Discussion paper

The Scale and Scope of Environmental Taxation

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The Scale and Scope of Environmental Taxation*

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Abstract

This paper provides a discussion of the principles of environmental taxation. It considers the empirical identification of environmental taxes and the problems associated with the choice of the right tax base from the point of view of the correction of market incentives. It then presents a model of optimal second best environmental taxation when taxes must fulfil the double role of modifying market incentives and generating tax revenue. It also considers the issues of the double dividend, the interaction between intrinsic and extrinsic incentives and the problem of designing a tax policy for the alleviation of global environmental problems.

JEL classification: D62, H23, Q50

1. Introduction

One of the first lessons that beginning students of economics learn about the principles of public finance is that indirect or commodity taxes are harmful to the efficiency of the economy. The partial equilibrium analysis that forms the basis for this conclusion is a simple and compelling one: A commodity tax drives a wedge between the marginal cost of production (as represented by the supply curve) and the marginal consumer benefit (as represented by the demand curve). The tax therefore prevents the market mechanism from reaching the efficient equilibrium solution where marginal cost is equal to marginal benefit.

In a later lesson the student may learn that there are exceptions to this rule. If there are negative externalities associated with the production or consumption of a particular commodity - the typical example being adverse effects on the quality of the environment - efficiency may in fact be improved by taxation. Suppose, for the sake of the argument, that the externality in question generates a positive difference between social and private marginal cost, while private and social marginal benefits coincide. The requirement for efficiency is that the social marginal cost of production should be equal to the social marginal benefit, which again is equal to the private marginal benefit:

$$SMC = SMB = PMB.$$

Suppose further that this market operates according to the principles of perfect competition except that the market prices with which producers and consumers are faced are allowed to differ. Producers, who are assumed to maximize profits, set their private marginal cost equal to the producer price (p), while consumers, who maximize utility, equate their marginal benefit to the consumer price (P):

$$PMC = p, PMB = P.$$

Now, if the tax rate is defined by the equation $P = p + t,$ we can substitute in the first equation to obtain the socially optimal deviation between the consumer and producer prices,

$$SMC - PMC = P - p,$$

or the socially optimal tax rate

$$t = SMC - PMC.$$

A tax rate that is equal to the difference between social and private marginal costs perfectly internalizes the externality and restores efficiency to a market that would otherwise have found itself at an inefficient equilibrium. Thus, the case for an environmental or green or Pigouvian tax basically rests on its incentive effects; it ensures that decisions about production and consumption that are rational from a private point of view are consistent with efficiency for society as a whole. In addition, since t is the same for all polluters, the taxation scheme ensures that the marginal cost of pollution cutbacks is the same for all polluters, implying that the aggregate social cost of pollution reduction is minimized.

A further benefit of environmental taxes is that they generate revenue for the government, and they do so without creating inefficiencies in an otherwise efficient market system. Substituting environmental taxes for ordinary commodity and income taxes should accordingly be able to raise the same amount of revenue as before but with less social cost. This "double dividend" of environmental taxes could be expected to make them extremely popular taxes; in fact, one would expect them to be the first building block of an efficient tax system. But this is rather far from being the case in real life. There could be several reasons for this, and some of them will be explored in a little more detail in the following.

2. History of environmental taxes

The history of environmental taxation can be regarded from two different angles. One is the perspective of the history of economic thought, while the other is the history of the taxes and tax systems that have actually been used.

The first to set out the basic idea of environmental taxation was A. C. Pigou who first introduced it in his 1920 book *The Economics of Welfare* with further discussion in his later *A*

Study in Public Finance (1928).[1] He did not use the concept of environmental taxation, although he discussed a number of examples that we would now classify as environmental problems. Instead, he set his discussion in the more general analytical framework of deviations between private and social net product, as he called it; this corresponds roughly to the concepts of private and social marginal costs that were used above.[2] His analysis covered not only negative but also positive externalities that called for subsidies ("bounties") to the commodities or activities that generated them. He sketched a situation where he appeared to have in mind a tax system whose only task was to introduce corrections to situations where private incentives needed to be supplemented by interventions to overcome these deviations:

> "... it is always possible, on the assumption that no administrative costs are involved, to correct them [the deviations] by imposing appropriate rates of tax on resources employed in uses that tend to be pushed too far and employing the proceeds to provide bounties, at appropriate rates, on uses of the opposite class. There will necessarily exist a certain determinate scheme of taxes and bounties, which, in given conditions, distributional considerations being ignored, would lead to the *optimum* result." (Pigou 1928; 1947, p. 99.)

Today, public finance and environmental economists recognize this idea as a fundamental and important one. But in the first few decades following Pigou's analysis, it received relatively little attention in the academic literature. A prominent example of this neglect of the idea is Musgrave's famous treatise on public finance (Musgrave 1959) which devotes little more than a paragraph to Pigouvian taxation and this in a chapter entitled "The ability-to-pay approach". The environmental perspective is not mentioned in this paragraph and indeed is absent from the book as a whole.

The interest in Pigouvian taxation as a tool of environmental policy started to take off around 1970. Since then the idea has been explored in depth by a number of researchers. Among the most significant extensions of Pigou's analysis have been the generalization of the theory from a partial to a general equilibrium framework, the attention to issues of second best where environmental taxes must be introduced in a distorted market system, and the broadening of

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[1] Externalities had also been discussed by Pigou's teacher, Alfred Marshall, but his interest was mainly motivated by his desire to explain how the industry supply curve could be downward-sloping under competitive conditions.

[2] The distinction between on the one hand deviations between private and social marginal costs and on the other hand between private and social marginal benefits is often arbitrary and of little real significance. One of the costs that car congestion imposes on society is an increase in the time use required to commute, but whether this should be classified as an extra cost or as a reduction in the benefits of driving is mostly a matter of analytical convenience.

the perspective from local and national environmental issues to those that arise in the global environment.

To what extent has environmental taxation actually been used? There is no doubt that these taxes are on the policy agenda to a larger extent than ever before, but summary measures of their importance are hard to obtain. How is importance to be measured? One suggestion has been to use the share of green taxes in government revenue or GDP. Data from the OECD for the period 1994-2006 show that the share of "environmentally related taxes"[3] in GDP varied from 4.5-5 per cent (Denmark) to less than 1 per cent (United States); the weighted average for all OECD countries was a little less than 2 per cent, while the unweighted average for all 30 countries included in the survey was about 2.5 per cent. In most of the countries the share was fairly stable over this period, although it dropped slightly in 2006. In terms of the share of environmental taxes in total tax revenue, the weighted average was a little less than 6 per cent, while the unweighted average was about 7 per cent. It is worth noting that these figures exclude fees and charges (e.g. for road use and parking).[4]

These figures should naturally be interpreted with some care. There is an inevitable element of judgement involved in selecting the taxes that are environmentally related. Also, the period considered is too short to allow us to draw conclusions about long-term trends. Nevertheless, we may conclude that we are concerned with taxes that are of substantial importance for government revenue and the economy as a whole, although they have fallen considerably short of satisfying the revenue needs of modern governments.

3. Financial vs. environmental impact

To calculate the financial importance of environmental taxes is clearly an interesting exercise. However, if we are concerned with the effects of taxes on the quality of the environment this cannot be the main focus of our interest. Instead, this should be the effects that these taxes might have on the activities or commodities whose consumption and production we wish to reduce. The crucial concepts to use in this connection are the elasticities of demand and

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[3] These are defined as unrequited payments to governments on tax bases that are deemed to be of particular environmental relevance. Tax bases of this kind are mainly to be found in the fields of energy, transportation, emissions to air and water, waste management and noise.

[4] For a more detailed presentation of the OECD data and an outline of recent environmental tax policy in various countries see Barde and Braathen (2005).

supply. I focus here on demand elasticities, taking the view that the composition of output is essentially driven by consumer demand.

It is easy to see that in terms of environmental impact, the share of a particular tax in government revenue or GDP is a poor measure of its environmental effect. In the case of a commodity with a very high elasticity of demand, a substantial effect on the environment may be achieved at a very low rate of tax, while conversely when the elasticity of demand is low the effect on the environment may be very small although the tax could generate substantial revenue. In that case, Pigouvian tax enthusiasts will have to face the common criticism that this is just another way for the government to satisfy its demand for increased tax revenue.

In general, economists ought perhaps to be more explicit about the time frame that they have in mind when analyzing green tax effects on behaviour. The introduction of taxes on cars and car use may be a case in point[5]. In the short run, the effects of taxes on cars and petrol may be small, given the existing stock of cars and the supply of collective transport alternatives. But in a longer perspective this may change as a result of the long run tax incentives. Households may decide not to replace their second car or modify their habits as regards travelling to work. In the even longer run, increased taxes on private transport may reverse the trend in city development that has been so characteristic of the post-war period. Instead of the continuation of urban sprawl, we may come to see a movement towards more compact cities and greater reliance on less energy intensive and collective means of transportation. The Marshallian insight that elasticities are higher in the long run than the short is of crucial importance for environmental policy.

The magnitude of the price elasticities are also likely to depend on other elements of public policy. According to Leape (2006), the success of the London congestion charge in reducing traffic in the central areas of the city was to a large extent due to the presence of a substitute for car use in the form of a well-developed system of public transport. The availability of this substitute was probably also the main reason why the congestion charge could be introduced with only minor effects on local business. Thus, the design of environmental tax policy should be seen in conjunction with that of publicly provided goods and services.

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[5] The various externalities connected with car ownership and use have been discussed by Parry, Walls and Harrington (2007).

4. The identification of environmental taxes

How do we decide which taxes are green taxes? It is natural, as in the OECD procedure, to define green taxes as those which are levied on tax bases that are correlated with adverse environmental effects. But this correlation may take many forms, and the classification of taxes may to a large extent depend on the judgement of those who carry it out.

As an example of the difficulties that arise we may once more take taxes related to car use. In many countries, including my own, there are three classes of such taxes or charges. The first is related to car ownership: In Norway you pay an annual tax on cars and lorries (in addition to what you may pay on their asset value through the wealth tax) that is related to size, although there is no differentiation between different types of passenger cars[6]. The second type is the tax on petrol which is clearly directly related to car use. The third class consists of charges related to road use and includes tolls and parking fees.

All three types have their obvious weaknesses as instruments of environmental policy. In the short run, the annual car tax does not discourage car use since it does not vary with the use of the car. However, in the long run it may affect the number of cars owned by families and thereby the intensity of car use. The petrol tax payments do vary with car use and the petrol tax can therefore with greater justification be called an environmental tax. But the petrol tax still suffers from some weaknesses in terms of environmental policy; it does not discriminate between various uses of the car according to location and time of day which may have very different environmental effects. Tolls and road user charges clearly have the potential to function as Pigouvian taxes in that the use of congested roads could be taxed at higher rates than other uses[7]. Parking fees can also be designed so as to vary with time and location and thereby improve environmental quality in congested cities.

The tax rate should reflect the difference between social and private marginal cost, but how do we know whether a particular tax rate satisfies this requirement or whether it is too high or too low? This is a difficult question to answer and will have to be decided on empirical

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[6] The exception to this rule is el-cars that receive preferential treatment in being allowed to drive in the bus lanes and park at meters without charge.

[7] A sophisticated scheme for road pricing along these lines was proposed by Vickrey (1963). For a recent discussion of road user and congestion charges see Newbery (2005).

grounds in each particular case, but it also raises complex and interesting issues of a theoretical nature[8].

5. The activities perspective and the tax base

Environmental pollution may be generated both on the production and consumption sides of the economy. To simplify the theoretical treatment, the focus in the following will be on environmental externalities generated by consumers - in their capacities as drivers, energy users etc. It is by focusing on consumers that we most easily see some of the most crucial problems of environmental policy, such as the measurement of costs and benefits, issues of optimal taxation and distributional considerations.

In much of the theoretical literature, the assumption is made that environmental effects depend on the aggregate consumption of particular commodities, and that there is a one-to-one correspondence between externalities and goods. Although this assumption is often sufficient to analyze the central theoretical issues it also gives a highly simplified picture of the difficulties of policy design. As was illustrated by the example of the taxation of cars, environmental effects are basically generated by *activities* which may depend on the consumption of goods in rather complicated ways. An activity like driving during the rush hour uses the car, gasoline and time as important inputs, while the activity of central heating may depend on inputs like house insulation and electricity. Obviously, consumer goods like electricity, gasoline and time are used in additional activities that may have no or very much smaller environmental effects. The general perspective is that the total quantity that the consumer buys of any particular commodity is allocated between a number of different activities, some of which have negative effects on the quality of the environment and some have not.

Suppose now that one particular activity generates environmental externalities and that we wish to internalize these effects by means of Pigouvian taxation. The first question that arises is what the tax base should be. Obviously, if it is the activity that generates the pollution, the tax should ideally be levied at the amount of the activity undertaken by consumers. This is an

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[8] The question has been discussed in Bruvoll (2009) who compares the OECD assessment of the revenues from environmental taxes in Norway with an estimate based on a more narrow definition used by a government commission on excise taxes. The latter shows the revenue from environmental taxes in Norway in 2007 to be less than 20 per cent of the OECD estimate.

application of the general principle of policy targeting. But in practice this advice may be difficult to follow: The level at which the activity is carried out may be difficult to measure, because the activity itself is not a subject of market transactions. A more feasible alternative is to tax goods, but the taxation of goods encounters difficulties when it comes to the discrimination between the uses of the goods in different activities. We may ideally wish to tax the use of a particular commodity in a particular activity, but administrative feasibility may limit us to the taxation of the total quantity bought by the consumer, whereby we tax the use of the commodity in all activities, whether they have adverse environmental effects or not. The car example affords a good illustration of the problems involved. For environmental reasons we might wish to tax the activity of driving in particular areas and at particular times. But if this is not feasible, the petrol tax might seem like a more practical alternative. However, for administrative reasons petrol has to be taxed at the same rate, whatever the activity is for which it is being used. The Pigouvian taxation of commodity i in activity j therefore has to be linked with the distortionary taxation of commodity i as it is used in environmentally neutral activities.

This formulation provides a stylized explanation of why the ideal base for Pigouvian taxation may be difficult to achieve. Since there are high informational and administrate costs involved in taxing polluting activities, one has in practice to tax goods rather than activities. But because of the additional difficulty of linking environmental damage to the use of one particular commodity in the context of the harmful activity, the ideal of perfect targeting may be hard to achieve. With broad-based commodity taxes - in the sense of taxes that are levied at the same rate on all uses of the commodity - environmental taxes are likely to introduce distortions jointly with the corrections of imperfections in the market mechanism. This leads to the conclusion that several commodity taxes - or even several commodity taxes supplemented by quantitative regulations - may have to be used in order to achieve an optimal result.[9]

It might perhaps be tempting to draw pessimistic policy conclusions from this analysis: If corrective Pigouvian taxes are likely to introduce new distortions, is it not to be expected that the net welfare gain from their use might easily become negative? In my view, this pessimism is unfounded. It is important to distinguish between achieving on the one hand a social

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[9] This issue was discussed in the context of optimal taxation theory in Sandmo (1976).

optimum and on the other hand a welfare improvement. Imperfect taxes, if used with good judgement and empirical knowledge, can clearly result in substantial welfare improvement in spite of falling short of the first best welfare ideal.

6. Principles of optimal taxation

Needless to say, taxes are not only imposed for the purpose of improving the environment; their primary purpose is to raise revenue for publicly provided goods. Now since environmental taxes are not the only taxes used by the government to raise revenue, the question arises of how Pigouvian taxes should be determined given the existence of these other taxes. The simplest case is that where the government's other source of revenue is lump sum taxes: Taxes that are levied on individuals as a fixed sum with a marginal tax rate of zero. In that case the Pigouvian taxes on commodities that generate adverse environmental effects should simply be equal to the difference between social and private marginal costs - the marginal social damage - all other commodity taxes being set equal to zero. This is often referred to as the first best case of environmental taxation.

Unfortunately, for all practical purposes, ideal lump sum taxes do not exist outside of economic textbooks. To move the theory closer to the concerns of the problems faced by policy makers we have to consider environmental taxes in the context of a more realistic environment in which the government uses both ordinary - i.e. non-environmental - commodity taxes as well as direct taxes on income and wealth. These taxes introduce distortions in the economy by violating the conditions for an optimal allocation of resources or Pareto optimality.

In the standard theory of optimal taxation, which goes back to the work of the English economist and mathematician Frank Ramsey (1927), the problem of externalities is neglected, and the focus is on the issue of how to raise a given amount of revenue from commodity taxes with a minimum loss of efficiency for the economy as a whole. Ramsey showed that under some simplifying assumptions tax rates should be inversely proportional to the elasticities of demand: Commodities with inelastic demand should be taxed at high rates, while those whose demand is more elastic should be taxed at lower rates. This is in contrast to the idea, which used to be prevalent in the public finance literature, that the least distortionary system of

commodity taxation would be one where taxes were uniform, i.e. levied at the same percentage rate on all goods. The Ramsey elasticity rule indicates that what we should worry about is not the distortions of relative prices but of relative quantities, and this is precisely what is achieved by the inverse elasticity rule[10]. Similarly, the marginal rate of income tax, to the extent that it applies mainly to income from labour, should be higher, the lower is the elasticity of labour supply.

How are environmental taxes to be fitted into this framework of optimal taxation? For simplicity of exposition, let us assume that there is one commodity, the consumption or production of which creates a negative environmental externality (in the jargon of environmental economists this is often referred to as a "dirty good"). The remaining commodities have no such effects (they are "clean goods"). Then it can be shown (Sandmo 1975, 2000) that for all clean goods the optimal tax rates satisfy the Ramsey rule: The rates should be inversely proportional by a factor *a* to the elasticities of demand. In the case of the dirty good, the tax rate should be a weighted average of that computed under the Ramsey inverse elasticity rule and the Pigouvian marginal social damage term, the weights being *a* and *(1-a)*. The magnitude of *a* should reflect the tightness of the government's budget constraint or the marginal cost of public funds. If this is very high, the parameter *a* becomes a number close to one, and the tax structure becomes similar to that which maximizes the revenue to the government. In this case the whole tax structure becomes very similar to that of Ramsey. If, on the other hand, *a* is very small the structure of the optimal tax system moves closer to that of the first best Pigouvian structure: Taxes on clean goods are approximately zero, while the taxes on dirty goods reflect their respective marginal social damage, just as in the first best case.

One simplifying assumption that underlies this analysis should be emphasized: The version of the Ramsey rule that has been used here makes optimal tax rates proportional to the own elasticities of demand, while cross elasticities are disregarded. However, the Ramsey rule can be extended to the case of cross elasticities that differ from zero, and it can be shown that a similar rule, as well as the weighted average formula for dirty goods, holds for the more general case also.[11]

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[10] Indeed, one interpretation of the inverse elasticity rule is that the percentage reduction of private consumption should be the same for all goods.

[11] For more details, the reader is referred to the mathematical appendix to this article.

A short semi-mathematical digression may illuminate this. Let us denote by θ_R the ad valorem tax rate that maximizes government revenue (i.e. the inverse elasticity) and by θ_D the rate that reflects the marginal social damage. Then, if θ is the overall tax rate, the optimal tax structure can be shown to satisfy the conditions

$\theta = a\theta_R$ for all clean goods,

and

$\theta = a\theta_R + (1-a)\theta_D$ for all dirty goods.

A remarkable feature of this solution is that the tax rates on none of the clean goods should contain a component reflecting the marginal social damage, whether the clean goods are substitutes or complements in regard to the dirty good. This is an example of the principle of targeting: The policy instrument should be targeted as precisely as possible on the goal that it aims to influence.

There are a number of special cases and extensions of this line of reasoning. Suppose that one of the clean goods is interpreted as leisure; the optimal tax rate could in this case be interpreted as the marginal rate of income tax under a linear tax system. Assume now that the demand for leisure - or, equivalently, the supply of labour - is completely inelastic. In this case an arbitrary large amount of revenue can be raised by the income tax without adverse distortionary effects. The income tax therefore becomes the equivalent of a lump sum tax, and the optimal solution is to raise the required revenue through the income tax while letting commodity taxes serve the sole purpose of correcting the market failure that follows from the environmental externalities. Commodity taxes should be zero on clean commodities and positive on dirty commodities.

A difficulty about this whole line of reasoning is that it disregards distributional effects. To see the shortcomings of this restriction, assume that the benefits of environmental improvement accrue mainly to the rich while the "dirty goods" are chiefly consumed by the poor. In this example the effects of a green tax reform would be regressive, redistributing real income from the poor to the rich. With even a mildly egalitarian social welfare function such

an outcome would be unattractive and would need to be modified in the direction of more social justice. This could be done along several lines. One solution is to modify the tax formulas above: In the calculation of the aggregate marginal social damage, the damage suffered by the rich could receive a lower weight than the damage experienced by the poor. Moreover, in calculating the Ramsey efficiency terms of the marginal tax formulas, the inverse elasticity terms could be weighted according to the distributive profile of the consumption patterns of the various goods. By so doing, there would be a bias towards taxing necessities (which tend to have low price elasticities of demand) at lower rates than luxury goods (whose elasticities are higher). The overall tax structure would therefore emerge as a compromise between the regard for social efficiency and distributive justice.

Another response to the possible conflict between the concerns for efficiency and distributive justice is to develop policy instruments that are better targeted on the redistributive goal. We have already noted the administrative impossibility of a system of individualized lump sum taxes, but there are clearly interesting cases in between this extreme case and the other extreme where all taxes are proportional. One possibility that has been extensively discussed in the literature is that of a general non-linear income tax, an idea that receives its inspiration from the work of Mirrlees (1971). In the theoretical formulation of Mirrlees the marginal rate of income tax is allowed to vary continuously with income, and it has been shown that the optimal marginal tax rate at the top of the income scale should in fact be zero. In an aggregate perspective, this is just the outcome that we would have under lump sum taxation, and under some particular assumptions it has been demonstrated that with a general non-linear income tax the redistributive concern should in its entirety be taken care of by the income tax, while Pigouvian environmental taxes should be calculated according to the first best rule; see Kaplow (2008).

The discussion above has proceeded on the assumption that environmental damage is generated by the consumption and production of particular commodities that are feasible objects of taxation. This is not always a realistic assumption. As pointed out in Section 5 above, environmental externalities are frequently generated by activities, not goods. But the taxation of activities may be difficult since activities as such are not traded in the market and therefore are awkward bases for taxation. To achieve an effective taxation of activities one has to have a broad-based system in which taxes are levied on several commodities that go into the production of the activity in question. This, of course, is a type of policy with which

we have practical experience: Car use is taxed by a number of different tax types, and the same is true for other kinds of environmental problems.

7. The double dividend issue

One issue that has received a lot of attention in policy debates and also in the academic literature is that of the so-called double dividend. We have already touched upon the main point: Green taxes improve the environment, but they also raise revenue. Consider a tax reform where environmental taxes are increased while other taxes, like income taxes and the VAT, are reduced in an amount that keeps total tax revenue constant. Since these other taxes impose efficiency losses on the economy, this reform succeeds in substituting efficiency-enhancing for efficiency-reducing taxes. So the result is apparently that we are able to raise the same amount of tax revenue with less dead-weight loss at the same time as we improve the quality of the environment. This implies that we get two benefits or dividends from a green tax reform: (1) the state of the environment is improved and (2) we adopt a tax system with less distortion of commodity and factor markets. The argument is an attractive one with a strong appeal to economic intuition. But a closer analysis shows that we need to think carefully about it before making serious recommendations about tax reform.[12]

One problem with this idea is that it fails to be precise about the assumption that is made about the state of the tax system at the time of the reform. To see the importance of this, let us assume that the tax system has been optimized according to the principles laid out in the previous section. Then, by the nature of an optimum, a small shift in the tax system towards more green taxation will have no effect on social welfare; the change in the environmental dividend is exactly cancelled by the associated change of the tax efficiency dividend. There is no double dividend at all.

But the assumption that the tax system is optimal to begin with is an extreme one. The theory of optimal taxation was never designed to provide a realistic description of the *actual* tax system. An alternative approach is therefore to start from some description of the actual tax system that is closer to what the proponents of the double dividend idea have probably had in mind. One such assumption is that we start from a situation with no green taxes at all. The

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[12] An anthology of recent contributions and a survey of the double dividend debate is Goulder (2002).

reason for this state of affairs might be that individuals and politicians have been ignorant of the environmental problems that exist in the economy or have not been aware that taxation could provide the solution to the problems. Then environmental taxes are introduced as a new element of the overall tax system with a reduction of the level of distortionary taxation in commodity and factor markets. Can we be sure, abstracting from distributional effects, that there is a gain in economic welfare?

The answer, in general, is no, and it is not difficult to see why. The demand both for clean and dirty goods depends on the whole set of tax-inclusive prices in the economy. Thus, a reduction in the consumer price of a particular clean good could increase the demand for a dirty good, thereby counteracting the initial effect of an increase in green taxes, making the environmental dividend doubtful. On the other hand, a price increase for dirty goods could by a similar argument affect the structure of demand for clean goods in such a way as to make the effects of price distortions worse than they were before.

Our conclusion regarding the existence of a double dividend from a green tax reform must therefore be a cautious one: There could be such an effect, but it is not assured. Whether it will occur or not depends both on the initial state of the tax system and on the structure of demand, especially as regards the cross price effects between markets for clean and dirty goods. Empirical studies are required in order to determine the outcome in any particular reform situation.

A special version of the double dividend hypothesis concerns its effects on unemployment. It has been argued by several economists and policy makers that a tax reform which increases the level of green taxes and combines this with a cut in the payroll tax would lead both to an environmental gain and to a higher level of employment. The underlying idea is that in a situation of some kind of Keynesian unemployment equilibrium actual employment is determined by the demand for labour in private firms, and by lowering the payroll tax one decreases the price of labour to employers, thereby generating an increase of labour demand and employment.[13]

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[13] Among the contributions to the analysis of this issue are Bovenberg and van der Ploeg (1996) and Koskela, Schöb and Sinn (1998).

It should be noted that in order to evaluate this claim we need to use a model that is different from that of perfect competition. If the wage rate does not adjust so as to equalize demand and supply for labour we need an alternative theory of wage formation. One possibility is to use a model of trade union behaviour in which the union sets the wage rate while firms, taking this wage rate as given, determine the amount of employment - the so-called monopoly union model[14]. In this case, the union will set the wage above the level that leads to elimination of unemployment. Although the union aims to maximize the welfare of its members, it has to weigh the welfare effects of higher wages for the employed against the welfare of the unemployed, and this will result in a wage rate that is above the market-clearing level. Cutting the payroll tax, it could be argued, leads to a reduction of the wage rate and therefore to less unemployment.

Like the previous argument in favour of the double dividend, this also needs careful evaluation. A notable weakness of it is that it completely disregards the problem of tax incidence. If firms are confronted with lower gross wages (wages plus payroll tax) so that they earn higher profits, it is reasonable to believe that unions will claim some of these gains for themselves by increasing their wage demands; if so, this would lead to a smaller gain for society in terms of unemployment reduction. A further complication is that the increase of green taxes on goods like energy and transportation will reduce the real wage of the workers, giving them cause to argue for compensatory nominal wage increases. Taking account of both elements of tax incidence, one has to face the possibility that the net effect of a green tax reform on wages and unemployment may in fact be quite small.

Although our discussion of the double dividend has to end on an agnostic note, this is not to say that a green tax reform may not be able to produce both a better environment and a more efficient tax system. But whether it will actually succeed in this is a question that cannot be settled on theoretical grounds alone; each tax reform proposal has to be evaluated on the basis of the empirical context in which it is proposed.

8. Taxes, regulations and the costs of administration

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[14] An excellent survey of such models, although now somewhat dated in its coverage of the literature, is Oswald (1985).

Pigouvian taxes are clearly not the only instruments whereby governments can attempt to internalize environmental externalities. An alternative to taxes in many cases is to use transferable quotas. This instrument, however, has so many points of similarity with taxes that it will not be discussed further here.[15] But in practice governments use a number of other instruments, and although economists have traditionally had a strong preference for the market based instruments of taxes and transferable quotas, the use of command-and-control instruments exemplified by non-transferable quotas and direct regulation of production technology or product quality is in fact widespread.

The standard criticism of command-and-control instruments is first that they are likely to have higher administrative costs and second that they fail to achieve a given reduction of pollution at minimum cost to society. One may naturally ask, therefore, whether the use of command-and-control instruments is simply a case of misguided policy or whether it can be justified by more careful theoretical analysis. A crucial point regarding the efficiency properties of Pigouvian taxes is that the government is capable of choosing the right tax base. But, as pointed out in Section 5 above this is not always a reasonable assumption. Quite often it is the consumption or production of a particular good in a particular social situation or activity that generates the externality, whereas taxes typically have to be general taxes that are paid on every unit of the good that is produced or consumed.

A case in point is the consumption of cigarettes. The taxation of smoking is often justified by the argument that "smoking is bad for you", which is one that goes beyond the externalities framework. Although paternalistic arguments deserve more serious consideration than they often receive, the focus here will be on the externalities of cigarette smoking which have also been used as arguments for high excise taxes on cigarettes. But in many social contexts or situations it can be argued that there are hardly any externalities from smoking, or at least that the externalities generated in some contexts are much less than in other social settings. This would call for differentiated taxation of cigarettes depending on the social context or activity in which they are used; as pointed out in section 5, one would ideally like to tax activities rather than commodities. But this is not a feasible strategy of taxation, since it would involve prohibitive administrative costs. A simpler alternative would be to impose a ban on cigarette

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[15] The equivalence of taxes and quotas pertains especially to their efficiency properties. Their distributional consequences might, however, be quite different, dependent on the manner in which the government chooses to distribute quotas to polluters.

smoking in particular places like lecture halls, football stadiums and restaurants, where the negative externalities from passive smoking are particularly serious. A combination of taxes and regulations might therefore in many cases be a more efficient policy - both in the sense of minimizing distortions and having lower costs of administration - than that of exclusive reliance on taxes. This raises interesting questions of the choice of an optimum combination of taxes and regulations, and a number of these have been analyzed in a recent paper by Christiansen and Smith (2009). One of their conclusions is that if a Pigouvian commodity tax is supplemented by regulation it is the use of the commodity that causes the larger externality that should be regulated.

While the cost of differentiation is an important element of the overall costs of administration of the tax system, another element is the control of tax evasion. Tax evasion has received most attention by economists in the context of income tax compliance, but there is also considerable evidence of the importance of indirect tax evasion. An interesting question is now whether the efficiency properties of Pigouvian taxes carry over to the case where there is tax evasion. This problem has been analyzed in Sandmo (2002), where it is shown that to a large extent they do, since the theoretical analysis shows that decisions about output and emissions are often separable from the decision to evade taxes; the efficiency properties of taxes therefore remain the same as in the standard analysis. Using the same theoretical framework for the analysis of quota violations it can be shown that the combination of the fine or penalty rate and the probability of detection may be designed so that the expected fine has many of the efficiency properties of Pigouvian taxes. The gap between taxes and quotas on the one hand and regulations on the other may therefore not be as wide as often alleged in the literature.

9. Do taxes crowd out intrinsic incentives?

Most of the literature on the public good type of externalities - prophetically referred to as "the creation of atmosphere" by Meade (1952) - assumes that the individual consumer and firm do not care about the amount of their own emissions of pollution. The agent may care about the public good that is negatively affected by his activities, such as clean air and the absence of noise, but in his behaviour he does not take into account his own (negative) contribution to the public good. The reason is simply than in a setting where many agents

contribute to the quality of the public good, incentives are such that it is rational for the agent to neglect the link between his own decisions about consumption and production and the public good, although he may well realize that in the aggregate such a link does in fact exist. The purpose of environmental taxation is to create private incentives to act in a socially rational way by creating private incentives that would otherwise be non-existent.

However, the realism of this assumption is questionable. If it were literally true, we would certainly see much more littering of public places than we actually do, and there would be fewer cases of people who buy environmental-friendly products when cheaper alternatives are available. In order to capture this aspect of behaviour we need to extend our model of individual motivation. We must assume that the individual agent not only cares about his private interest in the sense of his utility of consumption or his profit, but that his own individual emissions contribute negatively to his utility or perceived profit.

In order to fix ideas it may be useful to consider the simple case of a competitive firm that emits a harmful substance as a by-product of its activities. The firm maximizes revenue minus costs, where the cost function varies positively with output and negatively with emissions (this implies that costs increase when emissions are reduced). Another deduction from revenue is a tax per unit of emissions. Under standard profit maximizing assumptions, the firm will set its marginal cost of production equal to the market price and the marginal cost of pollution reduction equal to the tax rate on pollution (the Pigouvian tax).

Suppose now that there is an additional element of cost that reflects the firm's negative evaluation of its pollution activities.[16] This subjective element of cost is increasing in the amount of pollution, and it is natural to assume that the marginal cost is also increasing. The conditions for profit maximization are now, first, that the marginal cost of production equals the market price as before, and that the marginal cost of pollution reduction is equal to the sum of the Pigouvian tax and the "conscience tax". The latter concept is simply the additional element of cost that is incurred with a small increase in the amount of pollution.

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[16] It may be objected that this assumption is inconsistent with the assumption of competitive markets with free entry: If the firm imposes such a cost on itself it will be squeezed out of the market by new entrants that do not "suffer" from concerns about the environment. On the other hand, it is open to debate whether a realistic model of competitive markets really requires this knife-edge view of the consequences of deviations from pure profit maximization. Anyway, the case that is discussed here should be taken as a simple example of a more general approach that needs more justification than can be provided in the present context.

An interesting question is what happens to the conscience tax with an increase in the Pigouvian tax rate. This implies that "extrinsic incentives" are introduced in a situation where "intrinsic incentives" already exist and an important question is now whether a strengthening of the former will lead to a weakening of the latter.[17] It has been claimed by several authors, e.g. by Weck-Hannemann and Frey (1995) and Frey (1997), that an increased use of extrinsic or financial incentives will so weaken intrinsic or moral incentives that the net effects of policy instruments like Pigouvian taxation may be doubtful. In the model outlined above this hypothesis is supported in the sense that an increase in the rate of Pigouvian tax leads to a reduction in the conscience tax, but by less than the increase in the formal tax rate. In other words, the conscience tax is partially but not completely crowded out by the Pigouvian tax. This tax still has the power to curb pollution but by less than one would be led to think on the basis of the pure theory of profit maximization.

How destructive are these considerations in relation to the economic case for green taxes? In the model of the example, an increase of the Pigouvian tax rate still leads to reduced emissions and is therefore an important policy instrument if policy makers consider that intrinsic incentives are too weak to reach the socially optimal reduction of emissions. Moreover, on the natural assumption that the conscience tax varies among individual agents, the Pigouvian tax helps to make the total tax on pollution - i.e. the formal tax rate plus the conscience tax - more uniform among polluters. This would be a step towards equalizing the marginal cost of pollution cutbacks across economic agents and therefore towards production efficiency in environmental policy.

There is more to be said about this issue, however. It is clearly possible to argue that the preservation of intrinsic incentives in itself is good for the well-being of society. An incentive scheme that drives out moral attitudes may in this view create a society of individuals and firms that feel less responsible towards the environment, and the social cost of such a development of moral attitudes may be serious. On the other hand, one could also argue that the adoption of a system of extrinsic incentives for environmental improvement could increase people's awareness of these problems and thus contribute to more environmental friendly attitudes.

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[17] A general analysis of the various issues that arise in the interaction between intrinsic and extrinsic incentives is Bénabou and Tirole (2006).

10. International aspects of environmental taxation

Some of the most significant environmental problems of our time are of a global nature.[18] In particular, the issue of global warming has caused great concern among natural scientists and politicians as well as among economists as witnessed by the debate following the publication of the Stern review (Stern 2006). The perspective taken by Stern is that of environmental policy as a form of social insurance: We may not know with perfect certainty the extent and effects of global warming, but the risks involved are certainly large enough to justify spending about one per cent of global GDP annually to reduce greenhouse gas emissions.

The policy alternatives that are available to achieve the goal of a substantial decrease in global emissions include both taxes, quotas and regulations, so that much of the analysis of international environmental policy, including the use of Pigouvian taxes, can benefit from the insights derived from the study of domestic policies. However, the international setting raises some new problems that require careful consideration.

The state of the atmosphere is an example of a global public good. A global public good is characterized by being publicly available to all of the world's population in equal amount. This does not imply that all the world's inhabitants value the good in equal measure, but simply that we cannot improve the quality of the atmosphere for one group of people without at the same time improving it for everyone in the world.[19] The optimal state of the atmosphere has been achieved when the marginal benefit of preventing global warming is equal to the cost of preventing it. One of the ways to achieve the reduction of emissions into the atmosphere is the use of Pigouvian taxes on a global scale.

The problem that arises at this stage is that while the benefits of environmental policy are global, the costs may have to be borne locally. Confronted with the problem of the determination of global public goods supply, all individual countries of the world find themselves in the situation of the single individual in a conventional public goods setting: In

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[18] Although the emphasis here is on global warming, there are other important examples of global environmental problems, such as pollution of the oceans and the reduction of global biodiversity.
[19] This statement needs some modification in that groups of the world's population might evaluate global warming positively because their own local environment might benefit from enjoying a more pleasant climate and higher agricultural productivity. For an analytical treatment of the theory of global public goods and externalities see Sandmo (2003, 2005).

the process of arriving at a global solution, each country has an incentive to misrepresent its preferences and costs and to free ride on the benefits provided by the policies of other countries. However, if all countries reason in the same way, the result will be a serious underinvestment in the prevention of global warming, taking the form e.g. of suboptimal use of green taxes from the point of view of global economic welfare.

One of the advantages of Pigouvian taxes in a domestic setting is that they tend to produce a reduction of pollution emissions that satisfies the demand for production efficiency. Because all polluters face the same tax rate, they will equate the marginal cost of pollution cutbacks to the tax rate. This marginal cost accordingly becomes equalized among producers and the aggregate reduction of emissions is minimized for society as a whole. Applying this line of reasoning to global externalities, one would like to ensure that the marginal cost of reducing pollution is the same for all polluters, and this can be achieved by imposing the same tax rate on emissions from all countries. This is the chief justification for the much discussed proposal of a global carbon tax, i.e. a tax on CO_2 emissions.

There are two issues that arise in connection with this proposal that are significantly different from the analysis of domestic taxes. One is the lack of an international authority that has the power to impose global taxes, i.e. taxes that all the world's nations would be obliged to adopt. In the absence of such an authority, the adoption of a global carbon tax requires the voluntary consent of all countries affected by the measure. This is clearly a difficult agreement to bring about in view of the international free rider problem. But even if this problem could somehow be overcome there is an additional although related problem regarding the distributional impact of the tax in a world with enormous disparities in terms of per capita income and consumption. Is it fair that the poor areas of the world should pay the same rate of tax per unit of CO_2 emissions as the rich industrialized countries?

There are basically two ways out of this dilemma. One is to differentiate the tax between rich and poor countries, letting the developing countries pay at a lower rate than the industrialized countries. Obviously, the differentiation scheme would have to be designed with some care, e.g. so as to avoid major jumps in the tax rate as countries move into higher tax brackets with increasing GDP per capita.[20] Whatever the degree of differentiation, this system would entail

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[20] Such jumps would have unfortunate effects especially with regard to tax compliance; they would give countries strong incentives to underreport their per capita GDP when it approaches the lower limit of a new tax

a loss of global production efficiency in that the marginal cost of pollution reduction would no longer be equalized among countries, but this could be regarded as a price to be paid for a more equitable distribution of world income. The other solution to the dilemma is to combine a uniform CO_2 tax with an international scheme of redistribution whereby rich nations make transfers of income to the poor countries in return for their agreement to adopt a globally uniform emissions tax. In this scheme, the international uniformity of the tax would ensure global production efficiency without adverse consequences for the degree of international inequality.

11. The political economy of environmental policy

Given the efficiency properties of green taxes one might expect them to be among the more attractive forms of taxation to be considered by governments and their electorates, but this is in fact far from being the case. Many politicians are difficult to convince about the social benefits of environmental taxation and among the general public proposals to introduce such taxes are frequently met with a good deal of scepticism if not outright hostility. There may be a number of reasons for this state of affairs, and the possible explanations may vary in importance from one country to another and also over time. Below I consider briefly some of these.

An important motivation for many of those on the right of the political spectrum who resist the introduction of environmental taxes is undoubtedly that they have a negative attitude towards attempts at what they see as unwarranted expansion of the public sector. The thought experiment of economists who analyze tax reform under the assumption of constant tax revenue is not well understood; instead, the arguments are interpreted as just another set of proposals to increase tax revenue and thereby the size of the public sector.[21]

Another explanation for sceptical attitudes towards green taxes is that the incentive arguments may in fact not be easy to understand. The arguments of economists regarding private incentives, the importance of elasticities, the efficiency costs of taxes etc. are much less

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bracket. Reinforcing this problem is the considerable degree of uncertainty attached to the computation of the exact magnitude of GDP. Letting small differences in the principles of GDP estimation have significant effects for a country's tax liability would clearly be undesirable.

[21] In fairness, it should also be pointed out that some of the adherents of environmental taxes on the left may put too much weight on these taxes as sources of revenue for a larger public sector.

evident to the general public than many economists tend to believe. Perhaps the emphasis in some of the policy literature on the double dividend from a green tax reform - especially in the form of its effects on unemployment - stem from the desire of some of its supporters to provide a sales argument that is of more concrete substance than the benefits to the natural and social environment.

A related explanation is that green taxes may be regarded by many as "lifestyle taxes". Higher taxes on petrol and other sources of energy will make it more expensive to drive private cars, live in the suburbs, have a second home in the countryside as well as carrying out a number of other energy-intensive leisure activities. To the extent that lifestyles are fixed in the short run, the argument that energy taxes may have long run benefits e.g. in the form of smaller houses that require less energy and less commuting may carry little weight with much of today's electorate. Taxes that threaten the financial viability of a lifestyle that one has become accustomed to are hardly likely to be very popular among voters.

For some aspects of environmental taxation there may also be considerable scepticism and ignorance regarding the real effects of environmental policy. This applies with special force to the crucial issue of global warming and may explain the popular appeal of the arguments advanced by those who claim that there is no global warming problem that requires painful measures like increased energy taxes. Obviously, it is also difficult to get popular support for policies that impose sacrifices on today's consumers and producers for what is seen as the doubtful benefits to those who will live in a distant future.

12. Further issues and concluding remarks

This paper has covered a number of problems related to the theory and practice of environmental taxation. Nevertheless, there are clearly a number of issues that have been left out and would have deserved more careful attention, and some of these may require brief mention.

First, as in almost the whole of the literature in this area, our discussion of environmental externalities has taken the competitive equilibrium as its point of departure. Firms and consumers take market prices as given; similarly, because of their individual inability to affect

market outcomes they also take tax rates as given. Analytically, there is much to be said for this procedure because it abstracts from the complexities involved in taking account of other imperfections of the market system. However, real economies are in fact characterized to a large extent by imperfect competition which raises two interesting issues for the analysis of environmental taxes. One is the design of optimal taxes in a setting where market prices, even in the absence of externalities, are not such as to lead to an efficient allocation. The other is that with only a few firms on the production side of the market, a tax that is levied on these is likely to be seen by the firms concerned as subject to negotiation with the tax authorities, and the competitive model with price and tax takers no longer applies.

I have only briefly touched on the argument of production efficiency in environmental policy: When all agents face the same tax rate on their polluting activity the marginal cost of pollution cutbacks will be equalized between them. (This argument applies obviously to firms, but it can also easily be adapted to the case of consumers, especially if we adopt the activities perspective of Section 5 above.) In this way, environmental taxation achieves *static production efficiency*[22]. But there is a further argument that relates to *dynamic efficiency*. The static argument applies to a situation where the technology of production is given. However, higher environmental taxes also provide incentives to change the technology of production so as to lower costs, thereby encouraging firms to develop new and more environmental friendly production technologies.

The foregoing discussion has set out the benefits of environmental taxation but it has also emphasized the difficulties that arise regarding their practical design. Although it is important to be aware of the complexities involved in a process of tax reform, it should also be pointed out that the adoption of green taxes that are less than perfect when measured in terms of idealized theoretical models may still involve substantial benefits for society. To revert once more to the car example: The fact that a tax on petrol is unable to differentiate between different types of car use should not be taken as a decisive argument against regarding the petrol tax as a green tax.

Green taxation is an interesting example of the cases where economists can be regarded as the inventors of policy instruments. While both the income tax and ordinary indirect taxes have

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[22] This argument received early emphasis in the article by Baumol and Oates (1971).

been developed over a long period of time, having been refined and extended by generations of politicians and bureaucrats, environmental taxation is a relatively recent innovation in the tax system that owes its existence to a large extent to the creative efforts of academic researchers. Since the time of Pigou, a number of economists have been involved in establishing both better theoretical insights and more extensive empirical knowledge of the effects of these taxes. More efforts should also be spent in making the theory of green taxation better understood among the general public.

Mathematical appendix

This appendix sets out in more (although not complete) detail the steps leading to the conclusions about the optimal tax structure in an economy with environmental externalities that are discussed less formally in Section 6.

Assume that the economy consists of n identical individual consumers. Each of them has a utility function that depends on the consumption of three private goods, numbered 0, 1, 2. In addition, utility depends on the amount of environmental pollution, e. Assuming that the utility function is weakly separable between consumption and the quality of the environment[23], the utility of a representative consumer can be written as

$$U = U(u(x_0, x_1, x_2), e). \tag{1}$$

The marginal utilities of the three consumption goods are positive[24], while the derivate with respect to the environmental variable, e, is negative. As another simplification, and abstracting from the complexities discussed in Section 5, the amount of environmental pollution is assumed to be proportional to the aggregate consumption of commodity 2:

$$e = nx_2. \tag{2}$$

The budget constraint of the consumer is

$$x_0 + P_1 x_1 + P_2 x_2 = y. \tag{3}$$

Thus, commodity 0 is taken to be the *numéraire*, which is untaxed, while P_1 and P_2 are the consumer prices. Specific taxes are levied on the two taxable goods, so that

$$P_1 = p_1 + t_1 \text{ and } P_2 = p_2 + t_2. \tag{4}$$

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[23] The implications of this assumption will be discussed below.
[24] If one of the three commodities is interpreted as leisure, the model could also be redesigned to accommodate a linear income tax.

Producer prices, denoted by p_1 and p_2, are assumed to be given from the production side of the economy.

We first consider the demand behaviour of the representative consumer. Maximizing the utility function (1) subject to the budget constraint (3) enables us to derive the individual demand functions as

$$x_0 = x_0(P_1, P_2, y), \quad x_1 = x_1(P_1, P_2, y), \quad x_2 = x_2(P_1, P_2, y). \tag{5}$$

Substituting the demand functions into the utility function (1) we get the indirect utility function

$$V = V(v(P_1, P_2, y), e). \tag{6}$$

At this point it is natural to remark on the assumption of weak separability that was introduced above. It is easy to see that because environmental pollution, e, does not enter into the sub-utility function u, nor into the budget constraint, the demand functions will be independent of the quality of the environment. If this assumption had not been made, we would have had to take account of the environmental feedback on demand: A price increase would have a direct effect on demand for each of the two goods, but since the price would also affect the quality of the environment via the consumption of commodity 2, there would be an additional effect which can be neglected in the present formulation.[25] However, this simplification does not affect the substantive economic contents of the analysis. Note also that consumers take the state of the environment as exogenously given so that each consumer disregards the fact that his own consumption affects the state of the environment, which is a natural assumption in the context of a large economy.

The government chooses optimal tax rates t_1 and t_2 with the objective of maximizing the utility of the representative individual. This objective is obviously equivalent, in the case of identical individuals, to the utilitarian sum of utilities.

$$W = U(u(x_0, x_1, x_2), e) = V(v(P_1, P_2, y), e). \tag{7}$$

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[25] For a fuller discussion of the environmental feedback effect see Sandmo (2000, Ch. 5).

The budget constraint of the government requires that a given amount of per capita revenue, T, be raised through commodity taxation, so that

$$t_1 x_1 + t_2 x_2 = T. \tag{8}$$

It is assumed that lump sum taxation, i.e. a tax levied directly on y, is not an available instrument of tax policy. The impossibility of lump sum taxation is motivated by more complex models with heterogeneous individuals and informational problems; here we use this insight in a simplified context which in itself admittedly does not explain the impossibility of first best optimal taxation.

The government maximizes social welfare subject to its revenue constraint. Forming the Lagrangian function

$$\Lambda = V(v(P_1, P_2, y), e) + \mu[t_1 x_1 + t_2 x_2 - T], \tag{9}$$

we can take the derivatives with respect to t_1 and t_2 and use the first order conditions to characterize the optimal tax system. Instead of presenting the results in their most general form, given the limitations of the three commodity model, we focus on the special case where demand functions are independent, so that the cross price derivatives are zero (for more details of the mathematical derivation as well as an analysis of the more general case, see Sandmo (2000)). Defining the percentage tax rates as $\theta_1 = t_1/P_1$ and $\theta_2 = t_2/P_2$ we can write the optimal tax rates as

$$\theta_1 = a(-1/\varepsilon_{11}) \tag{10}$$

$$\theta_2 = a(-1/\varepsilon_{22}) + (1-a)(-nV_e/\lambda P_2) \tag{11}$$

Here we have defined $a = (\mu-\lambda)/\mu$ as the percentage gap between the marginal utilities of income in the public and private sectors. In order to interpret the optimality conditions, it is useful to begin by disregarding the second term in equation (11). We see then that optimal tax rates are characterized as being proportional to the inverse of the price elasticities of demand; a result first derived by Ramsey (1927) and later restated and extended by Samuelson (1951;

1986), Diamond and Mirrlees (1971) and many others. Intuitively, taxes ought, for efficiency reasons to distort relative quantities as little as possible, and this is precisely what is achieved by taxing the more price elastic commodities at the highest rates.

The second term in equation (11) expresses the marginal social damage. The damage at the individual level, expressed in unities of the polluting commodity, is $V_e/\lambda P_2$, and this must be multiplied by n to arrive at the social damage.

Finally, in order to connect this analysis with the presentation in the main text of this paper, we may define

$$\theta_{1R} = (-1/\varepsilon_{11}), \; \theta_{2R} = (-1/\varepsilon_{22}) \text{ and } \theta_D = (-nV_e/\lambda P_2).$$

Substituting these expressions into (10) and (11), the equations can be rewritten as

$$\theta_1 = a\theta_{1R}. \tag{12}$$

$$\theta_2 = a\theta_{2R} + (1-a)\theta_D. \tag{13}$$

These equations correspond to the expressions in the text of Section 6 above.

As also noted in Section 6, a notable feature of this solution is that the marginal social damage only enters into the tax formula for commodity 2, while the tax on commodity 1 is characterized by its Ramsey term only. This is an example of the principle of targeting.

References

Barde, Jean-Philippe and Nils Axel Braathen (2005), "Environmentally related levies." Chapter 5 in Cnossen (2005).

Baumol, William J. and Wallace E. Oates (1971), "The use of standards and prices for protection of the environment." *Swedish Journal of Economics 73,* 42-54.

Bénabou, Roland and Jean Tirole (2006), "Incentives and prosocial behavior." *American Economic Review 96*, 1652-1678.

Bovenberg, A. Lans and Frederick van der Ploeg (1996), "Optimal taxation, public goods and environmental policy with involuntary unemployment." *Journal of Public Economics 62*, 59-83.

Bruvoll, Annegrete (2009), "On the correct measurement of environmental taxes." Forthcoming Discussion Paper. Oslo: Statistics Norway.

Christiansen, Vidar and Stephen Smith (2009), "Externality-correcting taxes and regulation." Working Paper W09/16. London: Institute for Fiscal Studies.

Cnossen, Sijbren, ed. (2005), *Theory and Practice of Excise Taxation.* Oxford: Oxford University Press.

Diamond, Peter A. and James A. Mirrlees (1971), "Optimal taxation and public production I-II." *American Economic Review 61,* 8-27, 261-278.

Frey, Bruno S. (1997), "A constitution for knaves drives out public virtues." *Economic Journal 107,* 1043-1053.

Goulder, Lawrence H., ed. (2002), *Environmental Policy Making in Economies with Prior Tax Distortions.* Cheltenham: Edward Elgar.

Kaplow, Louis (2008), *The Theory of Taxation and Public Economics.* Princeton: Princeton University Press.

Koskela, Erkki, Ronny Schöb and Hans-Werner Sinn (1998), "Pollution, factor taxes and unemployment." *International Tax and Public Finance 5*, 379-396.

Leape, Jonathan (2006), "The London congestion charge." *Journal of Economic Perspectives 20* (4), 157-176.

Meade, James E. (1952) "External economies and diseconomies in a competitive situation." *Economic Journal 62,* 54-67.

Mirrlees, James A. (1971), "An exploration in the theory of optimum income taxation." *Review of Economic Studies 38,* 175-208.

Musgrave, Richard A. (1959), *The Theory of Public Finance*. New York: McGraw-Hill.

Newbery, David M. (2005), "Road user and congestion charges." Chapter 7 in Cnossen (2005).

Oswald, Andrew J. (1985), "The economic theory of trade unions: An introductory survey." *Scandinavian Journal of Economics 87*, 160-193.

Parry, Ian W. H., Margaret Walls and Winston Harrington (2007), "Automobile externalities and policies." *Journal of Economic Literature 45*, 373-399.

Pigou, Arthur C. (1920), *The Economics of Welfare*. London: Macmillan.

Pigou, Arthur C. (1928; 1947), *A Study in Public Finance.* London: Macmillan.

Ramsey, Frank P. (1927), "A contribution to the theory of taxation." *Economic Journal 37,* 47-61.

Samuelson, Paul A. (1952; 1986), "Theory of optimal taxation." Unpublished version, 1952; *Journal of Public Economics 30*, 137-143.

Sandmo, Agnar (1975), "Optimal taxation in the presence of externalities." *Swedish Journal of Economics 77*, 86-98.

Sandmo, Agnar (1976), "Direct versus indirect Pigovian taxation." *European Economic Review 7,* 337-349.

Sandmo, Agnar (2000), *The Public Economics of the Environment*. Oxford: Oxford University Press.

Sandmo, Agnar (2002), "Efficient environmental policy with imperfect compliance." *Environmental and Resource Economics 23*, 85-103.

Sandmo, Agnar (2003), "International aspects of public goods provision." Inge Kaul & al. eds., *Providing Global Public Goods.* Oxford: Oxford University Press.

Sandmo, Agnar (2005), "Environmental taxation and revenue for development." A. B. Atkinson, ed., *New Sources of Development Finance*. Oxford: Oxford University Press.

Stern, Nicholas (2006), *The Economics of Climate Change: The Stern Review.* Cambridge: Cambridge University Press

Vickrey, William (1963), "Pricing in urban and suburban transport," *American Economic Review 53*, 168-181. Reprinted in R. Arnott, K. Arrow, A.B. Atkinson and J.H. Drèze, eds., *Public Economics. Selected Papers by William Vickrey.* Cambridge: Cambridge University Press.

Weck-Hannemann, Hannelore and Bruno S. Frey (1995), "Are incentive instruments as good as economists believe?" Chapter 8 in Lans Bovenberg and Sijbren Cnossen, eds., *Public Economics and the Environment in an Imperfect World.* Dordrecht: Kluwer Academic Publishers.

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