the government's problem as that of choosing the optimal commodity taxes, i.e. the optimal consumer prices, and the amount of abatement, *g*, subject to the public sector's budget constraint which requires that tax revenue be equal to expenditure on abatement. Writing the Lagrangian as

$$\Lambda = nv(P_1, P_2, G) + \mu[nt_1x_1 + n\, t_2x_2 - p_g g], \qquad (16)$$

and, taking account of the emission function (2), we can write its partial derivatives as

$$\partial\Lambda/\partial t_1 = -\lambda nx_1 - n^2 v_G(dx_2/dP_1) + \mu[nx_1 + nt_1(dx_1/dP_1) + nt_2(dx_2/dP_1)] = 0. \qquad (17)$$

$$\partial\Lambda/\partial t_2 = -\lambda nx_2 - n^2 v_G(dx_2/dP_2) + \mu[nx_2 + nt_1(dx_1/dP_2) + nt_2(dx_2/dP_2)] = 0. \qquad (18)$$

$$\partial\Lambda/\partial g = nv_G[n(\partial x_2/\partial G) + 1] + \mu[nt_1(\partial x_1/\partial G) + nt_2(\partial x_2/\partial G) - p_g] = 0. \qquad (19)$$

To get an intuitive understanding of the implications of these conditions we proceed in a stepwise fashion, using first equations (17) and (18) to solve for t_1 and t_2. Defining $\gamma = \lambda/\mu$, these solutions – or rather characterizations – can be written as

$$t_1 = (1-\gamma)\{[x_2(dx_2/dP_1) - x_1(dx_2/dP_2)]/[(dx_1/dP_1)(dx_2/dP_2) - (dx_2/dP_1)(dx_1/dP_2)]\}, \tag{20}$$

$$t_2 = (1-\gamma)\{[x_1(dx_1/dP_2) - x_2(dx_1/dP_1)]/[(dx_1/dP_1)(dx_2/dP_2) - (dx_2/dP_1)(dx_1/dP_2)]\} + \gamma n(v_G/\lambda). \tag{21}$$

This is a modified version of the Ramsey-Pigou conditions for optimal taxation as first formulated in Sandmo (1975); see also Sandmo (2000, Chapter 5). Equation (20) is the standard Ramsey condition for the case of two taxable goods[3], while (21) combines elements of the Ramsey condition and the Pigouvian tax rule. The Pigouvian term enters only into the optimal tax characterization of the polluting or “dirty” good; in the case of the “clean” good, the social benefit of a cleaner environment does not enter the determination of the optimal tax, regardless of the nature of interdependence of demand between the two goods.

Keeping this in mind, we may get a clearer understanding of the nature of the optimal tax solution by considering the special case where the cross-derivatives of the demand functions vanish, so that $dx_1/dP_2 = dx_2/dP_1 = 0$. In that case, equations (20) and (21) can be rewritten as

$$t_1 = (1-\gamma)\{[-x_1(dx_2/dP_2)]/[(dx_1/dP_1)(dx_2/dP_2]\}, \tag{20'}$$

$$t_2 = (1-\gamma)\{[-x_2(dx_1/dP_1)]/[(dx_1/dP_1)(dx_2/dP_2)]\} + \gamma n(v_G/\lambda). \tag{21'}$$

[3] Note, however, that the derivatives of demand with respect to prices are the total price effects as discussed above.

Defining the ad valorem tax rates as $\theta_j = t_j/P_j$ and the elasticities of demand as ε_{ij} $(j = 1,2)$, we can characterize the optimal tax rates in a particularly simple and intuitive form:

$$\theta_1 = (1-\gamma)[-1/\varepsilon_{11}]. \qquad (22)$$

$$\theta_2 = (1-\gamma)[-1/\varepsilon_{22}] + \gamma n(v_G/\lambda P_2). \qquad (23)$$

Equation (22) is analogous to the famous Ramsey inverse elasticity rule, saying that the tax rate on the non-polluting good should be inversely proportional to the own elasticity of demand. As explained above, the elasticity differs from the standard concept in the optimal tax literature by including the environmental feedback on demand. The tax rate on the polluting good, as expressed by (23) is a weighted average of two terms. The first is the inverse elasticity as in (22), while the other is the social benefit of reducing environmental pollution. To see that the latter is essentially the same as the first best expression (11), note that from (14) $v_G = u_G$, while from the consumer's optimum conditions it follows that $\lambda P_2 = u_2$. From this it follows that the second term on the right hand side of equation (23) can be rewritten as $n(u_G/u_2)$. This is the same as the expression for the first best optimal Pigouvian tax (11), except that the aggregate benefits have been expressed in units of good *2* rather than in terms of the *numéraire* good *0*.

The factor of proportionality $(1-\gamma)$ reflects the marginal cost of public funds or the tightness of the government's budget constraint. To see this, consider the case $\gamma = 1$. In this case, the revenue from the environmental part of the tax on commodity 2 (the second term in equation (23)) happens to be exactly sufficient to finance the government's expenditure on abatement, so that $\theta_1 = 0$ and θ_2 becomes equal to its first best Pigouvian level. In the opposite extreme case, $\gamma = 0$ and the need for tax revenue is so high that the tax rates must be set at the levels that maximize revenue, which naturally correspond to the inverse values of the price elasticities of demand.

This interpretation of the tax conditions is partial in nature, since it does not take account of the optimality condition for the provision of abatement which is determined simultaneously with the optimal tax conditions. Rearranging the terms in equation (19), we obtain the following condition for the optimal balancing of economic benefits and costs:

$$n(v_G/\lambda)[1 + n(\partial x_2/\partial G)] = \gamma^{-1}\{ p_g - [nt_1(\partial x_1/\partial G) + nt_2(\partial x_2/\partial G)]\} \qquad (24)$$

Compared to the first best Samuelson rule (7), we see that the present characterization introduces modifications both on the benefit and cost sides of the equation. To begin with the cost side, consider first the term in curly brackets on the right. This is the sum of the direct resource cost p_g and the change in the tax base that is caused by increased expenditure on abatement (and therefore a reduced amount of the public good). If the change is negative, i.e. if a decrease in the amount of the public bad leads to a shrinking of the tax base, this adds to the cost of public goods supply, while if it is negative, it acts as a subsidy. The total cost term is "blown up" by the parameter γ, representing the marginal cost of funds. When this is close to one, tax finance is basically Pigouvian with $t_1 = 0$ and we are led back to the first best characterization of the environmental tax as equal to the marginal cost of abatement. As γ moves towards zero, however, the social marginal cost of abatement depends both on the second best tax structure and on the effects of abatement on the tax base.

On the left hand side of the equation, the term in square brackets is the environmental feedback on the demand for the polluting good. If increased abatement leads to a reduction of demand for this good, there is a need for a positive adjustment of the Pigouvian benefit term, since abatement not only has a direct negative effect on the public bad but also an indirect effect that leads in the same direction.

In spite of what was said above about the importance of the environmental feedback on demand, it is interesting from a pedagogical point of view to consider the case where it is in fact zero. In this case the terms in square brackets vanish and we are simply left with

$$n(v_G/\lambda) = \gamma^{-1} p_g \qquad (24')$$

Substituting this expression into the characterization (23) of the optimal tax rate on the polluting good, it is easy to see that we get

$$\theta_2 = (1-\gamma)[-1/\varepsilon_{22}] + (p_g/P_2) \qquad (25)$$

As in the case of the first best, the Pigouvian term in the optimal tax formula becomes equal to the unit price of abatement, although expressed in units of good *2* rather than the *numéraire*; polluters pay the amount required to neutralize the effect of their emissions. As before, it should be kept in mind that this particular result is heavily dependent on the normalization in the formulation of the emission equation (2) which implies that the polluting good and abatement are measured in the same units. Suppose instead that the emission equation were written as

$$G = - \alpha n x_2 + g, \qquad (2')$$

so that the neutralization of one unit of emissions requires α units of abatement. In that case equation (25) must be modified to read

$$\theta_2 = (1-\gamma)[-1/\varepsilon_{22}] + (\alpha p_g/P_2). \qquad (25')$$

The economic interpretation, however, remains the same: Polluters pay the cost of abatement.

The special case considered here in which all cross effects vanish, both between consumer goods markets and between the environment and the demand for private goods, is obviously a highly special one. Still, it is of some inherent interest. From a purely theoretical point of view, it may be pointed out that the independence assumption both with regard to prices and public goods follows if preferences are Cobb-Douglas, so that there is some degree of consistency between the assumptions made and the basic requirement of regular preferences and utility maximization. From a more practical viewpoint, it seems to be a fact that in general we have less empirical information about the magnitude of cross effects than about direct price effects. The independence case may therefore serve as a useful benchmark when thinking about policy design in this area.

4. The time and uncertainty dimensions

It lies beyond the scope of the present paper to extend the analysis of the formal models presented above to take account of the time and uncertainty dimensions of the problem, and I shall limit myself to some comments on how this might be done and the problems involved in such extensions.

From a purely theoretical point of view, the most direct way in which to achieve this type of generalization is through the Arrow-Debreu approach to general equilibrium theory[4]. In this framework the time dimension is handled through the concept of time-dated commodities and prices. Letting $x_{j\tau}$ be the quantity consumed of commodity j $(j=0,1,2)$ in period τ $(\tau=0,1, \ldots T)$ we may define the associated producer and consumer prices as well as the tax rates $t_{j\tau}$. This procedure allows us to reformulate the optimal tax problem – both under first best and second best conditions – as one extending over the entire time horizon of the model. In solving for the optimal tax structure we would in general expect taxes to vary over time, partly as the result of technical progress that would be reflected in changes in producer prices.

There is one aspect of the extension of the model to a multi-period setting that is of particular interest. This concerns the generalization of the emission function (2). For some types of environmental problems – such as traffic congestion - it may be realistic to assume that current environmental damage depends on the *flow* of current activities. For others, however, in particular for the case of climate change, current damage depends on the *stock* of emissions that have accumulated in the atmosphere. The emission function for any particular period therefore has to be written as dependent on emissions in all previous periods (in continuous time, this would correspond to the integral of past emissions). An implication of this perspective is that in the design of an optimal tax structure one has to take account of the effects of current tax changes on the future state of the environment.

The Arrow-Debreu approach to the incorporation of uncertainty follows similar lines by defining goods available in different states of nature as different goods: Let us define $x_{j\tau s}$ as the quantity consumed of commodity j in period τ if a particular event or state of nature s $(s=1, \ldots, S)$ occurs. Producer and consumer prices as well as tax rates $t_{j\tau s}$ can then be defined accordingly, which gives us a framework in which the analysis of optimal taxes and public expenditure can be carried out along the lines of the standard deterministic models.

In the original version of the model (e.g. Debreu 1959, Ch. 7) the sources of uncertainty are not made explicit, although the wording is suggestive for the modern economist who is concerned with problems of the environment: "the uncertainty of the environment … originates in the choice that Nature makes among a finite number of alternatives" (p. 98).

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[4] The basic references for this approach are Arrow (1953) and Debreu (1959).

Although the word “environment” in the quotation is evidently not intended to carry the same meaning as in “environmental economics”, it is indeed natural to interpret the model along these lines and assume that the different events or states of nature originate in the emission function. If this function is extended by including a stochastic element, possibly with a time trend, we have a model which can incorporate the assumption that the state of the environment is partly determined by purely exogenous forces, partly by human activity.

Of course, the extension of models of this kind to take account of the dimensions of time and uncertainty is not quite as straightforward as may be suggested by this brief discussion. There are e.g. problems related to population growth that are difficult to incorporate in models with a given set of individuals and that can be better analyzed in models of overlapping generations. There are also issues associated with the formulation of the government budget constraint that need to be reconsidered when the model is extended in these directions. I will leave these aside and instead focus on two additional topics that are of fundamental importance for the public economics of time and uncertainty.

The first of these concerns the notion of equilibrium in the Arrow-Debreu model. In the most literal interpretation of the model there are present markets for goods in all time periods and in all possible states. This is not a realistic description of an actual market economy; although the real world contains numerous examples of both future and contingent goods markets, these are far from complete. However, the model can be reinterpreted in terms of expectations, so that e.g. $P_{j\tau s}$ could be interpreted as the expected price of good j in period τ, given that state s occurs. Thus, even in the absence of a full set of markets, the model could still be useful as a framework for public policy analysis.

Note, however, that in our formal model the indirect or achieved utility depends on the state of the environment as well as on prices. In the extended framework the price vector would have to be reinterpreted as consisting partly of actual prices, partly of expected prices for future states of nature (which would presumably vary considerably between individuals). Similarly, utility would depend not only on the current state of the environment but also on its expected future state. An axiom of modern welfare economics is that social welfare should be based on individual utility, and this is sometimes expressed as the requirement that social judgements should respect individual preferences. But in the present case it is not only a question of respecting preferences but also of respecting individuals’ expectations and probability judgements. It is far from clear that there is a compelling ethical case for taking this view of the relationship between utility and welfare. Environmental problems raise difficult issues that require insights into complex relationships of natural as well as social science. If governments believe that people are seriously misinformed, what attitude should they take to policy formation? The answer that is most in line with the ideal of an enlightened democracy would be to choose policies that are in line with the preferences and judgements of the majority while at the same time striving to provide citizens with the best possible information about the connections between the environment and the mechanisms of the social and economic system. But given the urgency of many of the environmental problems that we are faced with, governments can hardy afford to wait until all citizens have acquired the best possible information about the problems involved. This raises interesting issues of political economy: Will governments take the risk of adopting policies that go against the actual preferences of the electorate although the policies are perceived as being in the long run interests of society as a whole? This question acquires a special urgency in the context of global environmental policy, which will be discussed in more detail below.

A further problem in political economy arises from the fact that the responses of consumers and firms to environmental policy measures depend not only on the measures that are currently in place but also on their expectations about taxes, quotas and regulations in the future. A democratic government can make promises about the adoption of future policies but it has limited ability to commit future governments that may possibly have quite different priorities. More attention needs to be paid to the problem of how to make environmental policy credible and sustainable over the longer run.

5. Tax design vs. tax reform

As originally pointed out by Feldstein (1976), the theory of optimal taxation is concerned with tax design; the objective of the theory is to provide a description of the ideal tax system, abstracting from the system that is currently in place. In partial contrast to this approach, the theory of tax reform tries to identify welfare improving changes in the tax system, starting from the current situation. While it is the tax reform approach which is of most obvious concern to policy makers, the two approaches are complementary. In order to decide about the best way to proceed with reforms, one must have an idea about the best direction to take in the revision of the current tax system.

In the academic debate, the discussion of the benefits of a green tax reform has been linked to the concept of the double dividend. The general idea of the double dividend is based on the assumption of a revenue neutral tax reform, in which the introduction of green taxes is coupled with a reduction of other types of taxes so as to keep total tax revenue constant. The primary benefit of such a reform is an improved state of the environment. A secondary benefit, it is argued, arises from the assumption that the tax rates that are reduced in the process are distortionary taxes, so that the reduction of these leads to less severe distortions of the price structure and hence to efficiency gains[5].

The nature of the double dividend is crucially dependent on the assumption that one makes about the initial (pre-reform) state of the tax system. To illustrate the point, let us assume that the tax system satisfies the optimality conditions set out in Section 3. If, starting from this situation, one introduces a revenue neutral reform that moves the tax system slightly towards a greener profile, there will by the definition of an optimum be neither a single nor a double dividend. In the general case where the reform starts from some arbitrary non-optimal state of the tax system, it can be shown that it is indeed possible to separate the gain from a green tax reform into two parts, analytically similar to the two-part separation of the formula for the polluting good (equations (21) and (23) above). However, it is in general not possible to determine the sign of either of the two effects (Sandmo 2000, Ch. 6). The reasons for this stem basically from the cross-effects of tax and price changes. On the one hand, the introduction of green taxes may exacerbate existing distortions e.g. in the markets for labour and capital; on the other hand, the reduction of some distortive taxes may generate increases of environmentally harmful activities.

These remarks are not meant to suggest that the idea of the double dividend is without merit. In spite of its appeal to economic intuition, however, its existence cannot be taken as established by pure theory. Careful attention must be paid to the initial state of the tax system[6]

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[5] A special version of the double dividend argument relates to a situation of unemployment in which the introduction of green taxes is coupled with a reduction of the payroll tax, leading to increased labour demand and less unemployment. A number of contributions to the debate on the existence and nature of the double dividend have been collected in Goulder (2002).

[6] One thought experiment that may be used in the definition of the double dividend is that green taxes are introduced as substitutes for quantitative regulations of emissions. The nature of the environmental dividend in this case is obviously of a different nature from the case where green taxes are being introduced into an otherwise unregulated setting.

and to the empirical interactions between markets before one can make more definite pronouncements about the welfare gains from a green tax reform.

6. Taxes vs. quotas

There is general agreement among economists that market based instruments of environmental policy are preferable to command-and control measures like non-transferrable quotas and other quantitative regulations. The efficiency advantages of taxes, whether they are levied on emissions or the use of harmful goods or factors of production are twofold: On the one hand, the use of taxes leads to a cost-minimizing reduction of emissions among polluters; this is the production efficiency argument in favour of taxes. On the other hand, if the tax is set at the right level it balances the marginal cost of emission reduction with the social marginal benefit of a cleaner environment; this is the consumption benefit argument. Quantitative regulations are likely to violate both of these efficiency criteria.

Tradable quotas is the other main example of market based instruments of environmental policy. Competitive trading in quotas will establish a unit price of quotas that is equivalent to a tax as far as production efficiency is concerned. The total supply of quotas should be fixed so as to achieve the efficient balancing of costs and benefits. If the supply of quotas is controlled by the government who sells them to polluters they will also generate public revenue in the same way as green taxes. The problem of measurement that arises in setting the tax at the right level or fixing the total volume of quotas is in essence the same, involving an assessment of costs and benefits at the margin.

What is the main argument for choosing tradable quotas rather than taxes? In a world of complete certainty the two instruments are equivalent. Under uncertainty, the main problem is to decide on the relative importance of benefits and costs, in particular on the importance of achieving a given reduction of emissions. Under quotas, this can be achieved directly by fixing the total supply of quotas. With the tax alternative, the effect on emissions of a given tax increase depends on behavioural responses whose magnitude may not be known to the policy maker. As an example, in the case of greenhouse gas emissions many would argue that the achievement of the targeted emission reduction is of such overriding importance that this is a strong argument in favour of tradable quotas rather than taxes.

This argument is simplified in that it abstracts from the possibility of tax evasion and quota violation (Sandmo 2002). Especially when the tax base or the amount of quotas is defined in terms of the quantity of emissions, so that the scale of the polluting activity cannot be traced through market transactions, the polluters may choose to underreport their actual emissions. Although they know that they are liable to punishment if discovered they may judge the probability of discovery and the resulting fine to be such that cheating is an attractive alternative.

7. The international dimension: Climate change

Climate change, in particular global warming and the challenges that it poses for tax policy, is a topic that has received enormous attention in recent years, with economists playing a significant role in the debate. One of the concepts that have been used to bring the issue of global warming within the range of economic analysis is that of global public goods. Thus, the Stern Review (2007) states that

> "[r]educing the risks of climate change is the most important example of the provision of a global public good … It is also in many ways the 'purest' example of a public good in that emissions of greenhouse gases … from any one country have the same effect on the atmosphere as those from any other." (Stern 2007, p. 510.)

A global public good is one that satisfies the Samuelson (1954) definition of a public good with respect to the world as a whole; specifically, a global public consumption good is one whose use or enjoyment by one person in the world does not reduce the amount that others can consume.

That global warming satisfies the definition of a public good is perhaps not quite as obvious as suggested by the quotation from the Stern Review. Although the global temperature in the sense of some average for the different regions of the world is expected to increase, the degree of increase is predicted to differ between regions and also go together with other changes in the climate that will show considerable regional variation; e. g., some areas are likely to become drier, while others will experience increases in their average rainfall. However, since all these changes have a common cause in the greenhouse effect, they can all be seen as being consequences of the rise in the global temperature. It is this argument that justifies the view of global warming as a "public bad" and its reduction as a public good.

A notable aspect of the Stern Review argument in support of regarding the reduction of global warming as a public good is that it does not really stress its "publicness"; instead, it emphasizes the fact that all greenhouse gas emissions have the same effect on the atmosphere. But this is more characteristic of a particular type of externality, the one referred to by James Meade more than a half-century ago as atmospheric externalities (Meade 1952). In an influential article on the theory of externalities (or external economies and diseconomies, as he called them), he distinguished between two classes of external effects in production, "unpaid factors of production" and "creation of atmosphere". As an example of the latter case, he mentions the case where

> "… afforestation schemes in one locality increase the rainfall in that district and that this is favourable to the production of wheat in that district. In this case the production of timber creates an atmosphere favourable to the production of wheat." (Meade 1952, p. 62.)

As seen from the point of view of the present, the term and the example chosen by Meade were indeed prophetic, since this was long before there was a common awareness that economic activity could have a significant effect on the atmosphere in the literal sense of the global climate. Indeed, at that time a more common view of the weather or climate[7] was that it was the prime example of a variable that was *exogenous* to the economic system. This view was shared by theorists and empirical economists alike. Thus, in his book on theoretical welfare economics, Jan de Graaff wrote that

> "... the weather is clearly an exogenous or non-economic variable, affecting individual choices but unaffected by them." (de Graaff 1957, p. 6.)

This view was echoed in Lawrence Klein's introductory textbook on econometrics where he stated that

> "Rainfall affects the economy but is not affected by the economy." (Klein 1962, p. 16.)

Thus, in line with the basic model discussed above, we may regard the global climate as a global public good whose quality is reduced by the emission of climate gases that lead to

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[7] There is a difference between the two concepts in that climate refers to the long term prevalent weather conditions.

global warming[8]. The quality of the global public good may be restored by curtailing the activities that contribute to it or by investment in abatement facilities like carbon storage or the prevention of deforestation. Since investments of this kind contribute directly to improvement of the climate, these investments themselves may be defined as public goods.

There are two main issues that arise in the extension of the basic model to the case of global externalities, such as climate change. The first is the choice of a measure of global economic welfare and the characterization of a global welfare optimum. The second is the implementation of this optimum by means of the design of economic policy. Rather than go into the details of modelling, I will discuss the issues informally, although with reference to the formulations in the models of Sections 2 and 3 above. There are a number of extensions and elaborations that can be made of the model; in the interests of simplicity I will leave them aside. In particular, the main analysis is limited to the first best case and ignores the complications that arise from the joint use of environmental and distortionary taxes.

As regards the first issue, in the discussion of global environmental policy a central concern of policy design is to reach agreement on the type of policy that is best from the point of view of the world as a whole. There are those who are in doubt as to whether ideas like “the public interest” or “social welfare” are meaningful concepts in the context of a single country; if so, they may see reasons to be even more sceptical to similar concepts applied to the world as a whole. However, if one strives to come to grips with the analysis of globally fair and efficient policies, it is hard to avoid the use of some concept of this kind. Its use does not imply that there exists a global authority that actually maximizes world welfare; the point is simply to illuminate how an enlightened observer would think about alternative choices of environmental policy when approaching them from the point of view of global welfare[9].

In this spirit, we may write the global social welfare function as a function of the utilities of all individuals in the world. In contrast to the single country case, it would hardly be acceptable to represent world social welfare as being proportional to the utility of a single representative agent: Although national environmental policy could arguably be designed separately from the concern for income distribution, this is hardy defensible in the global

[8] This formulation seems to imply that people in general think of the climate as worse, the warmer it is. This hypothesis clearly cannot claim to be of general validity. But for the particular use that I make of the concept of global warming here, it is the most natural assumption to make.
[9] For an early statement of the need to take a global view of economic welfare see Frankel (1943).

context where inequality between nations is an issue of major concern and where at the same time the use of internationally redistributive policies are severely restricted. In the interests of simplification, we shall assume that all individuals within a single country are identical, as in the model presented in Section 2. Global social welfare is taken to be the sum of utilities, and there are assumed to be *J* countries in the world with the number of individuals in country *j* being n_j and with u^j being the utility function of the representative consumer in country *j*. The global social welfare function can then be written as

$$W^* = \Sigma_j n_j u^j(x_{0j}, x_{1j}, x_{2j}, G). \qquad (26)$$

This particular function should be thought of as a special case of a more general formulation in which global welfare is simply some increasing function of the utility levels of all individuals in the world. The special additive structure of the function (26) should be thought of as a convenient simplification that allows us to consider the relationship between global goals and national incentives in a particularly transparent manner. This will become clear below.

Another element of the single-country model that has to be reconsidered when moving to a global setting is the emissions function (2). For a truly global externality such as global warming, the amount of the public good is affected in equal measure by the emissions of all countries in the world; similarly, the amounts of abatement undertaken in all countries contribute equally to the reduction of global warming. A natural generalization of (2) is therefore

$$G = -\Sigma_j n_j x_{2j} + \Sigma_j g_j. \qquad (27)$$

The first term on the right is the total of emissions from all countries, while the second term represents the total of all countries' abatement.

The characterization of optimal environmental policy in the single jurisdiction model had two components, viz. the Pigouvian tax rate and the optimal use of resources on abatement. Assuming that the constraint on world production takes the form of a global production possibility function with constant producer prices across countries, the global optimum can be characterized by the two conditions

$$t_2 = \Sigma_j n_j(u^j{}_G/u^j{}_0) \qquad (28)$$

and

$$\Sigma_j n_j(u^j{}_G/u^j{}_0) = p_g, \qquad (29)$$

and these correspond to equations (6) and (7) above. There should be an internationally uniform tax on emissions, and the measure of the benefits of abatement used in cost-benefit analysis should be the same in all countries. The interpretation is straightforward: We have here a case where a global externality and global abatement activities are affecting the amount of a global public good, so that the gains from reducing the externality must be measured by the global benefits which is the sum of the marginal rates of substitution over all individuals in the world.

These conditions represent the allocation of resources that would be chosen by a globally utilitarian decision maker. Although this case is clearly of interest from a theoretical point of view, as a normative foundation for policy analysis it suffers from the weakness that there exists no single decision maker who can make choices regarding global taxation and abatement policy. It is a cooperative solution to the global environmental problem, but it should be contrasted with the arguably more realistic non-cooperative case where each country acts on its own with the objective of maximizing the welfare of its own citizens. This is essentially the case studied in Section 2, and the characterization of each country's optimal policy choice becomes

$$t_{2j} = n_j(u^j{}_G/u^j{}_0) \qquad (j = 1, \ldots, J) \qquad (30)$$

$$n_j(u^j{}_G/u^j{}_0) = p_g. \qquad (j = 1, \ldots, J) \qquad (31)$$

The optimal tax on the polluting good 2 in general varies between countries, depending on the preferences of their citizens. The assessment of the social benefits from abatement will in a similar fashion differ from one country to another.

In this non-cooperative case, taxes will be too low while the benefits from abatement will be underestimated in comparison with the global optimum. Each country, in taking account only of the interests of its own citizens, will neglect the spillover effects of its emission cutbacks and abatement investments in the form of benefits received by the citizens of other countries. A major task of international environmental policy is therefore to overcome this international free rider problem through a process of international negotiation and cooperation.

The design of such a process is a challenging task which goes beyond the type of modelling represented by the present paper. However, there is one aspect of the model which is clearly relevant to this issue. A feature of the first best analysis is the assumption of lump sum income transfers between countries[10]. In an international context one could imagine that environmental taxes, abatement and income transfers were all part of the bargaining agenda, so that poor countries could receive transfers in return for adopting environmental taxes and using resources on abatement[11].

In the absence of such transfers, other benchmark models have to be adapted for the cooperative solution. Thus, one could imagine that an international climate agreement could be made that would allow for different emission taxes in different countries, depending on their levels of per capita income. This solution would violate the efficiency conditions but might be used as a second best policy to implement the tradeoff between efficiency and equity in international climate policy[12].

8. The behavioural economics of the environment

The foregoing analysis of market failure in relation to environmental goods has been based on standard assumptions about competitive behaviour. In particular, it has been assumed that the consumption of any one individual is so insignificant relative to the market outcome that he has no incentive to limit his consumption of environmentally harmful goods. Thus, even if he suffers from environmental degradation and his market behaviour is influenced by it, he has

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[10] Income transfers within a given country are irrelevant in this particular model, since in each country individuals are assumed to be identical.

[11] For studies of international environmental policy cooperation see Barrett (2001, 2003) and Chander and Tulkens (1992).

[12] The tradeoff between production efficiency and international equity has been further discussed in Sandmo (2003, 2006).

no individual incentive to change his behaviour towards a more environmentally friendly pattern.

Environmental externalities are of many kinds, and how convincing this argument is depends on the nature of the externality in question. Global warming is a limiting case in that it involves billions of economic agents both as generators of the externality and as sufferers (although in some cases perhaps as benefactors) from it. At the other end of the scale are local environmental problems like traffic congestion and littering of neighbourhood streets. Obviously, the free rider problem is relevant even for the analysis of small-scale problems, but it is also undeniable that there are many people who either individually or through local social or political organizations involve themselves in efforts to solve these problems. In this sense, it may be that the competitive assumption in the theory of environmental externalities gives an exaggerated impression of the inability of a market economy to cope with its environmental problems.

A problem that arises in this connection is the possible conflict between intrinsic and extrinsic incentives, discussed e.g. by Bénabou and Tirole (2006) and Frey (1997). By introducing financial or extrinsic incentives like taxes and quotas to curb emissions the government may take these activities out of the moral sphere by making them into rights that people can buy and use with a good conscience, thus weakening their moral or intrinsic incentives. The analysis of the effects of taxes and quotas on polluting goods should therefore ideally take account of the possible crowding out of intrinsic incentives, although the empirical basis for such calculations may be difficult to identify.

Many local environmental issues are positively correlated with larger problems. Thus, a number of local measures designed to limit car use and extend the scope of public transportation may add up to a significant contribution to the limitation of climate gas emissions, a point argued forcefully by Ostrom (2009). Taking the argument a step further, it may not be unrealistic to assume that some national governments do have a concern for the welfare of the world and are prepared to take actions that transgress the narrow self-interest of their own country. The conclusion that global environmental policy necessarily requires global political action may therefore have to be modified; there may also be a role for "bottom-up" policies.

9. Concluding remarks

The formal models that have been presented in this paper should not be interpreted as cookbook formulas for environmental tax and abatement policies. The highly stylized nature of the analysis implies that the value that the models may have for actual policy analysis lies in their role as guides to clear thinking about the choice of policy instruments with a view both to their effects on the environment and their interaction with other instruments and other goals of economic policy. But even at the level of stylized theorizing, it is obvious that some serious concerns have been neglected. This is especially true of the concern for the distributive effects of environmental policy which are likely to be very important for political decision makers. The need to make allowance for distributive effects is perhaps most obvious for the case of taxation, but in a broader perspective the effects of green taxes on the distribution of income and welfare should be studied in conjunction with the distributive effects of environmental improvement.

Environmental economics is a field that has substantially broadened its horizons over the past half-century. Some of this is reflected in the present paper, in particular the increased attention paid to problems that are global in nature. However, environmental issues have also invaded a number of other fields of economics, such as international trade, the economics of growth and development, industrial organization and institutional economics. This is a very positive trend that can only lead to increased realism and relevance of the economic analysis of environmental policy.

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