ENVIRONMENTAL TAXATION AND REGULATION

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ABSTRACT

This chapter examines government policy alternatives for protecting the environment. We compare environmentally motivated taxes and various non-tax environmental policy instruments in terms of their efficiency and distributional impacts. Much of the analysis is performed in a second-best setting where the government relies on distortionary taxes to finance some of its budget. The chapter indicates that in this setting, general equilibrium considerations have first-order importance in the evaluation of environmental policies. Indeed, some of the most important impacts of environmental policies take place outside of the market that is targeted for regulation.

Section 2 examines the optimal (efficiency-maximizing) level of environmental taxes. Section 3 analyzes the impacts of environmental tax reforms, concentrating on revenue-neutral policies in which revenues from environmental taxes are used to finance cuts in ordinary, distortionary taxes. We explore in particular the circumstances under which the "recycling" of revenues from environmental taxes through cuts in distortionary taxes can eliminate the non-environmental costs of such reforms. Section 4 compares environmental taxes with other policy instruments – including emissions quotas, performance standards, and subsidies to abatement – in economies with pre-existing distortionary taxes. We first compare these instruments assuming that regulators face no uncertainties as to firms' abatement costs or the benefits of environmental improvement, and then consider how uncertainty and associated monitoring and enforcement costs affect the choice among alternative policy instruments. Section 5 concentrates on the trade-offs between efficiency and distribution in a second-best setting. Section 6 offers conclusions.

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1. Introduction

Many aspects of the natural environment are public goods. Air and water quality are shared (nonrival) goods, as are the wildlife and natural landmarks enjoyed in forests and wilderness areas. Property rights for environmental resources are often difficult, if not impossible, to assign; hence private ownership is the exception rather than the rule. The absence of private ownership implies a lack of markets for important environmental amenities. Since no one owns the air, for example, no one can charge for use of the air (that is, for degradation of the air from pollution) and thus no market arises for air quality. The absence of markets, in turn, implies inefficient use of the environment. Without government intervention, decentralized market economies tend to generate an inefficient balance between the "supply" of environmental goods and services (that is, the levels of environmental quality) and the supply of other goods and services.

Inefficient market outcomes suggest a role for the public sector. In principle, government environmental policies can provide the missing markets or improve the functioning of existing ones. In practice, however, government agencies face daunting challenges in the environmental arena. It is exceptionally difficult to determine, or even approximate, the efficient degree of environmental protection. This requires information about the value that the public attaches to environmental improvement. Because of the public goods nature of environmental amenities, such values are not easily identified. Moreover, determining the appropriate form of government intervention is a difficult enterprise. Pigou's classic contribution showed that taxes could be employed to account for environmental externalities. However, in realistic policy settings, where other (non-environmental) distortions are present, where information about benefits and costs is incomplete, and where distributional concerns and political constraints must be considered along with the efficiency outcomes, the choice among instruments for environmental protection becomes more complicated. In these circumstances it may no longer be optimal to introduce taxes along Pigovian lines -- or even to introduce taxes at all -- in order to protect the environment.

In this chapter we examine government policy alternatives for protecting the environment. We pay considerable attention to how taxes can be employed to achieve this goal. However, we will also examine alternatives to taxes, such as emissions quotas and performance standards, and compare these alternatives with taxes along efficiency and other dimensions.

Traditionally, analyses of environmental taxes and other regulations have been partial equilibrium in nature. Such analyses ignore two channels that significantly influence the impacts of environmental policies. First, they disregard the budgetary impacts of environmental policies and the extent to which governments need to rely on other, distortionary taxes for revenue. Second, they ignore interactions between environmental policy initiatives and the functioning of markets outside of the market that is targeted by the environmental regulation. In particular, they disregard how the costs of environmental policies are influenced by pre-existing distortions in "other" markets, including prior distortions caused by the tax system. The analyses described in this chapter indicate that these general equilibrium considerations have first-order importance. Indeed, some of the most important impacts of environmental policies take place outside of the market that is targeted for regulation.

Sandmo (1975) was the first to consider general equilibrium interactions in his important contribution analyzing optimal commodity taxation when one of the commodities involves an externality. More recent work shows that such interactions have economic implications that extend beyond those revealed in Sandmo's seminal analysis. The recent work emphasizes two fundamental ideas. First, environmental taxes and other forms of environmental regulations act as implicit taxes on factors of production because they raise the costs and prices of produced goods relative to the prices of factors, thereby lowering real factor returns. Second, these implicit taxes typically compound the distortions posed by pre-existing explicit factor taxes.

These two notions have profound implications for a number of issues in environmental regulation -- for the costs of revenue-neutral environmental tax reforms, for the optimal environmental tax rate, and for the choice between environmental taxes and other instruments for environmental protection. They imply that, in many circumstances, the gross costs[1] of environmental tax reforms are higher in a second-best world than in a first-best setting. (This does not remove the efficiency rationale for environmental taxes: the analyses presented in this chapter show that environmental taxes still can produce significant net efficiency gains, once environment-related benefits are taken into account. But prior distortionary taxes tend to imply higher gross costs than otherwise would be the case.) These two notions also imply that under plausible circumstances the optimal rate of tax on environmentally harmful activities will be less than the rate endorsed by Pigou -- that is, less than the marginal external damages. In addition, they imply that pollution taxes may have a significant potential advantage over (non-auctioned) pollution quotas because only the former raise revenue that can finance cuts in pre-existing distortionary taxes, thereby avoiding some of the efficiency costs that such prior taxes generate.

We explore these issues in detail in the rest of this chapter, which is organized as follows. Section 2 examines the optimal level of environmental taxes, both in a first-best setting and in a second-best setting where the government needs to impose distortionary taxes to generate revenues. Section 3 analyzes the impacts of environmental tax reforms, concentrating on revenue-neutral policies in which revenues from environmental taxes are used to finance cuts in ordinary, distortionary taxes. Here we consider the welfare implications of such policies, decomposing the impacts into environment-related benefits and non-environment-related costs. An issue of particular interest is the circumstances under which the "recycling" of revenues from environmental taxes through cuts in distortionary taxes can eliminate the non-environmental costs of such reforms. Whether green tax reforms can be introduced at zero cost has become a controversial issue in recent years. Section 4 compares environmental taxes with other policy instruments -- emissions quotas, performance standards, and subsidies to abatement -- in a second-best setting with pre-existing distortionary taxes. We

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[1] Gross costs are the costs before netting out the benefits associated with the policy-related improvement in environmental quality.

first compare these instruments assuming that policy makers face no uncertainties as to firms' abatement costs or the benefits of environmental improvement. We then expand the analysis to consider how uncertainty on the part of regulators and associated monitoring and enforcement costs affect the choice among alternative policy instruments. Section 5 concentrates on the trade-offs between efficiency and distribution that arise in a second-best setting. Section 6 offers conclusions.

2 Optimal environmental taxation

This section employs simple general equilibrium models to examine the optimal rate of tax on environmentally damaging activities. We first pose this issue as a planner's problem, and then consider how the government can produce the optimum in a decentralized market economy. We will consider these issues both in a first-best setting (devoid of pre-existing distortions) and in a more realistic setting involving other, distortionary taxes.

2.1 The basic model

Consider a representative household that derives utility $U = u(C,D,V,G,Q)$ from private goods -- namely, a "clean" private good (C), a "dirty" private good (D), and leisure (V) -- and from two public goods -- non-environmental (i.e., produced) public goods (G) and the quality of the environment (Q). We apply the label "dirty" to those goods or services whose production or consumption directly contributes to deterioration of the environment. Let production be described by the constant-returns-to-scale production function $F(NL,X,R)$ for which the inputs are aggregate labor (the product of the number of households, N, and per capita labor supply, L), a "clean" intermediate good (X), and a "dirty" intermediate good (R). Gross output can be used to provide (non-environmental) public goods, to meet demands for clean or dirty intermediate inputs, or to meet household demands for clean or dirty consumption goods. Thus, the material balance condition for the economy is

$$F(NL,X,R) = G+X+R+NC+ND \tag{1}$$

We have normalized units so that the constant rates of transformation between the five produced commodities are unity.

Environmental quality, Q, deteriorates with the quantity used of dirty intermediate and dirty consumption goods:

$$Q=q(R,ND), \qquad q_R, q_{ND} < 0 \tag{2}$$

Throughout, a subscript to a function will denote a partial derivative with respect to a given variable. Each household has one unit of time available that can be used for either work (L) or leisure (V):

$$V + L = 1 \tag{3}$$

2.2 The first-best solution in a command economy

The first-best outcome can be attained in a command economy. The social planner's objective is to maximize the utility of the representative household subject to (1), (2), and (3). This constrained optimization problem yields the following first-order conditions:

$$u_C = u_V/F_{NL} = Nu_G = u_D + Nu_Q q_{ND} \tag{4}$$

$$F_X = 1 = F_R + Nu_Q q_R / u_C \tag{5}$$

Expression (4) indicates that u_V / u_C, the marginal rate of substitution between leisure and clean consumption, must equal the economy's marginal rate of transformation, which in this model is F_{NL}, the marginal product of labor. In addition, the marginal utility of *C* should equal the marginal social value of *G* and of *D*. The marginal social value of the (nonrival) public good *G* is the incremental utility, summed over the *N* households. The marginal social value of *D* is u_D plus a (negative) term correcting for the environmental damages associated with producing or consuming *D* (note $q_{ND} < 0$). The latter term is the sum of individual environmental damages over the households, reflecting the nonrival nature of environmental quality. Thus, the incremental social value of *D* involves both private-good and public-good elements, since greater provision and use of *D* affects utility not only through its private consumption but also by reducing *Q*, the "environmental public good."

Expression (5) governs the optimal use of intermediate inputs. At the optimum, the marginal product of the clean intermediate input *X* equals the marginal rate of transformation (i.e., unity). The marginal product of the dirty intermediate input *R*, in contrast, exceeds the marginal rate of transformation by an amount representing the marginal environmental damage associated with using this input.

2.3 First-best outcome in a decentralized market economy: The "Pigovian result"

If the government has access to a sufficient set of policy instruments, it can achieve the first-best outcome in a decentralized market economy. To obtain this outcome, the government must be able not only to impose taxes on goods but also to employ lump-sum taxes or subsidies. With these instruments at its disposal, the government's budget constraint amounts to:

$$T + G = t_X X + t_R R + t_C NC + t_D ND + t_L wNL \tag{6}$$

where *w* is the after-tax wage and t_i $(i = X,R,C,D,L)$ represents the tax rates on the transactions of *i*. The labor tax rate t_L is an ad-valorem tax on wages. *T* represents lump-sum transfers provided by the government to each household.

In a decentralized economy, households face the following budget constraint:

$$(1+t_C)C+(1+t_D)D=wL+T \tag{7}$$

Private agents ignore environmental externalities when they implement their decentralized decisions. Accordingly, maximizing utility subject to the budget constraint (7) involves the following optimality conditions for the representative household:

$$u_C=u_V[(1+t_C)/w]=u_D[(1+t_C)/(1+t_D)] \tag{8}$$

Under perfect competition, firms maximize profits by equating the marginal product of each factor to its user cost:

$$F_{NL}(1,X/NL,R/NL)=w_p \tag{9}$$
$$F_X(1,X/NL,R/NL)=1+t_X \tag{10}$$
$$F_R(1,X/NL,R/NL)=1+t_R \tag{11}$$

where w_p equals $w(1+t_L)$ and represents the producer wage.

The government can establish the first-best outcome by levying taxes on the dirty intermediate and dirty consumption good. The first-best production condition (5) can be obtained if the government imposes a tax on the dirty intermediate good at a rate given by:

$$t_R=t_R^P\equiv Nu_Q(-q_R)/u_C \tag{12}$$

The first-best optimal value of the tax rate t_R is equal to the social cost associated with the environmental harm from an increment in R. We define t_R^P as this marginal environmental harm. t_R^P is often referred to as the "Pigovian" tax rate, after Pigou (1938), who articulated the idea that taxes could be used to generate an efficient outcome by "internalizing" environmental costs. Without government intervention, there is a wedge between marginal social and private cost. Decentralized firms consider only private cost (that is, the market prices of inputs), ignoring the environmental component of the social cost associated with the use of the dirty intermediate input. The Pigovian tax serves to eliminate the cost wedge, raising private cost to a level that corresponds to social cost. In this way, the Pigovian tax internalizes the social cost from pollution.

Equation (12) can be interpreted as the condition for the optimal provision of the environmental public good. Note that this condition resembles the well-known "Samuelson condition" (see Samuelson (1954)) for the optimal provision of the (non-environmental) public good G. The Samuelson condition is implied by (4) and can be written as:

$$1=Nu_G/u_C \tag{13}$$

Expression (12) equates marginal social costs and (environmental) benefits related to a reduction in R, while equation (13) equates marginal social costs and benefits related to an increase in G. In both (12) and (13) the right-hand side expresses the benefits in terms of the sum, over the N households, of the marginal rates of substitution between the public good involved and clean private goods. The left-hand side of (13) represents the social cost of a one-unit increase in G. This is the marginal rate of transformation between private and produced public goods (i.e., unity). The left-hand side of (12) stands for the social cost of improving environmental quality through a one-unit reduction in the use of R. This social cost corresponds to the loss of tax revenue associated with this one-unit reduction; hence this cost is simply the tax rate, t_R. Thus, the optimal value for t_R is the marginal social benefit from the environmental improvement stemming from a one-unit reduction in R.

The government can induce households to make efficient decisions by having the three tax rates t_C, t_D, and t_L meet the following two conditions:

$$(1+t_C)(1+t_L)=1 \tag{14}$$

$$(1+t_D)=(1-Nu_Q q_{ND}/u_C)(1+t_C) \tag{15}$$

As in other optimal tax models with constant-returns-to-scale production functions, the government has one degree of freedom in setting these tax rates. This occurs because the household budget constraint (7) is unaffected if both expenditures (the left-hand side) and income (the right-hand side) are multiplied by the same factor. With one degree of freedom, we can choose to normalize the tax system by setting one of the tax rates to zero and solving for the other two.[2] In the rest of this chapter we normalize the tax system by selecting the clean consumption good as the untaxed commodity (i.e. $t_C = 0$). Under our normalization, t_D isolates the differential taxation of the dirty consumption good. This is the taxation over and above the implicit taxation of all consumption from the labor tax, which is equivalent to a uniform tax on both consumption commodities. When one refers to pollution taxes, one typically has this tax differentiation in mind.

The government can produce the first-best outcome by refraining from taxing labor and by setting the tax on dirty consumption equal to the Pigovian tax:

$$t_D = t_D^P \equiv \frac{Nu_Q(-q_{ND})}{u_C} \tag{16}$$

The first-best solution also requires determining the optimal quantity of G and the optimal level of lump-sum transfers T. The Samuelson rule (13) determines the optimal quantity of G. Optimal lump-sum transfers are given residually from the government budget constraint (6).

2.4 When lump-sum taxes are not available: the second-best optimum

In practice, lump-sum taxes and subsidies typically are not available because of political and administrative constraints. Under such circumstances, the government's problem

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[2] This degree of freedom implies that the first-best equilibrium can be achieved, in principle, even if administrative or political constraints prevent the government from introducing the tax t_D on dirty consumption. In this event, the first-best can be achieved through the combination of a subsidy to clean goods equal to $t_C = N(u_Q\, q_{ND}/u_C)/[1-(Nu_Q\, q_{ND}/u_C)]$ and a labor tax equal to $t_L = -N(u_Q\, q_{ND}/u_C)$. Fullerton (1997) points out that this solution -- a labor tax plus a subsidy on clean consumption -- resembles a deposit-refund system.

is to select values for its five fiscal instruments (t_L, t_D, t_X, t_R, and G)[3] in order to optimize household utility subject to the government budget constraint and decentralized optimizing decisions by firms and households. The Lagrangian function is therefore:

$$NW((1+t_D),w,G,q(R,ND)) \; + \; \mu\left[t_L wNL \; + \; t_D ND \; + \; t_X X \; + \; t_R R - G\right] \tag{17}$$

Here W represents indirect utility and μ denotes the marginal disutility of raising one additional unit of public revenue. The optimization problem yields the following optimal tax rates on intermediate inputs (see Bovenberg and Goulder (1996)):

$$t_X = 0 \tag{18}$$

$$t_R = \left[\frac{Nu_Q(-q_R)}{u_C}\right]\frac{1}{\eta} \tag{19}$$

where η is defined as μ/λ, with λ representing the marginal utility of private income. Thus, η is the ratio of the shadow cost of raising government revenue to the shadow value of an incremental increase in private income. This is usually referred to as the marginal cost of public funds (MCPF).[4]

In the rest of this sub-section we assume that environmental quality is weakly separable from other goods in utility; that is, $U = u(P(C,D,V,G), Q)$. The more general case is explored in sub-section 2.5.1. With this utility function, the first-order conditions with respect to t_L, t_D, and G yield the following expressions:

$$(\lambda-\mu)L \; + \; \mu\left[(t_D - t_D^Q)\frac{\partial D}{\partial w} + t_L w\frac{\partial L}{\partial w}\right] \; = \; 0 \tag{20}$$

$$(\lambda-\mu)D \; - \; \mu\left[(t_D - t_D^Q)\frac{\partial D}{\partial t_D} + t_L w\frac{\partial L}{\partial t_D}\right] \; = \; 0 \tag{21}$$

$$N\left(\frac{u_G}{u_C}\right) \; = \; \eta\left[1 - (t_D - t_D^Q)N\left(\frac{\partial D}{\partial G}\right) - t_L Nw\left(\frac{\partial L}{\partial G}\right)\right]. \tag{22}$$

where

$$t_D^Q \equiv \left[\frac{Nu_Q(-q_{ND})}{u_C}\right]\frac{1}{\eta} \tag{23}$$

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[3] Recall that we normalize the tax system by setting the tax rate on consumption equal to zero.

[4] In the presence of distortionary taxes, the MCPF depends on the choice of the untaxed good (see Boadway and Keen (1993)). By selecting clean consumption as the untaxed good, we measure the MCPF in terms of clean consumption.

We shall refer to these expressions in the discussion of optimal taxes below.

2.4.1 Optimal taxes on intermediate inputs

Expression (18) reveals that the clean intermediate input should not be subject to any tax. This is an application of the well-known optimality of production efficiency derived by Diamond and Mirrlees (1971). They demonstrated that, if production exhibits constant-returns-to-scale, an optimal tax system should not distort production, that is, should not directly alter the relative prices of intermediate inputs.[5] Intuitively, consumer taxes can yield the same effects on relative prices as a tax on intermediate inputs. Thus a tax on intermediate inputs does not provide any benefits relative to consumer taxes in terms of changes in relative consumer prices. At the same time, a tax on intermediate inputs introduces additional inefficiencies relative to optimal consumer taxes because it distorts relative input prices. Accordingly, consumer taxes dominate taxes on (clean) intermediate goods.

Expression (19) indicates that the tax on the dirty intermediate input t_R should be positive as long as households value environmental quality (i.e., $u_Q>0$). The term between square brackets on the right-hand-side of (19) corresponds to the Pigovian tax (see (12)). The Pigovian tax is optimal only if the marginal cost of public funds, η, equals unity. A unitary MCPF means that obtaining a dollar of public revenue involves, in general equilibrium, a one-dollar sacrifice of private income. In a second-best world without lump-sum taxation, the MCPF typically differs from one. Hence the MCPF term in (19) indicates how second-best considerations affect optimal environmental taxation. In particular, the higher the MCPF, the smaller the optimal environmental tax, *ceteris paribus*.

The optimal environmental tax is inversely related to the MCPF for the following reason. The government employs the tax system to simultaneously accomplish two goals: raising revenues and internalizing environmental externalities. Environmental taxes directly affect both objectives. If raising public revenues becomes more costly, as indicated by a higher MCPF, the balance between the revenue and environmental-quality objectives is best struck at a lower rate for the environmental tax. Specifically, the optimal pollution tax must balance the marginal social benefit from one unit of pollution reduction (the term in brackets on the right-hand side of (19)) against the gross marginal social cost of a one-unit pollution reduction. The latter is the social cost associated with the reduction in pollution-tax revenue from a one-unit reduction in pollution. This, in turn, is equal to the MCPF times the pollution tax rate. Dividing these marginal benefits and costs by the MCPF gives (19). Therefore, the higher the social cost of raising revenue, the higher the marginal social benefits from pollution abatement have to be to justify a given environmental tax. Thus, high estimates for the efficiency costs of existing taxes imply lower values for the optimal environmental tax rate.

To illustrate the analogy of environmental quality with other public consumption goods, we write (22) for the case of a produced public good G that is weakly separable from private goods:

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[5] Under decreasing returns to scale, production efficiency continues to be optimal so long as a 100 percent profit tax is available.

$$\frac{1}{\eta}\left(\frac{Nu_G}{u_C}\right) = 1 \tag{24}$$

The right-hand side of (24) is the marginal rate of transformation between private and public goods. The MCPF drives a wedge between this rate of transformation and the sum of the marginal rates of substitution. A higher MCPF means that higher marginal benefits from public consumption are necessary to offset the higher efficiency cost of financing this public good. This is analogous to the effect of the MCPF on the required marginal benefits from the environmental public good (see (19)).

2.4.2 Optimal taxes on consumer goods

To explore the optimal taxes on labor and dirty consumption (i.e., t_L and t_D), we first derive "Ramsey tax rules." These rules yield the least distortionary way of financing public spending if environmental externalities are absent (i.e., when $u_Q=0$). We then turn to the more general policy problem in which taxes face the dual task of not only generating revenues to finance public spending but also internalizing environmental externalities.

Ramsey tax schemes

Without environmental externalities (i.e., with $t_D^Q = 0$), (20) and (21) can be solved to yield (see Bovenberg and van der Ploeg (1994b)):

$$\left(\frac{t_D}{1+t_D}\right) = \left(\frac{\varepsilon_{CL}-\varepsilon_{DL}}{\varepsilon_{CD}-\varepsilon_{DD}}\right) t_L. \tag{25}$$

where ε_{ik} stands for the compensated elasticity of demand for commodity i with respect to the price of commodity k. Optimal government policy thus involves both a tax on labor (which is equivalent to an equal tax on both consumption goods) and a tax or subsidy on the "dirty" consumption good.[6] The combination prescribed by (25) is equivalent to a set of taxes on the two consumption goods, with a different tax rate applying to the dirty consumption good. In the absence of externalities, the tax on the dirty consumption good is a Ramsey tax; it is motivated purely by non-environmental considerations. The sign of this tax depends on the cross-elasticities with leisure. In particular, the tax rate is positive if $\varepsilon_{CL}>\varepsilon_{DL}$, that is, if the clean consumption good is a better substitute for leisure than the dirty consumption good is. In that case, the dirty consumption good is a relative complement to leisure. Thus it is optimal for the government to levy (via the labor tax) a uniform tax on clean and dirty consumption goods,

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[6] We retain the label "dirty" despite the assumption here that there are no environmental externalities.

and to supplement this with a tax on the good that is most complementary to leisure.[7]

Integrating Ramsey and Pigou

We now turn to the case with environmental externalities. In the presence of externalities, t_D^Q is non-zero, and thus in (20)-(22) the term $(t_D - t_D^Q)$ replaces what was simply t_D when externalities were absent. Now the tax t_D has both a Ramsey (or distortionary) component and an environmental (or non-distortionary) component. The term $(t_D - t_D^Q)$ is the Ramsey component. It follows that the optimal tax rate is the sum of the Ramsey and externality-correcting terms:[8]

$$\frac{t_D}{1 + t_D} = \left(\frac{\varepsilon_{CL} - \varepsilon_{DL}}{\varepsilon_{CD} - \varepsilon_{DD}} \right) t_L + \frac{t_D^Q}{1 + t_D} \tag{26}$$

The first part of the optimal pollution tax on consumption (i.e., the first term on the right-hand side of (26)) is the Ramsey component of the tax on polluting consumption. Together with the optimal labor tax, the optimal level of the Ramsey component is determined on the basis of the familiar Ramsey formulas for raising revenues with the lowest costs to private incomes (see (20) and (21)). This component measures the social contribution (in terms of government revenues) of additional demand for the dirty consumption good as the difference between a positive and a negative contribution. On the one hand, consumption of the dirty consumption good boosts the tax base and thus facilitates the financing of ordinary public goods. On the other hand, it damages the environment, thereby reducing the supply of the environmental public good.

The second part of the optimal pollution tax is t_D^Q (expression (23)). This part corrects for the environmental externality. The expression for t_D^Q looks very similar to the expression for the optimal tax t_R on the dirty intermediate input (see (19)). It is the Pigovian tax divided by the MCPF. Using (20), we can write the MCPF as:

$$\eta = \left(\frac{1}{1 - (t_D - t_D^Q)(D/wL)\varepsilon_{DL}^U - t_L \varepsilon_{LL}^U} \right) \tag{27}$$

where ε_{ik}^U stands for the uncompensated elasticity of demand for commodity *i* with respect to

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[7] See also Corlett and Hague (1953), and Diamond and Mirrlees (1971, p. 263) for an analogous expression to (25) and a related discussion.

[8] See Sandmo (1975). Ng (1980) explores the sign of the optimal pollution tax. He finds that, in the presence of environmental externalities (i.e. $u_Q > 0$), the pollution tax is typically positive. However, if the revenue requirement is small and falls short of the revenues from the Pigovian tax, the optimal pollution tax may actually be negative. In this counterintuitive case, a lower consumption wage must be very effective in reducing dirty consumption, compared to a higher consumption price for dirty consumption. Hence, the combination of a wage tax and a subsidy on dirty consumption reduces pollution.

the price of commodity k. The MCPF exceeds unity if financing additional public spending erodes the base of existing Ramsey (or distortionary) taxes.[9]

A special case

To generate further insights, we derive results for the particular case where the utility function is homothetic and clean and dirty consumption are weakly separable from leisure. This implies that the compensated elasticities ε_{CL} and ε_{DL} are identical. In this case the Ramsey tax term in (26) is zero and the pollution tax reduces to the externality-correction term (i.e., $t_D = t_D^Q$). In this special case, the MCPF can be written as (from (27) with $t_D = t_D^Q$):

$$\eta = \left[1 - t_L \varepsilon_{LL}^U\right]^{-1} \tag{28}$$

The MCPF thus exceeds unity if, first, the uncompensated wage elasticity of labor supply, ε_{LL}^U, is positive and, second, the distortionary tax on labor, t_L, is positive. The latter condition holds when Pigovian taxes are not sufficient to finance the optimal level of public consumption. These results are consistent with the literature on the MCPF surveyed in Ballard and Fullerton (1992). In the case where utility from public consumption is separable from consumer's choice on leisure and consumption, this literature finds that distortionary labor taxes raise the marginal costs of public spending above unity if the uncompensated wage elasticity of labor supply is positive. The same condition on this uncompensated elasticity determines whether distortionary labor taxes raise the marginal cost of the environmental public good above its social benefit (see (19), (23) and (28)).

Optimal level of public consumption

The adjusted Samuelson rule (22) indicates that there are two reasons why the marginal rate of transformation between private and public goods differs from the corresponding sum of the marginal rates of substitution. The first is that the marginal cost of public funds (η) may differ from unity. As indicated in expression (27), raising additional government revenue may cause an erosion of the base of pre-existing distortionary taxes, thereby imposing costs over and above the revenue collected from the new tax. In such circumstances the marginal cost of public funds exceeds unity.

The second reason for the divergence between the marginal rates of transformation and substitution is that, if public goods are complementary to taxed commodities ($t_D \partial D/\partial G > 0$ or $t_L \partial L/\partial G > 0$), raising public spending alleviates the excess burden of distortionary taxation by boosting the consumption of taxed commodities. For example, the construction of public

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[9] If taxed commodities are inferior, the MCPF may actually fall short of unity. The reason is that the negative income effect associated with a higher tax level may raise the consumption of taxed commodities. The MCPF is smaller than unity if, in the terminology of Atkinson and Stern (1974), the "revenue effect" of a tax increase boosts the demand for taxed commodities and is large enough to more than offset the "distortionary effect" of tax increases. See also Section 5.1 of the chapter by Auerbach and Hines in this volume, and Ballard and Fullerton (1992).

highways between suburbs and cities may induce some agents to work more and thus pay more labor tax. Public libraries, in contrast, may encourage private agents to enjoy more leisure, thereby eroding the base of the labor tax. For this reason the social cost of funds devoted to libraries can exceed the cost of the same amount of funds allocated to highways.

2.5 Some complications to the second-best problem

2.5.1 The environment as a non-separable consumption good

Thus far, we have assumed that environmental quality is separable in utility from consumption and leisure. If this is not the case, environmental quality directly affects private decisions and the optimal non-distortionary component of the tax on dirty consumption is given by (see Bovenberg and van der Ploeg (1994b)):

$$t_D^Q = \frac{N(-q_{ND})}{u_C \eta}\left(\frac{u_Q + \mu\left[t_D \frac{\partial D}{\partial Q} + w t_L \frac{\partial L}{\partial Q}\right]}{1 - N\frac{\partial D}{\partial Q} q_{ND}}\right). \qquad (29)$$

Equation (23) showed that when the MCPF differs from unity, the optimal environmental tax t_D^Q differs from the sum of the marginal rates of substitution. When the environment is non-separable in utility, an additional factor contributes to a difference between t_D^Q and the sum of marginal rates of substitution. In particular, if the environment is a gross complement to leisure (i.e., if $\partial L/\partial Q<0$), then improvements in environmental quality come at a higher cost because the environmental tax leads to a greater reduction in the labor tax base. (See the numerator of the far-right term in (29)). In this case, the social value of environmental protection is reduced and the optimal environmental tax falls.[10]

The denominator of the term in large brackets in (29) accounts for environmental quality's "feedback effect" on the demand for dirty goods. In particular, if an improvement in environmental quality raises the demand for dirty goods (i.e. $\partial D/\partial Q>0$), the net benefit from increased environmental quality is reduced. Traffic congestion illustrates this case. Less traffic congestion encourages more traffic. Accordingly, while higher taxes on gasoline reduce congestion, the overall impact of these taxes on congestion is mitigated by the feedback of reduced congestion on traffic.[11]

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[10] These findings parallel results obtained in the literature on the optimal supply of ordinary (i.e., non-environmental) public goods in the presence of distortionary taxation. In that literature, the way a particular public good enters utility affects the marginal costs of financing such a public good. See Wildasin (1984) as well as subsection 2.4.2 on the optimal level of public consumption.

[11] Cornes (1980) and Sandmo (1980) show that for the aggregate demand function to be stable, the feedback effect cannot be too large in absolute value. This stability condition ensures that the denominator of the last term on the right-hand side of (29) is positive.

2.5.2 The environment as a public input to production

The foregoing analysis treats environment quality as a public consumption good. Amenities like clean air, relative quiet, and greater visibility fall into this category. However, environmental quality also functions as a public input into production. For example, since certain types of agricultural production benefit from a cooler climate, slowing down global warming can avoid some losses of agricultural productivity. Furthermore, reduced air pollution is likely to improve health and thereby boost labor productivity. To model the impact of the environment on production, we specify production as follows:

$$Y = a(Q)F(NL, X, R) \ , \qquad a'(Q) > 0; a''(Q) \leq 0 \tag{30}$$

With this formulation, the expression for the optimal tax rate on dirty inputs becomes (see Bovenberg and van der Ploeg (1994a)):

$$t_R = [\frac{Nu_Q(-q_R)}{u_C}]\frac{1}{\eta} + (-q_R)a'(Q)F \tag{31}$$

The first term on the right-hand side matches the one that applies when the environment is only a consumption good (see expression (19)). This term represents the consumption externality. The second term on the right-hand side represents the adverse effect of pollution on productivity. In contrast with the first term, the second term does not involve the marginal cost of public funds.[12]

2.5.3 Environmental damages from accumulated pollution stocks

Thus far we have associated environmental quality with the current level of output of dirty goods. For certain types of pollution, where the flow of pollution does not contribute to a durable stock, environmental quality can be viewed as directly connected to the pollution flow. Noise pollution provides a pertinent example. But in most circumstances, environmental quality or damage is more closely connected to the stock of pollution, and in such cases the relationship between pollution emissions and environmental quality is inherently dynamic. These dynamic connections imply a more complex formulation of the optimal environmental tax rate, although this formulation still echoes the principles that apply when a simpler pollution-quality relationship is assumed.

Here we consider the optimal environmental tax rate in a model that relates environmental quality (or damages) to pollution concentrations. Our example is the climate-

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[12] Environmental regulations discourage labor supply by implicitly taxing labor, that is, raising the costs of consumption goods relative to leisure. At the same time, when the environment is a productive input such regulations promote greater labor supply by enhancing labor productivity (i.e., avoiding damages to production). As shown by Williams (1997), these two effects cancel out at the optimum, which implies that MCPF need not be considered in determining the contribution of the production-side effect to the optimal tax rate. See also Eskeland (2000). This result reaffirms Diamond and Mirrlees' (1971) finding that production efficiency is optimal.

related economic damage associated with atmospheric accumulation of carbon dioxide (CO_2). The problem at hand is to obtain the optimal profile of taxes on CO_2 -- carbon taxes -- to maximize environmental gains net of abatement costs induced by the tax. The first analytical studies of this problem appear to be Nordhaus (1980, 1982).[13] The problem can be viewed as maximizing the discounted stream of utility from consumption:

$$\max_{\{c(t)\}} U = \int_0^\infty \exp(-rt)\, u(c(t))\, dt \tag{32}$$

where $c(t)$ denotes consumption at time t and r is the utility discount rate. (c should be distinguished from the clean consumption good C, which appeared earlier.) At each point in time, consumption depends on $e(t)$, current CO_2 emissions, and on $S(t)$, the current atmospheric concentration of CO_2:

$$c(t) = f[e(t)] - h[S(t)] \tag{33}$$

The function f indicates that abating emissions involves economic costs that translate (other things equal) into a loss of consumption; the function h indicates that increases in the stock of CO_2 affect climate patterns and thereby reduce consumption. The evolution of the CO_2 stock is given by:

$$\dot{S}(t) = \alpha e(t) - \delta S(t) \tag{34}$$

where α and δ are parameters. The solution to this problem (see Nordhaus (1982)) is:

$$\begin{aligned} -\Omega(t) &= f'[e(t)] \\ &= \frac{\int_t^\infty \alpha e^{-(r+\delta)} u'[c(s)]\, h'[S(s)]\, ds}{\nu(t)} \end{aligned} \tag{35}$$

where $\Omega(t)$ (a negative number) is the shadow value of the stock of CO_2 at time t, and $\nu(t)$ is the shadow value of consumption at time t. Expression (35) indicates that, at the optimum, the CO_2 shadow price is equal to both the marginal cost of reducing emissions (the expression to the right of the first equality sign) and the discounted cost of the change in atmospheric

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[13] For other analytical treatments, see Sinclair (1994), Ulph and Ulph (1994), Peck and Wan (1996), and Goulder and Mathai (2000). Nordhaus (1994), Peck and Teisberg (1994), Manne and Richels (1992), Farzin and Tahvonnen(1996) and several other authors have employed simulation models to solve numerically for optimal carbon tax profiles.

concentration stemming from a marginal increase in emissions (the expression to the right of the second equality sign). The latter is equivalent to the marginal benefit from incremental emissions reductions. Thus, at the optimum, marginal costs and benefits of emissions reductions are equated. If the government sets the carbon tax equal to marginal benefits from incremental emissions reductions (or marginal damages from incremental emissions), it will satisfy the second condition in (35). If producers are competitive, they will equate marginal costs of abatement to the carbon tax, thereby satisfying the first line in (35). Thus, the optimal carbon tax profile involves setting carbon taxes equal to the negative of $\Omega(t)$ at all periods of time.

The negative of the shadow price of carbon concentrations (or optimal carbon tax) evolves according to:

$$-\dot{\Omega}(t) = (r+\delta)[-\Omega(t)] - h'(S(t)) \tag{36}$$

Other things equal, a higher discount rate r necessitates a faster increase in the optimal carbon tax. Higher discount rates reduce the relative price of future abatement costs relative to current abatement costs. Hence more future abatement becomes justified, and the carbon tax must rise more quickly to encourage relatively more abatement (less emissions) in the future. A higher value for the "removal" rate δ implies a faster increase in the carbon tax. Higher values for δ mean that carbon decays more quickly in the atmosphere. If δ is positive, a one-unit increase in emissions in period t accompanied by a one-unit reduction in emissions in some future period $t + s$ would imply a greater overall amount of dispersion and thus a lower carbon concentration S in all periods after $t + s$. Hence there is a value to postponing emissions reductions. This value is larger, the higher is δ. Hence a larger value of δ justifies greater relative abatement in the future and thus a more steeply rising carbon tax.

The right-hand term in (36) indicates a relationship between the slope of the damage function h and the growth of the optimal carbon tax. The more that $h(S)$ is increasing in S, the greater the value to postponing emissions of CO_2, since postponed emissions delay the augmentation of the stock and thus imply a smaller present discounted value of damages. Thus larger values for h' imply a more slowly rising carbon tax profile, *ceteris paribus.*

This analysis of optimal tax rates disregarded second-best considerations. Such considerations do not fundamentally alter the results. The essential difference is that in a second-best setting the optimal carbon tax should equal marginal damages divided by the marginal cost of public funds, rather than simply the marginal damages. The optimal carbon tax still exhibits a profile similar to that given by (36), assuming that the marginal cost of public funds does not change much through time. Second-best considerations imply a lower path for the optimal carbon tax, but the shape of the path need not differ much from that suggested by (36).

2.6 Empirical issues and assessments

2.6.1 Marginal environmental damages

The foregoing analysis indicates that optimal pollution tax rates should reflect two main elements: the marginal environmental damages from pollution, and the MCPF. The model presented above did not reveal explicitly the complex connections between the use of certain inputs or products associated with pollution ("dirty" intermediate inputs or consumption goods) and the ultimate damages to the environment. Usually, several connections are involved: (1) from the use of an input or product to emissions of given pollutants, (2) from emissions of pollutants to concentrations, and (3) from concentrations to environmental damages.

These connections suggest that it may be more effective, other things equal, to impose taxes on emissions of specific pollutants rather than on given inputs or products associated with pollution, since emissions are more closely linked to the ultimate environmental damages. However, it may be more costly to monitor emissions than the use of inputs or products. These considerations are discussed in more detail in Section 4.[14]

The second and third connections above imply that the marginal damages may not be a simple function of emissions. If the concentration-damage relationship is nonlinear, the impact of an additional unit of emissions of a given pollutant depends on the concentration of the pollutant. Moreover, in some cases pollutants interact, so that environmental damages depend on the mix of pollutants rather than individual concentrations. For example, the extent to which atmospheric concentrations of nitric oxides or volatile organic compounds contribute to respiratory problems depends on the mix of these pollutants (specifically, the amount of ground-level ozone produced by the mix) rather than the individual concentrations. Finally, the relationship between emissions and concentrations (connection (2)) can depend on geographical conditions and meteorological factors (prevailing winds, etc.).

All of this indicates a great deal of complexity and heterogeneity in the relationship between emissions of given pollutants and the marginal environmental damages. Any estimates of *average* damages per ton of pollutant therefore will mask a great deal of spatial and temporal variation. With this important caveat in mind, we present estimates in Table 1 of average marginal damages for four of the six "criteria" air pollutants subject to Federal regulation in the U.S. under the 1990 Clean Air Act Amendments:

[Table 1 here]

2.6.2 Estimates of the MCPF

The other key element in determining optimal tax rates is the MCPF. Optimal tax rates

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[14] In some cases, emissions are strictly proportional to the use of a given input, and in this case there is little sacrifice involved in treating the use of the input as a proxy for emissions. The clearest example of this is the relationship between the use of inputs of fossil fuels and emissions of carbon dioxide. For virtually all uses of fossil fuels or refined fossil-fuel products, the release of CO_2 into the atmosphere is strictly proportional to the carbon content of the fossil fuel or the refined product. Thus, a carbon tax is an excellent proxy for a tax on CO_2 emissions. Such proportionality, however, tends to be the exception rather than the rule.

depart from the Pigovian rates (that is, from the marginal environmental damages) to the extent that the MCPF differs from unity. A condition for an optimal tax system is equality in the MCPF for all taxes that generate government revenue. However, empirical estimates of the MCPF are obtained from tax systems that are generally suboptimal from an efficiency point of view. As a result, the estimates of the MCPF span a wide range, not only because studies employ different data and methodologies, but also because they reveal significant variations in the MCPF depending on the particular source of revenue involved. Table 2 provides a sampling of MCPF estimates:

[Table 2 here]

These results suggest that for the U.S. environmental tax rates should be about 20-50 percent below the marginal environmental damages. The Hannson-Stuart results indicate that Swedish rates should be a smaller fraction of marginal damages.

2.6.3 Constrained-optimal policies: the case of the carbon tax

Bovenberg and Goulder (1996) consider these second-best issues in assessing optimal carbon taxes. Using a numerically solved intertemporal general equilibrium model of the U.S., they find that the optimal carbon tax rate tends to be approximately 20 percent below the marginal environmental damages (the central estimate of the MCPF is approximately 1.25).

They also consider a "constrained-optimal" carbon tax policy: a case where revenues from the tax are returned in lump-sum fashion rather than in the form of cuts in existing distortionary taxes (like the labor tax in the model above). In this case, the government forgoes an opportunity to avoid some of the distortionary costs imposed by existing taxes. This implies a higher schedule for the marginal costs of abatement relative to the case where revenues are returned through cuts in marginal rates:

[Figure 1 here]

The figure provides schedules for the general equilibrium gross marginal cost of abatement under different assumptions about the use of the tax revenues. Here marginal cost is a gross concept in that it abstracts from the benefits associated with environmental improvement. The intercept of the marginal cost function is strictly positive for the case where revenues are returned lump-sum, whereas it is close to zero for the case where revenues are returned through cuts in distortionary taxes.[15] In the scenario involving lump-sum recycling of the revenues, the positive intercept of this marginal cost function represents a threshold value for marginal

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[15] It is slightly positive because, according to the assumptions of the model, the U.S. tax system is suboptimal on non-environmental dimensions. In particular, capital is overtaxed relative to labor. The intercept is zero under a counterfactual benchmark where labor, capital, and other non-environmental taxes are set optimally.

environmental benefits from abatement: if marginal benefits are below this threshold, any emissions abatement (or any positive carbon tax) is efficiency-reducing. Bovenberg and Goulder's central estimate for the intercept in the constrained-optimal case is about $50 per ton, which is higher than most estimates of marginal benefits from reducing carbon dioxide emissions. Thus, failing to use revenues optimally can preclude efficiency gains from carbon taxation, and in this case a positive carbon tax is no longer efficiency-improving.[16] The use of revenues is also an important issue in the evaluation of environmental tax reforms, the subject of the next section.

3 Environmentally motivated tax reforms

This section considers reforms involving environmentally motivated taxes. Although proponents of policy reforms regard such changes as yielding improvements in economic outcomes, in contrast with the previous section the rates of environmental and other taxes examined here need not be optimal or even constrained-optimal.

Recently, environmental tax reforms have received increasing attention. One reason for this appears to be an increasing concern about environmental quality. A second and related reason is a growing recognition of options for substituting environmental taxes for other taxes as sources of revenue.[17] This latter issue is at the heart of most discussions of "green tax reform." Currently, revenues from environmental taxes represent on average about two percent of GDP and six percent of aggregate tax revenues in OECD countries (see Figure 2). Petroleum, diesel fuel and motor vehicle taxes account for most of these revenues (see Table 3). Proponents of green tax reform argue that society would benefit from increased reliance on environment related taxes.

[Figure 2 and Table 3 about here]

In examining environmental tax reforms, it will be useful to divide the welfare impacts into gross benefits and gross costs. The gross benefits are the gross welfare gains associated with environmental improvement (or the avoidance of environmental deterioration). The gross costs are the gross welfare losses (ignoring environmental effects) associated with the

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[16] The optimal carbon tax in this case is negative, assuming that the revenue cost of the negative tax is financed through lump-sum taxes. Just as a carbon tax implicitly raises factor taxes, a subsidy to carbon implicitly reduces such taxes. The implicit reduction in factor taxation yields a non-environmental efficiency improvement that more than offsets the efficiency loss associated with increased environmental damage. Of course, this policy is fairly unrealistic. If lump-sum taxes could finance a carbon subsidy, they might as well finance other aspects of government spending, making distortionary taxes unnecessary.

[17] Terkla (1984), Lee and Misiolek (1986), Ballard and Medema (1993), and Oates (1993) were among the first to analyze the potential efficiency benefits from using pollution-tax revenues to finance cuts in other, distortionary taxes. See Poterba (1993), Goulder (1994), and Oates (1995) for related discussions.

economic sacrifices necessary to achieve reductions in pollution. A tax reform is efficiency-improving if it produces positive net benefits, that is, if gross benefits exceed gross costs.

Some analysts have suggested that replacing distortionary taxes by environmental taxes involves zero or negative gross costs. If this is so, such policies yield a "double dividend" by not only improving the environment but also reducing the non-environmental costs of the tax system. The interest in the second dividend reflects the political attractiveness of "no-regrets" policies: if the second dividend materializes, then environmental improvements can be produced with no cost to the economy. The interest also reflects the desires of policy analysts to justify policy reforms despite the significant uncertainties about the size of the first, environmental dividend. In the presence of the second dividend, the burden of proof facing policy makers is much reduced: to justify the environmental tax on benefit-cost grounds, it suffices to know that environmental benefits are non-negative. In this section we analyze the economic forces that determine the prospects for a double dividend. We show that although the double dividend is possible, it is unlikely to arise except under fairly unusual circumstances. More generally, this section examines how environmental taxes interact with other, distortionary taxes, and the implications of these interactions for the efficiency impacts of environmental reforms.

3.1 Gross costs and environment-related benefits of revenue-neutral reforms

We can evaluate the double dividend using the model from section 2. Our approach will be to determine the welfare impacts of a revenue-neutral environmental tax reform, and to divide these impacts into environmental and non-environmental components. Consider the welfare effects of a revenue-neutral change in the tax mix (i.e., a change in taxes such that $dG=0$). Taking the total differential of utility, we obtain:

$$dU = u_C dC + u_D dD - u_V dL + u_Q q_R dR + N u_Q q_{ND} dD \tag{37}$$

Substituting the first-order conditions for household optimization (from (8)) into (37), we can write:

$$\frac{dU}{u_C} = dC + (1+t_D) dD - w dL + \frac{u_Q q_R dR}{u_C} + \frac{N u_Q q_{ND} dD}{u_C} \tag{38}$$

Taking the total differential of goods-market equilibrium (1) and substituting the first-order conditions for profit maximization (i.e., (9), (10), and (11)), we find:

$$N w_p dL + t_X dX + t_R dR = N dC + N dD \tag{39}$$

Using (39) to eliminate dC from (38), we arrive at:

$$\frac{dU}{u_C} = w\,t_L\,dL + \left[t_D - \frac{N u_Q(-q_{ND})}{u_C}\right]dD + \left[t_R - \frac{N u_Q(-q_R)}{u_C}\right]\frac{dR}{N} + t_X\frac{dX}{N} \tag{40}$$

Equation (40) shows the welfare impacts associated with the changes in labor supply, input demands, and consumption. The first term on the right-hand side of (40) stands for the distortionary effect in the labor market, which is regulated by the pre-existing tax on labor income. The next two terms correspond to the effects on the environmental margin. The welfare impact of a marginal increase in the demand for dirty goods amounts to the difference between a tax term, which measures the social benefits of additional tax revenue due to a wider revenue base, and the marginal social damage from pollution. When t_D and t_R are set at the Pigovian tax rates (see (16) and (12), respectively), each of the terms in the square brackets is zero: beneficial environmental effects associated with less pollution exactly offset the adverse welfare effects due to an erosion of the tax base.

We can diagnose the welfare effects of tax changes by rearranging expression (40):

$$\frac{dU}{u_C} = -\frac{u_Q}{u_C}\left[N(-q_{ND})dD + N(-q_R)\frac{dR}{N}\right] + \left[w\,t_L\,dL + t_D\,dD + t_R\frac{dR}{N} + t_X\frac{dX}{N}\right] \tag{41}$$

The product of $-u_Q/u_C$ and the first bracketed element on the right-hand side of equation (41) represents the welfare effect of changes in environmental quality. The first "dividend" from environmental tax reform arises if this product is positive.

The other bracketed element on the right-hand side of (41) stands for the welfare effect from changes in the tax base. This element is the *tax-base effect.* Each term contributing to this effect is the change in a tax base times the tax rate corresponding to that tax base.[18] This effect can be expressed as dY^D, the change in real private (after-tax) income enjoyed by households:

$$dY^D \equiv L\,dw - D\,dt_D = wt_L\,dL + t_D\,dD + t_R\frac{dR}{N} + t_X\frac{dX}{N} \tag{42}$$

The tax-base effect represents the gross cost (i.e., the cost before netting out the environmental benefits) of the tax-induced changes in the allocation of resources. If this gross cost is negative, the environmental reform offers a second "dividend" in the form of a less costly tax system on non-environmental grounds. We now investigate the sign of the tax-base effect.

3.2 Employment and welfare impacts of revenue-neutral reforms

Consider in particular a reform in which the government introduces pollution taxes on

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[18] This formula for the first-order welfare change in the absence of externalities is standard in the tax reform literature. Aronsson (1999) derives analogous expressions in a dynamic framework that considers the time-path of various endogenous variables in general equilibrium.

household consumption or intermediate inputs and uses the revenues to finance cuts in the labor tax rate. We assume that the tax rate on the clean intermediate input is zero (i.e., $t_X = 0$).[19] Utility is given by $u = u((M(J(C,D),V), G, Q)$. Hence, private goods are weakly separable from the public goods G and Q, so that environmental quality and public consumption do not directly affect private demand. The sub-utility function J aggregating clean and dirty consumption into a composite consumption good is homothetic. This specification of utility implies that, in the absence of environmental externalities, a uniform tax on clean and dirty consumption would be optimal.

Equation (42) implies that the non-environment-related welfare impact or gross cost of the reform depends on the reform's impact on labor supply. Because of this connection we first focus on the reform's impact on the base of the labor tax, that is, on employment.[20]

To determine the general equilibrium employment effects of the pollution tax t_D, we first derive $(u_D/u_C) = (1+t_D)$ from household optimization. Taking the total differential, we find:

$$\tilde{C}-\tilde{D} = \sigma_J \tilde{t}_D \tag{43}$$

where $\tilde{t}_D \equiv dt_D/(1+t_D)$. For other variables, a tilde (~) stands for a relative change. σ_J represents the substitution elasticity between clean and dirty consumption in the sub-utility function $J(C,D)$. In deriving (43), we have used the assumption that, in private utility, leisure is weakly separable from the produced commodities C and D. Under these separability assumptions and homotheticity of the sub-utility function $J(C,D)$, the first-order conditions for optimal household behavior can be written as $u_Q/u_V = p_J/w$, where p_J is the ideal consumer price index of the consumption basket J. Taking the total differential of this first-order condition, and using (43) and the total differential of the household budget constraint (7) (with $T=0$), we obtain:

$$\tilde{L} = \varepsilon_{LL}^{U} \tilde{w}_R \tag{44}$$

$$\tilde{C} = \tilde{L} + \tilde{w}_R + (1-\alpha_C)\sigma_J \tilde{t}_D \tag{45}$$

$$\tilde{D} = \tilde{L} + \tilde{w}_R - \alpha_C \sigma_J \tilde{t}_D \tag{46}$$

where $\varepsilon_{LL}^{U} \equiv (1-L)(\sigma_M-1)$ stands for the uncompensated wage elasticity of labor supply, and σ_M denotes the substitution elasticity between leisure and composite consumption. $\tilde{w}_R = \tilde{w} - \tilde{p}_J$ represents the relative change in the real after-tax wage, and $\alpha_C \equiv C/wL$ is the share of non-polluting consumption in overall household consumption. The uncompensated wage elasticity is positive if the substitution effect of a change in real wages dominates the income effect, that is, if σ_M exceeds unity. We assume that the labor-supply curve is indeed

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[19] As discussed in Section 2, there is no efficiency rationale for a tax on the clean intermediate input.

[20] In a model with several production factors and several distortionary tax rates, the effect on the *overall* tax base is relevant. In such a model, an expansion in employment (i.e., the base of the labor tax) is neither a necessary nor sufficient condition for a positive second (non-environmental) dividend.

upward-sloping, as most empirical studies yield positive estimates for this elasticity.

To find the impact of the pollution tax t_R, we use (10) and (11) to log-linearize the demand for the dirty intermediate input conditional on employment:

$$\tilde{R} = \tilde{L} - \varepsilon_R \tilde{t}_R \tag{47}$$

where $\tilde{t}_R \equiv dt_R/(1+t_R)$ and $\varepsilon_R \equiv -[\partial R/\partial t_R]\,[(1+t_R)/R]$. We can write goods-market equilibrium (39) as (with $t_X=0$):

$$\omega_L \tilde{L} + \theta_R \omega_R \tilde{R} = (1-\theta_L)\omega_L\,[\alpha_C \tilde{C} + ((1-\alpha_C)/(1+t_D))\tilde{D}] \tag{48}$$

where $\theta_i \equiv t_i/(1+t_i)$, $i=L,R$ and ω_L and ω_R represent the shares of labor and dirty intermediate inputs in production, respectively. Substituting (44) - (47) into (48) (with $t_X = 0$), we arrive at:

$$\tilde{L} = \frac{\varepsilon_{LL}^{U}}{\Delta}[-\theta_R\omega_R\varepsilon_R\tilde{t}_R - \theta_D\alpha_C(1-\alpha_C)\omega_L(1-\theta_L)\sigma_J\tilde{t}_D] \tag{49}$$

where

$$\Delta \equiv (1-\theta_L)\omega_L(1-\theta_D(1-\alpha_C)) - \varepsilon_{LL}^{U}[\omega_L\theta_L + \theta_R\omega_R + \theta_D(1-\alpha_C)\omega_L(1-\theta_L)] > 0 \tag{50}$$

"Small" environmental taxes

We first consider the equilibrium impacts of an incremental environmental tax, when the initial equilibrium involves no such taxes (i.e. $t_D=t_R=0$ and hence $\theta_D=\theta_R=0$). This sets the stage for examining the more general case involving larger pollution taxes. Expression (49) indicates that the introduction of pollution taxes does not affect employment (the expression in square brackets is zero if $\theta_D = \theta_R = 0$), even though the revenues from the pollution taxes allow for lower taxes on labor.

Why is labor supply unaffected? The key to the answer is that environmental taxes are implicit taxes on labor. Like explicit labor taxes, they influence the real wage and labor supply incentives. Swapping environmental taxes for labor taxes amounts to substituting implicit labor taxes for the explicit labor tax. While the imposition of the environmental taxes tends to increase labor's tax burden, the reduction in the labor tax tends to reduce it. When the environmental tax is small, these two effects exactly offset each other. Hence the real wage is not changed, which implies that labor supply is unchanged as well.[21]

To view this more closely, consider in particular the case where only the tax t_D on the dirty consumer good is raised. Insofar as revenues from the tax t_D can be used to reduce

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[21] This result depends on leisure being separable from clean and dirty consumption in utility. See subsection 3.3.2 below for how results may differ under non-separable utility functions.

explicit taxes on labor, they raise the real wage. At the same time, however, the tax t_D raises the price of consumption, which has the opposite impact on the real wage. Expression (49) attests to the fact that for a small value of t_D that finances a reduction in t_L, these two effects exactly cancel out. The same result holds in the case where only the tax t_R is introduced. This tax reduces the demand for polluting inputs, thereby reducing labor productivity and thus the before-tax wage. If the initial pollution tax is zero, the adverse effect of the lower before-tax wage on the after-tax wage is exactly offset by the positive effect of lower taxes on labor income.[22]

"Large" environmental taxes

This exact offset does not apply to the case of "large" environmental taxes, however. We can ascertain the impacts of large pollution taxes by analyzing the situation in which environmental taxes are raised from an initial equilibrium in which environmental taxes are positive (i.e. t_D, $t_R > 0$).[23] Expression (49) indicates that in this case an increase in the pollution tax leads to a reduction in the real wage and a corresponding drop in employment.[24]

The negative effect on the real after-tax wage comes about because the lower tax rate on labor income does not fully compensate workers for the adverse effect of the pollution tax on their real after-tax wage. This incomplete offset reflects the fact that environmental taxes tend to be less efficient instruments for raising revenue than a broad-based labor tax. In contrast to a labor tax, pollution taxes on dirty consumption not only affect the labor market but also "distort" the composition of the consumption basket.[25] Furthermore, taxing gross instead of net output by levying pollution taxes on intermediate inputs "distorts" the input mix into production. These "distortions" account for the net reduction in real after-tax income following the revenue-neutral policy change. Of course, these "distortions" in consumption patterns or input choice are desirable on environmental grounds. Indeed, the same features of environmental taxes that make them unattractive from a revenue-raising point of view -- their focus on particular inputs or consumption goods -- makes them attractive as instruments for environmental improvement.

The term between square brackets in (49) represents the additional tax burden associated with a revenue-neutral increase in the pollution tax. This additional burden depends on two elements: the initial levels of pollution taxes, and the substitution elasticities between clean and dirty commodities. The initial pollution taxes regulate the marginal abatement costs.

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[22] For a more detailed examination of this issue, see Bovenberg and de Mooij (1994a) and Bovenberg and Goulder (1996).

[23] The incremental results shown here indicate the impact of a large reform because a large reform's impact is the integral of the impacts of a series of incremental reforms, where the pre-existing pollution tax rates are incrementally larger with each new reform.

[24] Recall that we assume that the uncompensated wage elasticity of labor supply, ε_{LL}^{U}, is positive.

[25] The word "distort" is in quotes to acknowledge the notion that the change in resource allocation may be justified once environmental benefits are taken into account.

Without prior pollution taxes, reducing a marginal unit of pollution comes free. However, the higher the initial pollution taxes, the larger the marginal costs of increasing environmental quality, since higher initial environmental taxes intensify the adverse revenue effects associated with the erosion of the base from an increment to these taxes. Also, larger substitution elasticities between dirty and clean commodities yield a higher tax burden from a given increment to the pollution tax. Larger substitution elasticities imply larger gross distortions from a given pollution tax (while also implying larger improvements in environmental quality).

Implications for the double dividend hypothesis and welfare

Having diagnosed the general equilibrium effects on employment, we can now return to expression (41) to evaluate the double-dividend issue. We have seen that revenue-neutral environmental tax policies lead to a reduction in employment (for all but infinitesimal environmental tax rates). With a negative value for dL and non-positive values for dD and dR in (41), the tax-base effect is negative. By harming employment, pollution taxes narrow, rather than widen, the tax base. As noted earlier, this means that the non-environmental component of welfare falls. Thus, the double-dividend hypothesis fails.

The absence of the double dividend does not mean that *overall* welfare falls, however. To the contrary, expression (40) indicates that welfare will rise provided that environmental taxes are not "too large." For "small" environmental taxes, the impact on employment is small. Hence the first right-hand term in (40) is close to zero. At the same time, for small taxes the next two right-hand-side terms in (40) are positive, assuming that marginal environmental benefits ($Nu_Q(-q_{ND})$ and $Nu_Q(-q_R)$) are large for initial reductions in pollution. Thus overall welfare rises.[26] Hence the failure of the double dividend claim does not imply that green tax reforms are inefficient. It simply means that environmental improvement comes at a (gross) cost.

Significance of second-best considerations

Equations (42) and (49) imply that the gross distortionary cost of a given environmental tax will be larger, the higher the pre-existing taxes on labor. Environmental taxes introduce gross distortions by reducing the labor supply. The larger the pre-existing labor taxes, the greater the wedge between the private and social value of labor, and thus the larger the gross cost associated with a given reduction in the labor supply. Thus, higher pre-existing labor tax rates imply larger costs from given environmental tax reforms.

These results show that partial equilibrium analyses of the gross distortionary costs of environmental taxes can be misleading. Environmental taxes may importantly affect distortions in markets other than those in which the tax is applied. Figure 3 offers the typical partial equilibrium and first-best framework for analyzing welfare effects of an environmentally

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[26] Recall that t_X is assumed to be zero.

motivated tax on coal. *MC* denotes the private marginal costs of producing coal.[27] MC_{soc} represents the social marginal cost curve, incorporating the marginal external damage, *MED,* from coal combustion. *MB* stands for the marginal benefit (demand) curve. If a tax is imposed equal to the marginal external damage, social and private marginal costs coincide. The usual textbook analysis regards the welfare gain as area *B*. This is the value of the environmental improvement $(A + B)$ minus the gross costs of the tax (A).

[Figure 3 about here]

The area *A* in Figure 3, which corresponds to firm's marginal cost of pollution abatement, can be termed the *primary cost* of the environmental tax. In a world without distortionary taxes, the gross cost of the environmental tax is simply the primary cost. However, in the presence of distortionary taxes, the analysis in Figure 3 needs to be modified in two ways. First, the revenues *R* can be employed to cut distortionary taxes. Such "revenue-recycling" works toward an improvement in efficiency and thus suggests that the partial equilibrium analysis would overstate the gross cost of environmental taxes. At the same time, since environmental taxes are implicit factor (labor) taxes, a new environmental tax functions as an increase in existing factor taxes. This has the opposite influence on gross costs, tending to raise costs relative to the primary costs indicated in Figure 3 and suggesting that the partial equilibrium analysis understates gross costs. Under the assumptions in our analysis (where the clean and dirty consumption goods are weakly separable from leisure), the latter effect dominates the former: for a "large" revenue-neutral environmental tax, in the presence of prior taxes the gross costs are higher than the primary costs from Figure 3 -- even when revenues are recycled through cuts in the distortionary tax.

Figure 4 schematizes these effects. Adopting terminology similar to that introduced by Parry (1995), we call the former additional effect the *revenue-recycling effect* and the latter additional effect the *tax-interaction effect.* Overall gross cost is primary cost plus the tax-interaction effect minus the revenue-recycling effect. Figure 4 recapitulates the earlier result that an incremental environmental tax reform (associated with incremental abatement) involves zero marginal (gross) cost. However, for a "large" environmental tax (corresponding to a large amount of abatement), the marginal cost is positive. Moreover, under the assumptions in this analysis the tax-interaction effect exceeds the revenue-recycling effect, so that the overall gross cost exceeds primary cost. Thus, this analysis indicates that in the presence of distortionary taxes the gross costs of pollution abatement from revenue-neutral environmental taxes exceed firms' abatement costs.[28]

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[27] Here we treat coal as equivalent to pollution. In Section 4 we distinguish emissions of polluting compounds from the output or fuel (such as coal) with which pollution is associated. The qualitative results described in the present section are maintained when one refines the analysis to acknowledge this distinction.

[28] Some distinctions are worth making here. First, the main comparison here is between primary costs and gross costs (of a given environmental tax) within a single, second-best setting. The analysis indicates that, in this setting, the gross costs from a given tax exceed the primary costs of the tax. A different issue is whether, for a given environmental tax, the gross costs in a setting with prior distortionary taxes (a "second best setting") are greater than the gross costs in a setting without prior distortionary taxes. This would be the case if primary costs were the same in both settings, since gross costs exceed primary cost in the former (second-best) setting, but are equal to primary cost in the latter setting. However, primary costs need not be identical in both settings. Still, numerical simulation studies (see, for example, Goulder, Parry, Williams, and Burtraw (1999)) indicate that primary costs are very similar

Note that to obtain a double dividend (negative gross costs), the revenue-recycling effect would have to be large enough to offset both the primary cost and the tax-interaction effect. In subsection 3.3 below we discuss special circumstances under which this can occur.

In Section 4 we will return to the tax-interaction and revenue-recycling effects, which are important to the choice between taxes and other instruments for environmental improvement.

[Figure 4 here]

3.3 Complicating factors

3.3.1 Nature of environmental benefits

Subsection 3.2 assumes that the environment is a public consumption good that enters the utility function in a weakly separable way. As a direct consequence, the improved quality of the environment does not affect the labor market. However, a cleaner environment can affect the labor market through two channels. The first channel applies when environmental quality enters household utility in a non-separable fashion. If environmental quality is complementary to leisure, a cleaner environment makes leisure more enjoyable. In this case, the environmental benefits negatively affect labor supply and thereby magnify the adverse employment effects associated with pollution taxes. If environmental quality is a substitute for leisure, improvements in environmental quality mitigate the adverse employment effects.

The second channel applies when environmental quality exerts a direct effect on labor productivity. To the extent that environmental quality enhances labor productivity, it increases the demand for labor. This offsets the adverse labor-supply impact of the environmental tax and thereby reduces the welfare cost associated with the tax-base erosion effect.[29]

These considerations indicate that in principle one should explore the feedback on the economy of a higher supply of the public good of the environment. However, most models exploring the consequences of an environmental tax reform abstract from this feedback. In

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in the presence or absence of distortionary taxes, and that gross costs are indeed higher in a second-best setting than in the absence of prior distortionary taxes. The most policy-relevant comparison seems to be the former one indicating whether, in a realistic second-best setting, gross costs exceed primary costs – that is, whether cost-estimates based on firms' abatement costs understate overall costs.

Second, the focus here is on the costs of a given tax or the costs of given amounts of pollution *abatement*, not the costs of achieving a given amount of environmental *quality*. As pointed out by Gaube (1998) and Metcalf (2000), the underlying level of pollution prior to the introduction of an environmental tax may be different in a world with no prior taxes as compared with a world with distortionary taxes. Pollution levels may be lower in the latter case because of the negative impact of distortionary taxes on factor supply and output. To the extent that initial pollution levels are lower in a second-best setting, the amount of abatement necessary to achieve a given level of environmental quality may be lower in a second-best world. As a result, the cost of achieving a given quality level may be lower in the second-best world, despite the higher costs per unit of abatement.

[29] For a detailed analysis of this issue, see Bovenberg and van der Ploeg (1994a) and Williams (1997).

particular, they ignore the impact of environmental benefits on both labor demand and labor supply. This is a valid assumption only if the environment enters households' utility function as a consumption good in a weakly separable way and is not an input into production.

3.3.2 Inefficiencies in the existing tax system

If the initial tax system is inefficient from a non-environmental point of view, an environmental tax reform may be able to reduce the overall burden of taxation and achieve the double dividend after all. The key requirement is that the revenue-neutral reform end up alleviating these prior inefficiencies and move the rest of the tax system closer to its non-environmental optimum. This general point can be illustrated with a number of examples.

Clean consumption a better substitute for leisure

The first example involves the taxes on clean and dirty consumption in the model of Section 2. Expression (26) shows that the Ramsey tax on dirty consumption should exceed the corresponding tax on clean consumption if, compared to dirty consumption, clean consumption is a better substitute for leisure. Accordingly, if the initial tax system features only a tax on labor (i.e., a uniform tax on clean and dirty consumption), an environmental reform raises private income. Here, raising the tax on dirty consumption and using the revenues to cut the labor tax moves the tax system closer to its optimal Ramsey structure. In this case, the reform boosts employment, thereby alleviating the distortions imposed by the labor tax, and the double dividend thus materializes. However, if dirty consumption is a better substitute for leisure than clean consumption, the Ramsey tax on dirty consumption is negative and the double dividend is even less likely to occur than in the benchmark case examined in subsections 3.1 and 3.2.

Pre-existing subsidies on polluting activities

The overall burden on polluting activities may be too low initially -- even from the point of view of maximizing private income -- because these activities are subsidized initially. The tax reform analysis in section 3.2 illustrates this. If the polluting intermediate input is subsidized in the initial equilibrium (i.e. $t_R < 0$), employment (and hence private income) expands if this subsidy is reduced. Shah and Larsen (1992) emphasize this point in considering the case for carbon taxes in developing countries.

Environmental taxes as optimal tariffs

In an open economy, governments can employ pollution taxes as a means of improving the terms of trade. For example, a large oil-importing country may improve its terms of trade if it reduces the demand for oil by raising the tax burden on fossil fuels. Similarly, a large exporting country can boost the prices of its exports by imposing pollution taxes that reduce the supply of these commodities. These terms of trade gains shift some of the cost of environmental improvement onto foreigners and lower the domestic welfare cost of environmental policy. If the terms of trade gains are large enough, the domestic welfare cost vanishes.

Environmental taxes as rent taxes

Environmental taxes may be an implicit way to tax the scarcity rents associated with natural resources. Taxes on the demands for fossil fuels, for example, may be borne largely by the owners of reserves of fossil fuels, as these taxes may reduce significantly the net-of-tax prices of these fuels. To the extent that the burden of environmental taxes falls on the owners of inelastically supplied reserves, the environmental tax functions as a rent tax and involves no efficiency cost. This improves the prospects for the second (non-environmental) dividend. However, this same phenomenon implies less scope for environmental improvement: the more the tax is borne by owners of reserves, the smaller the increase in the gross-of-tax price to demanders of these fuels. Thus, to advocates of green tax reform, rent taxes are a mixed blessing: they improve the prospects for the second dividend while reducing the scope of the first.

Inefficient factor taxation

If the initial tax system involves differences in the marginal excess burdens of various taxes, an environmental tax reform can boost private incomes by shifting the tax burden away from factors with high marginal excess burdens to factors with low marginal excess burdens (see Christiansen (1996), Bovenberg and Goulder (1997), and Goulder (1995a)). The gross cost of a revenue-neutral environmental tax will be lower to the extent that:

1. in the initial tax system, the differences in marginal efficiency costs (of various tax instruments) are large,
2. the burden of the environmental tax falls primarily on the factor with relatively low marginal efficiency cost, and
3. revenues from the tax are devoted to reducing tax rates on the factor with relatively high marginal-efficiency cost.

These conditions ensure that the efficiency gains from shifting the tax burden from the overtaxed to the undertaxed factor are sufficiently large to offset the costs associated with a cleaner environment.

These considerations may be especially relevant for the mix between capital and labor taxation. Most applied general equilibrium models of the U.S. economy suggest that, compared to taxes on labor income, taxes on capital income tend to produce larger marginal efficiency losses. The most direct way to improve the efficiency of the tax system as a revenue raising device would be to finance a cut in capital taxes with higher taxes on labor. However, if the government does not want to adopt labor taxes, it can use environmental taxes that are primarily borne by labor.[30]

The suboptimality of the initial tax system raises the question why governments have not reformed their tax systems to deal with these inefficiencies. The efficiency rationale for such a tax reform is independent of environmental concerns. However, in some instances, political constraints (perhaps stemming from distributional concerns) may prevent the government from introducing strictly non-environmental tax reforms that enhance the efficiency of the tax system as a revenue-raising device. Under these circumstances, there may be advantages to introducing a package deal in which environmental taxes generate revenues that are used to eliminate particularly inefficient taxes. This combination of environmental and non-environmental tax reforms may be necessary to generate sufficient political support for either type of reform. In situations like this, environmental taxes are the lubricating oil that makes possible a tax reform to eliminate particularly "bad" taxes.

Inefficient Commodity Taxation

Some tax policies favor certain forms of consumption over others. For example, the U.S. tax system provides tax deductions for consumer spending on housing or health care. Such policies may be desirable on equity or other grounds, but at the same time they may imply inefficiencies in the allocation of consumer expenditure. To the extent that revenue-neutral environmental tax policies lead to reduced factor tax rates, the values of these tax deductions are reduced. Parry and Bento (2000) show that when this channel is taken into account, the predicted costs of a revenue-neutral environmental tax reform are lowered significantly. In particular, the gross costs of such a reform might well be significantly below the primary costs.

3.3.3 Involuntary unemployment

The previous analysis assumed a well functioning labor market with a flexible wage rate that assures full employment. In Europe, where involuntary unemployment is widespread, there has been considerable interest in green tax reform as a vehicle for reducing unemployment as well as improving the environment. This has prompted several studies investigating the effects of revenue-neutral environmental tax reforms in situations involving involuntary unemployment.

Bovenberg and van der Ploeg (1998a) analyze the consequences of an environmental tax reform in a model where involuntary unemployment stems from a rigid consumer wage. Hence this model incorporates labor-market distortions as well as the tax distortions already considered. In addition to labor, a clean non-labor production factor, which is fixed in supply,

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[30] See Goulder (1995a) for further discussion of this issue. The welfare effects associated with a sub-optimal initial tax system do not necessarily make environmental tax reforms more attractive, because the burden of the environmental tax could well fall on the factor that is already overtaxed from an efficiency point of view. Indeed, the numerical general equilibrium analysis in Bovenberg and Goulder (1997) suggests that inefficiencies in the initial U.S. tax system may make carbon taxes less rather than more attractive.

enters production.[31] Non-labor income is subject to a fixed tax rate of less than 100 percent.

The analysis shows that an environmental tax reform may reduce involuntary unemployment by expanding labor demand. Specifically, in the presence of a non-labor production factor, an environmental tax reform can shift part of the tax burden away from labor to the inelastically supplied non-labor factor. This tax-shifting effect exerts a positive impact on employment because it allows for a fall in wage costs, thereby boosting labor demand. In this model, there is a wedge between the marginal social value and marginal social cost of employment both because of the distortionary labor tax and because of the gap between the actual consumer wage and the reservation wage (i.e. the wage at which households would be willing to work). Hence the increase in employment from the environmental tax reform yields a first-order welfare gain.

These results are another example of how the prospects for the double dividend improve when the initial tax system is inefficient from a non-environmental point of view (see also subsection 3.3.2). Since the non-labor production factor is fixed in supply, a 100 percent tax on non-labor income would be most efficient. However, if such a tax is infeasible for political or other reasons, a second-best alternative is to introduce the pollution tax, an implicit tax on the fixed factor (and labor). Substituting the pollution tax for the labor tax improves efficiency by shifting more of the burden of taxation onto the fixed factor.

Several papers (see, e.g., Koskela and Schöb (1999), Nielsen, Pedersen, and Sørensen (1995), Schneider (1997) and Bovenberg and van der Ploeg (1998b)) explore how a green tax reform affects equilibrium unemployment in models with endogenous wage-setting. In these models, the impact on employment depends mainly on how an environmental tax reform affects unemployment benefits, which determine the threat point of employees in the bargaining process between employers and employees. In particular, if unemployment benefits are a fixed proportion of income in employment (implying a fixed replacement ratio), then all taxes are completely borne by employees (see Layard, Nickell, and Jackman (1991)). Hence, an environmental tax reform affects neither wage costs nor unemployment in equilibrium. The importance of the benefit regime applies to most equilibrium models of unemployment, including models of union-firm bargaining, monopoly unions, efficiency wages, and job search.

Koskela and Schöb (1999) illustrate these principles in the context of a model of wage-bargaining between unions and employers. They show that the employment effects of an environmental tax reform involving pollution taxes on dirty consumption depend crucially on the taxation of unemployment benefits. In particular, employment may expand if unemployment benefits are neither subject to the labor income tax nor indexed to the consumer price index. In that case, the unemployed pay the higher pollution taxes on consumption but are compensated neither by lower taxes on labor income nor higher gross benefits. Indeed, whereas the pollution tax hits workers and unemployed alike, only workers benefit from the recycled revenues in the form of lower taxes on labor. In this way, the environmental tax reform shifts the tax burden away from workers towards the unemployed. This tax-shifting effect makes the outside option of unemployment less attractive for workers, thereby

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[31] Without this latter production factor, both the consumer wage and the production wage would be fixed, and the market wage would be overdetermined.

moderating wage costs and thus boosting labor demand.

3.4 Numerical assessments of a green tax reform

The interest in green tax reform has prompted several empirical studies of potential reforms. Many of these studies employ sophisticated numerical general equilibrium models that contain considerably more detail than the analytically tractable model developed above.

3.4.1 Impacts on consumption and welfare

[Table 4 about here]

Table 4 summarizes results from numerical studies of a potential reform that has gained especially great interest: a revenue-neutral carbon tax policy. The table presents results from seven numerical models. These are the Goulder and Jorgenson-Wilcoxen intertemporal general equilibrium models of the U.S., the Proost-Regemorter general equilibrium model of Belgium, the DRI and LINK econometric macroeconomic models of the U.S., and the Shah-Larsen partial equilibrium model, which has been applied to five countries, including the U.S.[32] The results in Table 4 are for the revenue-neutral combination of an environmental tax (usually a carbon tax) and reduction in the personal income tax, except in cases where this combination was not available.

All welfare changes abstract from changes in welfare associated with improvements in environmental quality (reductions in greenhouse gas emissions). Thus they correspond to the gross distortionary cost concept discussed above. In the Goulder, Jorgenson-Wilcoxen, and Proost-Regemorter models, welfare changes are reported in terms of the equivalent variation; in the Shah-Larsen model, the changes are based on the compensating variation.[33] In the DRI and

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[32] For a more detailed description of these models, see Goulder (1995b), Jorgenson and Wilcoxen (1990, 1996), Shackleton *et al.* (1996), Proost and van Regemorter (1995), and Shah and Larsen (1992). In the models with explicit utility functions (all the models except for the LINK and DRI models), environmental quality is implicitly regarded as separable in utility from leisure and consumption. These models also assume, as in the analysis of subsections 3.1 and 3.2, that leisure and consumption are weakly separable. These assumptions reflect the lack of empirical information about the relative substitutability of consumer goods with leisure. Under these circumstances, assuming that all goods are equal substitutes with leisure (weak separability) seems reasonable.

The Shah-Larsen model is the simplest of the models, in part because it takes pre-tax factor prices as given. Despite its simplicity, the model addresses interactions between commodity and factor markets and thus incorporates some of the major efficiency connections discussed earlier.

[33] The equivalent variation is the lump-sum change in wealth which, under the "business-as-usual" or base case, would leave the household as well off as in the policy-change case. Thus a positive equivalent variation indicates that the policy is welfare-improving. The compensating variation is the lump-sum change in wealth which, in the policy-change scenario, would cause the household to be as well off as in the base case. In reporting the Shah-Larsen results we adopt the convention of multiplying the compensating variation by -1, so that a positive number in the table signifies a welfare improvement here as well.

LINK macroeconomic models, the percentage change in aggregate real consumption substitutes for a utility-based welfare measure.[34]

In most cases, the revenue-neutral green tax swap involves a reduction in welfare, that is, entails positive gross costs. This militates against the double dividend claim. Results from the Jorgenson-Wilcoxen model, however, support the double dividend notion. Relatively high interest elasticities of savings (a high capital supply elasticity) and the assumption of perfect capital mobility across sectors may partially explain this result, at least in the case where revenues from the carbon tax are devoted to cuts in marginal taxes on capital. These assumptions yield large marginal excess burdens (MEB's) from taxes on capital, considerably larger than the MEB's from labor taxes. As indicated in subsection 3.3.2, if the MEB on capital significantly exceeds that on labor, and the environmental reform shifts the tax burden on to labor, the double dividend can arise. Thus, the large MEB's from capital taxes help explain why, in the Jorgenson-Wilcoxen model, a revenue-neutral combination of carbon tax and reduction in capital taxes involves negative gross costs, that is, produces a double dividend.

Identifying the sources of differences in results across models is difficult, in large part because of the lack of relevant information on simulation outcomes and parameters. Relatively few studies have performed the type of analysis that exposes the channels underlying the overall impacts. There is a need for more systematic sensitivity analysis, as well as closer investigations of how structural aspects of tax policies (type of tax base, narrowness of tax base, uniformity of tax rates, etc.) influence the outcomes. In addition, key behavioral parameters need to be reported. Serious attention to these issues will help explain differences in results and, one hopes, lead to a greater consensus on likely policy impacts.

3.4.2 An employment dividend?

In Europe, policy makers have been especially interested in the possibility that green tax reforms could raise employment. Many politicians have supported reforms in which pollution taxes would be introduced and the revenues devoted to cuts in labor taxes. The preoccupation with employment impacts reflects in part the relatively high rates of unemployment prevailing in many European countries.

In models with only labor as a primary factor of production, the employment impacts of a revenue-neutral environmental tax reform are directly related to the impacts on the non-environmental component of welfare. In expression (41), the sign of dL determined the sign of the non-environmental-component of welfare. In more detailed models -- in particular, models that distinguish more than one primary factor of production -- the employment dividend is no longer tied so closely to the non-environmental-welfare dividend. Revenue-neutral reforms can produce an increase in employment without raising real incomes and non-environment-related welfare.

The crucial requirement for an increase in employment is that the reforms shift the tax

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[34] The demand functions in these models are not derived from an explicit utility function. Hence they do not yield utility-based measures.

burden from labor to other primary factors. Specifically, in models with capital and labor, the prospects for an employment dividend are enhanced to the extent that:

1. The industry or industries on which the environmental tax is levied (that is, the pollution-intensive industries) feature a relatively low labor intensity in comparison with other industries.

2. Revenues from the revenue-neutral policy are devoted primarily to cuts in labor taxes (rather than taxes on capital).[35]

Many numerical models have examined the employment impacts of revenue-neutral reforms, considering a wide range of energy and environmental taxes. Some models incorporate considerable detail on labor markets, including wage-formation by unions and labor-market wage rigidities that lead to involuntary unemployment.[36] Employment impacts can be quite sensitive to the specification of these features of the labor market. Although results vary widely, they indicate that the employment dividend can materialize when revenues are recycled through cuts in labor taxes and when the industries facing the environmental tax are not exceptionally labor-intensive.[37] An employment dividend also can arise if the revenue-neutral reform tends to shift the burden of taxation from labor to transfer recipients. This may occur, for example, when the government introduces an environmental tax and devotes the revenues to cuts in the labor tax. The environmental tax raises the real cost of output, but labor enjoys a reduction in the labor tax that more than offsets this increase. Transfer recipients, in contrast, are not compensated for the reduction in the real value of their transfers. Under these circumstances, labor enjoys an increase in real income from the revenue-neutral reform, despite the overall gross cost of the reform, because the tax burden is shifted to transfer recipients. Consequently, employment rises. Results from the MIMIC numerical general equilibrium model of the Netherlands exhibit this phenomenon.

4 Alternatives to pollution taxes

While economists tend to favor taxes as instruments for environmental protection, most environmental regulation is accomplished through other instruments. There are only a few

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[35] A further consideration is whether the environmental reform produces a *tax-shifting effect* that has a positive efficiency impact (see discussion in subsection 3.3.2). In particular, if the prior tax system overtaxes labor relative to capital, and the environmental reform shifts the burden from labor to capital, tax-shifting will lead to greater efficiency in the relative taxation of labor and capital. This, in turn, helps to raise the real wage, which tends to boost employment.

[36] See, for example, Brunello (1996) and Capros *et al.* (1996).

[37] See, for example, the results from the collection of models examined in Carraro and Siniscalco (1996).

instances of "environmental"[38] taxes in the U.S. -- a tax on gasoline, on motor fuels, on oil spills, on ozone-depleting chemicals, and on chemical feedstocks (associated with toxic waste production) -- and the bulk of environmental regulation is accomplished through mandated technologies or performance standards. In other countries the emphasis on taxes is even lighter in comparison with other instruments. In this section we consider some important alternatives to taxes.

4.1 Instrument choice in a certainty context

We compare different instruments using a slightly altered version of the model used in Section 2. Here we abstract from intermediate inputs and focus on pollution associated with the production or use of the "dirty" consumption good, *D*. Labor is the only input into production. To facilitate comparisons of alternative instruments, we generalize slightly the relationship between environmental quality, *Q*, and the output of the dirty consumption good, *D*. In particular, we now include in the model pollution abatement, *A*. By devoting resources to pollution abatement (for example, by implementing new, cleaner production processes), firms can reduce the amount of pollution per unit of production of the dirty consumption good. In this setting, environmental quality depends on pollution emissions E , which in turn depend on the level of production of the dirty consumption good and on the level of abatement expenditure. Hence $Q = q(E(ND, A))$, with $\partial Q/\partial E < 0$, $\partial E/\partial ND > 0$, $\partial E/\partial A < 0$.

In this altered model, the economy's transformation surface is:

$$NL = G + NC + ND + A \tag{51}$$

where, as before, we normalize units so that marginal rates of transformation are unity.

To provide a reference point, we first derive the welfare impacts of a tax t_E on emissions of pollution. Taking the derivative of the representative household's utility with respect to t_E yields:

$$(dU/dt_E)/u_C = \frac{1}{N}\,(t_E - t_E^P)\,\frac{\partial E}{\partial t_E} + \eta t_L w \frac{\partial L}{\partial t_E} + \frac{1}{N}\,(\eta - 1)\left[\frac{\partial (E\, t_E)}{\partial t_E}\right] \tag{52}$$

The welfare impact of an incremental change in t_E has three components. The first term on the right-hand side of (52) is the *primary gain,* the welfare change associated with a change in environmental quality, net of the primary cost (private abatement cost). This term is positive if the pollution tax is below the Pigovian rate, $t_E^P = -Nu_Q q_E/u_C$. This term vanishes if the pollution tax t_E equals the Pigovian tax t_E^P , that is, if the external effects of pollution are fully internalized. The second term represents the *tax-interaction effect* introduced in Section 3 (see Parry (1995, 1997)). As discussed earlier, because the environmental tax raises the costs of

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[38] The political motivation for introducing these taxes need not be environmental. Hahn (1989), Fullerton (1996) and Stavins (1998) examine the various environmental taxes employed in the U.S. and discuss their original rationales.

production and the prices of goods in general, it acts as an implicit tax on labor. The tax-interaction effect is the adverse welfare impact that results from this implicit tax's negative impact on the real wage and employment. The third term on the right-hand side is the *revenue-recycling effect*. It represents the beneficial welfare impact stemming from the environmental tax's generation of revenues that can be used to finance cuts in the labor tax. Two conditions ensure that the revenue-recycling effect is indeed positive (at the margin). First, the MCPF must exceed one. Second, the slope of the Laffer curve for the pollution tax must be increasing (i.e., $\partial(Et_E) / \partial t_E > 0$).

4.1.1 Pollution quotas

Now compare the impact of the pollution tax with that of a pollution quota. Under the quota policy, the government gives out free to each polluting firm a fixed number of pollution permits, where each permit entitles the owner to a given amount of emissions of pollution.[39] For now we treat firms as identical and as receiving the same quotas or numbers of permits. Thus, if the government's targeted level of aggregate emissions is $\bar{E}$, then $\bar{E}/K$ is the quota allocation to each of the K polluting firms. Under these conditions there is no scope for gains from trading permits. In subsection 4.1.2 below we consider permits trades among heterogeneous firms.

Taking the derivative of utility with respect to $\bar{E}$ yields

$$(dU/d\bar{E})/u_c = \frac{1}{N}(\bar{t}_E - t_E^P) + \eta t_L w \frac{\partial L}{\partial \bar{E}} \tag{53}$$

Let $\bar{t}_E$ represents the *virtual* tax rate on emissions associated with $\bar{E}$, that is, the emissions tax rate (with lump-sum replacement of tax revenues) that would yield the level of emissions under the quota. Multiplying (53) by $\partial\bar{E}/\partial\bar{t}_E$ yields an expression very similar to (52) except that the revenue-recycling effect -- the far-right term in (52) -- is missing. Since the pollution quota does not raise revenue,[40] it cannot finance cuts in the pre-existing labor tax. Thus it cannot yield the beneficial welfare impact associated with recycling of environmental tax revenues.

The absence of the revenue-recycling effect is a disadvantage of quotas relative to emissions taxes. The cost of achieving a given amount of pollution abatement is higher under quotas than under emissions taxes — assuming that revenues from the emissions taxes are used to finance cuts in pre-existing distortionary taxes. The significance of the revenue-recycling effect is most easily seen if one considers the welfare cost of the first unit of pollution abatement (that is, the impact of raising t_E or $\bar{t}_E$ from an initial value of zero). Under the

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[39] The instrument analyzed here is sometimes referred to as a uniform performance standard. However, we apply the term "performance standard" below to an instrument that limits the emissions rate rather than the quantity of emissions.

[40] To the extent that the quota affects production costs and thereby alters labor supply, it will affect the labor tax base and tax revenues. This effect is captured in the far-right (tax-interaction effect) term in (53).

conditions on utility in subsection 3.2, this increment to the pollution tax t_E produces a revenue-recycling effect that exactly offsets the tax-interaction effect: thus the last two terms in (52) cancel out. Hence, so long as marginal environmental benefits are strictly positive (i.e., $t_E^P > 0$), incremental pollution abatement by way of the pollution tax raises welfare. This result is consistent with traditional first-best analyses. Under the pollution quota, however, positive marginal environmental benefits do not guarantee a welfare improvement from incremental abatement. Under this policy the first unit of abatement produces a strictly positive tax-interaction effect, and there is no revenue-recycling effect to offset it. Expression (53) shows that welfare rises only if the marginal environmental benefits are large enough to overcome this tax-interaction effect. Specifically, a welfare gain requires that

$$\frac{1}{N} t_E^P > \eta t_L w \frac{\partial L}{\partial \bar{E}} \tag{54}$$

Thus, in a second-best setting, the choice between a pollution tax and pollution quota can affect not only the level but also the sign of the welfare impact!

In subsection 2.6.3 we observed that when revenues from a carbon tax are returned lump-sum, environmental benefits must exceed a certain threshold value for such pollution taxes to yield an efficiency improvement. Similarly, under non-auctioned pollution quotas the absence of the revenue-recycling effect implies that environmental benefits must also exceed a threshold value before efficiency gains become possible.

The efficiency advantage of the emissions tax over the emissions quota is premised on the idea that revenues from the emissions tax are used to finance cuts in pre-existing distortionary taxes. If, instead, the revenues from the emissions tax were returned in lump-sum fashion, the revenue-recycling effect would disappear and this efficiency advantage would vanish. Conversely, the disadvantage of the emissions quota stems from the fact that the quotas are not auctioned, yield no revenues, and thus do not exploit the revenue-recycling effect. Auctioned quotas whose revenues finance cuts in distortionary taxes would suffer no disadvantage relative to the emissions tax considered here. Thus, what is crucial to the efficiency impact is whether the policy manages to counter the tax-interaction effect by exploiting the revenue-recycling effect.

There is another way to interpret the parallel results under (non-auctioned) emissions quotas and under emissions taxes with lump-sum replacement of the revenues. Under both of these policies, the government effectuates a lump-sum transfer to households, either explicitly or by generating untaxed quota-related rents. In a second-best setting, such transfers are costly because they ultimately must be financed through distortionary taxes.[41] Hence the costs of achieving given emissions reductions through pollution taxes with lump-sum replacement, or through non-auctioned pollution quotas, are greater than the costs under a pollution tax (or auctioned quota) with revenues devoted to cuts in the marginal rates of pre-existing distortionary taxes.

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[41] Fullerton and Metcalf (2001) emphasize the importance of policy-induced rents in analyzing the different efficiency costs of incremental pollution taxes, quotas, and technology restrictions.

For given levels of abatement, the efficiency advantage of pollution taxes (with revenues devoted to cuts in marginal tax rates) over non-auctioned quotas rises with the size of the pre-existing tax rate on labor. This occurs because a higher pre-existing tax rate implies a larger revenue-recycling effect.

Goulder, Parry and Burtraw (1997) show that the efficiency advantage of taxes over (non-auctioned) quotas declines with the extent of pollution abatement. In the limiting case of 100 percent pollution abatement (either through a prohibitively high pollution tax or a "quota" of zero) the two policies generate identical efficiency impacts. In this extreme case, neither the pollution tax nor the quota raises any revenue: hence the revenue-recycling effect is absent under both policies and the two policies generate the same outcome. More generally, the *marginal* revenue ($\partial (Et_E)/\partial t_E$ in (52)) generated by a pollution tax usually declines and eventually becomes negative as the pollution tax (or amount of abatement) becomes quite large. At the point where the marginal revenue becomes negative (that is, where the peak of the Laffer curve is reached), the marginal revenue-recycling effect from the pollution tax switches sign -- an increment to the pollution tax reduces tax revenues and thus necessitates an *increase* in the tax rate on labor. Because the *marginal* revenue-recycling effect declines, the total gross costs of pollution abatement increase more rapidly, as a function of abatement, under the pollution tax than under the quota. At 100 percent abatement the total gross costs become identical.[42]

[Figure 5 about here]

Goulder, Parry, and Burtraw (1997) have examined these issues in the context of the regulation of sulfur dioxide emissions from U.S. coal-fired electric power plants.[43] Title IV of the 1990 Clean Air Act Amendments restricts emissions of SO_2 through a system of freely offered (or "grandfathered") emissions permits, which have similar efficiency properties to quotas. An alternative regulatory approach would be to auction the emissions permits or, equivalently, to impose an emissions tax. Figure 5 indicates Goulder, Parry, and Burtraw's estimates of the costs of SO_2 emissions reductions under freely offered permits (actual policy) and under auctioned permits. These estimates stem from a simple numerical general equilibrium model. The two solid lines in the figure are the ratios of total costs in a second-best setting (with a positive pre-existing tax rate on labor equal to 0.4) to total costs in a first-best setting (with no pre-existing tax on labor). In the case of auctioned permits (or pollution taxes), the line is almost perfectly horizontal: this ratio is approximately constant throughout the entire range of possible emissions reductions (0 to 20 million tons). Second-best considerations raise the costs of auctioned permits by about 30 percent, regardless of the extent

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[42] Thus the *marginal* costs of abatement eventually become higher under the pollution tax than under the quota. This implies that if environmental damages are sufficiently large to justify a large amount of pollution abatement, the optimal amount of pollution abatement will be higher under the quota than under the pollution tax. Somewhat less abatement is justified under the pollution tax because further abatement involves a costly loss of revenue. Indeed, the early literature on the revenue-raising capacity of pollution taxes focussed on the sign of the revenue-recycling effect by computing the revenue-maximizing rate in a partial equilibrium setting. See Terkla (1984) and Lee and Misiolek (1986). Lee and Misiolek compute elasticities of the pollution tax base to investigate whether current pollution taxes are set to maximize revenue.

[43] Parry, Williams, and Goulder (1999) apply similar models to compare the costs of carbon dioxide abatement under grandfathered (freely offered) carbon quotas and carbon taxes (or auctioned quotas).

of emissions abatement. In contrast, for the actual policy of freely offered emissions permits, the ratio of total cost is very sensitive to the extent of abatement. Under this policy the ratio begins at infinity[44], but as the level of abatement approaches 100 percent, the ratio of total costs approaches the ratio for auctioned permits. The 1990 Clean Air Act Amendments call for a 10-million-ton (or approximately 50 percent) reduction in SO_2 emissions. Significant distributional or political objectives may be served by grandfathering (i.e., giving permits out free to existing firms), but Figure 5's results indicate that they come at a high price in terms of the social cost of abatement. At 10 million tons of abatement, annual total costs under the actual policy are estimated to be 71 percent (or $907 million) higher than they would be in a first-best world. As indicated in this figure, more than half of this additional cost could be avoided by auctioning the permits or employing an SO_2 tax. These results indicate that pre-existing taxes and the presence or absence of revenue-recycling exert a substantial impact on the costs of environmental policies.

4.1.2 Tradeable emissions permits

Up to now we have abstracted from the considerable heterogeneity among producers within a given industry. In fact there is considerable heterogeneity of this sort, and this poses significant regulatory challenges. We have just noted that non-auctioned emissions quotas suffer a disadvantage relative to taxes because they fail to generate revenues and thus cannot exploit the revenue-recycling effect. In the presence of heterogeneity, another disadvantage may arise, depending on whether the quotas are tradeable. Efficient pollution regulation requires that marginal costs of abatement be equal across sources. If regulators impose non-tradeable pollution quotas, they are unlikely to have sufficient information to impose such quotas in a way that succeeds in equating the firms' marginal abatement costs. In contrast, the imposition of a pollution tax (or of tradeable pollution quotas) encourages firms to equate their marginal costs of abatement to the value of the pollution tax. Thus, if firms within the polluting industry face the same tax, the tax will promote equality of marginal abatement costs.

Despite this potential efficiency advantage of taxes, regulators are often reluctant to introduce them, in part because of political opposition connected with the fact that taxes require firms to pay for each unit of emissions, while quotas do not. A system of tradeable emissions permits may offer a partial solution to this dilemma. Such a system has the potential to yield a cost-effective allocation of abatement effort (equality of marginal abatement costs across firms) while, like quotas, enabling firms to produce a certain amount of emissions without being charged for it.

Tradeable emissions permits systems were first described in theoretical terms by Crocker (1966), Dales (1968), and Montgomery (1972). Subsequently, Hahn and Noll (1982), Tietenberg (1985), and others have shown how such systems could be implemented in realistic regulatory contexts. Under such a system, firms are allocated permits entitling them to certain levels of emissions over a given period of time. Firms can trade these permits and thereby either augment or reduce their emissions entitlements. In theory, permits trades lead to an

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[44] This is in keeping with the fact that the intercept of the marginal cost function is positive for this policy in a second-best world and zero in first-best world.

equilibrium in which marginal costs of pollution abatement are equalized across firms -- thus the equilibrium achieves given overall abatement targets cost-effectively.[45]

The basic workings of a tradeable permits system are as follows. Suppose that regulators issue to firms a total of Z pollution permits, where each permit entitles its owner to one unit of pollution emissions (over a given interval of time). Let z_{0j} represent the number of permits initially allocated (free) to firm j. Firms decide to purchase additional permits or sell some of their permits in order to minimize their costs. Let e_{0j} represent the firm's "unconstrained" emissions level, that is, the amount of emissions that the firm would generate if there were no regulation, and let e_j denote the firm's chosen emissions level after the implementation of the permits market.

The firm's problem is choose the emissions level e_j to:

$$\min_{e_j} \; c(e_{oj} - e_j) + p(e_j - z_{oj}) \tag{55}$$

where e_{0j} - e_j represents the firm's level of emissions abatement, $c(.)$ is the firm's abatement cost function, and p is the market price of permits. The second term in (55) indicates that to be entitled to generate emissions in excess of the amount z_{0j}, the firm must purchase the additional permits $e_j - z_{0j}$; similarly, if the firm wishes to reduce its emissions below z_{0j}, it can sell its excess permits $z_{0j} - e_j$. The first-order condition for this problem is:

$$-\partial c/\partial e_j = p \tag{56}$$

Firms purchase or sell permits until the marginal cost of abatement equals the price of a permit. A firm whose current stock of permits implies lower marginal costs of abatement than p will wish to sell permits (and be compelled to abate more); a firm whose current stock implies higher abatement costs than p will wish to purchase more permits. The market price of permits adjusts to a level that clears the permits market. In equilibrium, marginal abatement costs of all firms are equated to the market price, p. Thus, purchases and sales of permits generate production efficiency.[46]

Tradeable permits systems are a hybrid of quantity- and price-based regulations. They are quantity-based in that the total acceptable amount of emissions is set by the regulatory authority (in the choice of Z). They are price-based in that market forces determine the equilibrium prices of permits and the ultimate allocation of permits across firms. Because they help bring marginal abatement costs into alignment, they tend to be able to achieve given pollution-reduction targets at lower cost than would be possible under systems of mandated (non-tradeable) emissions quotas. We mentioned that a tradeable permits system has been implemented in the U.S. as part of the regulation of SO_2 emissions from coal-fired electric

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[45] In practice, the efficiency of tradeable permits markets may be compromised by non-competitive market conditions (see Hahn (1984) and Misiolek and Elder (1989) and transactions costs (see Stavins (1995)).

[46] By achieving production efficiency, tradeable permits systems tend to imply lower output prices relative to a system of non-tradeable quotas that achieves the same aggregate emissions reductions. This means that the tax-interaction effect will be smaller under tradeable permits than under non-tradeable quotas, which augments the efficiency advantage of the permits approach.

power plants under Title IV of the 1990 Clean Air Act Amendments. Tradeable permits programs have also been introduced in the U.S. to control the lead-content of gasoline from petroleum refineries, to reach compliance with the Montreal Protocol's mandated reductions in the production of chlorofluorocarbons (which contribute to the greenhouse effect), and to control emissions of sulfur oxide and nitrous oxide compounds from stationary sources in the Los Angeles airshed.[47] The Los Angeles program is estimated to yield cost savings of 40-50 percent over the period 1995-2010 relative to a system in which the same aggregate emissions reductions were achieved in the absence of trades.

It should be noted that the adoption of a tradeable permits system may help foster an efficient allocation of abatement effort, but does not generally guarantee an efficient level of aggregate pollution. The latter requires that the number of permits (Z) be chosen optimally. In addition, systems in which permits are initially freely allocated (or grandfathered) are at a disadvantage relative to emissions taxes in terms of efficiency. Such systems share the drawback of non-tradeable pollution quotas in that they fail to exploit the revenue-recycling effect. An alternative regulatory approach would be for the government to auction the permits. This alternative approach is formally equivalent to introducing an emissions tax. Like an emissions tax, this approach exploits the revenue-recycling effect and involves a smaller efficiency cost than grandfathered permits.

4.1.3 Subsidies to pollution abatement

Another way to discourage pollution emissions is to subsidize the abatement of pollution. In the case of an abatement subsidy, the government effectively grants pollution rights to firms, and obligates taxpayers to compensate firms for any reductions in pollution. This is consistent with the *victim pays* principle whereby the recipients of pollution must pay to induce pollution reductions. In contrast, an emissions tax effectively grants potential pollutees (taxpayers) the right to a pollution-free environment, and obligates firms to pay taxpayers (by paying emissions taxes) for the privilege of violating this right. This is consistent with the *polluter pays* principle whereby the generators of pollution must pay for the privilege of polluting.[48]

Consider the case where the government rewards firms at the rate s for each unit of

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[47] See Stavins (1998) and Tietenberg (1997) for a review of permits trading programs in the U.S.

[48] The victim-pays and polluter-pays principles represent differing initial specifications of property rights. Under the victim-pays principle, society initially offers potential victims the right to be free of pollution, and polluters must pay victims for the privilege of violating that right. In contrast, under the polluter pays principle, potential polluters initially enjoy the right to pollute, and victims must compensate polluters if they wish to be free of pollution. These contrasting initial specifications parallel the different cases considered by Coase (1960) in his famous theorem concerning the possibilities for efficiently solving externalities problems through voluntary agreements by affected parties. Coase's theorem asserts an efficient outcome can be produced under either specification of initial property rights. However, as we discuss below, when one moves from the Coasean setting involving voluntary arrangements to a setting involving government regulation and pre-existing distortionary taxes, it becomes important to examine how different property rights specifications are related to the acquisition and disposition of government revenue. We shall show that the polluter-pays principle has a potential efficiency advantage once these revenue issues are taken into account.

pollution abatement relative to some baseline amount e_0. Thus the firm with emissions e receives the subsidy payment $s(e_0 - e)$. Under these circumstances the firm loses the value s for each positive increment of pollution; hence, at the margin, the cost of emissions is the same as that of a pollution tax at the rate s.

Assume that, prior to regulation, K identical firms were responsible for pollution, with each firm generating emissions equal to e_0. Using the same approach as was employed with emissions taxes, we obtain the following expression for the welfare impact of the abatement subsidy:

$$(dU/ds)/u_C = \frac{1}{N}(s - t_E^P)\frac{\partial E}{\partial s} + \eta t_L w \frac{\partial L}{\partial s} + \frac{1}{N}(\eta - 1)\left[\frac{\partial[(E-E_0)s]}{\partial s}\right] \tag{57}$$

This expression differs from (52) only in that the subsidy s replaces the emissions tax t_E and E-E_0 replaces E in the far-right term representing the revenue-recycling effect. Thus, the subsidy produces the same primary gain and tax-interaction effects as does the emissions tax. This is consistent with the notion that, for a firm with baseline emissions of e_0, an emissions subsidy at rate t is equivalent to an emissions tax of that rate on emissions e plus a lump-sum payment of te_0. The revenue-recycling effect is different under the subsidy, however. Under the subsidy, the revenue-recycling effect works against efficiency, since the government must now raise labor taxes to finance the subsidy. Thus, in a second-best setting, an abatement subsidy suffers an efficiency disadvantage relative to an emissions tax that exploits the revenue-recycling effect because the subsidy must be financed through costly distortionary taxes.[49]

In a model where firms' production technologies do not exhibit constant returns to scale, an abatement subsidy can have an additional efficiency disadvantage by inducing excessive entry (i.e., too many firms).[50] To avoid such additional efficiency costs, the baseline e_0 on which the subsidy is calculated should be positive only for firms that, in the baseline, are actually generating emissions. Potential new entrants should have a value of zero for e_0. However, political considerations might tempt regulators to allow new entrants to enjoy the subsidy, which would require assigning positive values of e_0 to such entrants. As pointed out by Baumol and Oates (1988) and Pezzey (1992), doing so leads to excess entry. Under these circumstances, the lump-sum component of the subsidy, te_0, is no longer truly lump sum, because e_0 now depends on firms' decisions whether to enter the market.

Beyond these differences in efficiency , there are important differences between abatement subsidies and emissions taxes in terms of distribution, where that difference is

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[49] Parry (1998) was the first to provide an analytical general equilibrium treatment of the efficiency cost of abatement subsidies in the presence of distortionary factor (labor) taxes. His analysis of a subsidy to reduction in production of a "dirty" consumption good yields results similar to those we describe here. Parry considers other types of subsidies as well, including a subsidy to a non-polluting ("clean") consumption good. As shown by Fullerton (1997), this latter subsidy policy is functionally identical to (and produces the same efficiency impacts as) a tax on the dirty consumption good.

[50] The present model implicitly assumes that production involves constant-returns-to-scale and that the abatement subsidies are awarded only to existing firms.

represented by the lump-sum transfer sKe_0. In their roles as taxpayers, individuals would abhor the subsidies; but as owners of polluting enterprises, they would embrace them.

4.1.4 Performance standards

Much environmental regulation takes the form of performance standards -- ceilings imposed on the amount of pollution emissions per unit of output. Examples include automobile tailpipe emissions requirements and water-quality regulations that impose ceilings on effluent-output ratios. The performance standard can be represented by the constraint, $E/ND \leq \bar{\varepsilon}$, which we assume is binding.

Firms maximize profits subject to the performance constraint. The Lagrangian function associated with this profit-maximization problem is:

$$d(p_D - w_p) - aw_p - \lambda^e(e/d - \varepsilon) \tag{58}$$

where

$d \equiv ND/K$ = per-firm production of the dirty good
$a \equiv A/K$ = per-firm emissions abatement
$e \equiv E/K$ = per-firm emissions (as previously)

and where p_D is the price of the dirty consumption good, and w_p is again the producer wage (which, as before, is normalized to 1). To gauge the efficiency impacts of a performance standard relative to an emissions tax, it is useful to establish that this instrument is equivalent to the revenue-neutral combination of an emissions tax and a subsidy to production of the dirty good D. To see this, notice that under the combination of emissions tax t_E^R and production subsidy s^R, the firm's profit function is:

$$d(p_D - w_p) - aw_p - t_E^R e + s^R d \tag{59}$$

Revenue-neutrality requires that $s^R ND = t_E^R E$, or, equivalently, $s^R = t_E^R \varepsilon$. With $t_E^R = \lambda^e$, the firm's maximization problem under the tax/subsidy policy becomes identical to the Lagrangian under the performance standard, which establishes the equivalence between the two policies. Thus, the subsidy component of the performance standard constitutes the difference between a performance standard and a pure emissions tax. This component gives rise to an additional efficiency cost relative to that of the emissions tax. The added cost arises because the subsidy component makes the price of the dirty consumption good too low from an efficiency point of view.[51] As discussed below, it is possible to rectify this problem by combining a performance standard with a tax on the dirty consumption good.

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[51] Goulder *et al.* (1999) show that at the initial incremental unit of abatement, the performance standard has no efficiency disadvantage relative to the emissions tax. This is the case because the source of the disadvantage -- namely, the subsidy component s^R — approaches zero as the level of abatement and t_E^R approach zero. For a related discussion, see Fullerton and Metcalf (2001).

4.2 Uncertainty and instrument choice

Much of the preceding discussion suggests that environmental taxes enjoy significant efficiency advantages over other instruments for environmental protection. In the real world, however, environmental taxes are employed much less frequently than technology-based regulations or performance standards are. This may partly reflect the inability of lawmakers and the general public to appreciate the efficiency virtues of environmental taxes. It may also attest to the tendency of the political process to avoid the distributional impacts that would stem from emissions taxes, even when the efficiency virtues of such taxes are acknowledged. Still, the reluctance to embrace environmental taxes could reflect some efficiency *dis*advantages of emissions taxes that can arise in more complex settings than those considered so far. The presence of uncertainty, in particular, adds further dimensions to instrument choice, and in some circumstances may militate in favor of non-tax approaches. Moreover, uncertainty and associated costs of monitoring and enforcement may make taxes on output preferable to taxes on emissions, despite the fact that emissions taxes are more closely connected to the externality in question. We take up these issues in this subsection.

4.2.1 Instrument choice under imperfect or costly monitoring

Imperfect monitoring and the choice between emissions taxes and emissions quotas

In general, regulators lack perfect information as to the extent to which particular firms are complying with pollution-abatement rules. Under such circumstances, firms may exceed applicable pollution standards or they may under-report emissions in submitting emissions-tax payments. Harford (1978) analyzed the behavior of risk-neutral firms under pollution quotas (standards) or taxes in this setting.[52] In Harford's model, the government imposes fines on firms that are found to violate pollution regulations. The expected penalty (the product of the probability of detection and the size of the fine if a violation is detected) is an increasing function of the level of violation. Under pollution quotas, firms choose a level of emissions that equates the marginal increase in the expected fine with the marginal benefit (cost reduction) from a higher level of pollution. If the marginal penalty is an increasing function of the size of the violation, a tighter pollution standard raises the marginal penalty associated with any given level of pollution and therefore implies that firms will optimize at a lower level of pollution.

Under pollution taxes, the firm chooses both the actual level of pollution and the reported amount of pollution. Tax payments are based on reported pollution. The violation is the difference between actual and reported pollution. Harford finds that it is optimal for firms

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[52] Other studies of environmental regulation under imperfect or costly monitoring include Downing and Watson (1974), Harrington (1988), Lewis (1996), and Swierzbinski (1994).

to choose levels of actual pollution at which marginal abatement costs equal the tax rate.[53] The scale of the penalty function affects reported pollution, but not actual pollution. This suggests a potential advantage of emissions taxes over quotas when emissions cannot be perfectly monitored. If the emissions tax rate is set optimally, then the tax will generate the efficient level of actual pollution. In contrast, there is no simple way to induce an efficient pollution level under the quota.

Costly monitoring and the choice between emissions taxes and output taxes

Imperfect or costly monitoring can also affect the choice between emissions taxes and output taxes. An attraction of emissions taxes is that they produce both input-substitution and output-demand effects that contribute to efficient emissions reductions. The input-substitution effect is the substitution of non-polluting inputs for inputs associated with pollution. The output-demand effect is the substitution of other goods or outputs for the (now higher priced) good whose production involves pollution. While emissions taxes generate both effects, output taxes produce only the output-demand effect. In the absence of uncertainty, this makes output taxes less efficient than emissions taxes as instruments for reducing emissions.

As pointed out by Baumol and Oates (1988), output taxes may have a compensating advantage because it may be less costly to monitor output than to monitor emissions. This potential advantage must be weighed against the disadvantage of omitting the input-substitution effect. Schmutzler and Goulder (1997) employ a model in which monitoring emissions is costly but monitoring output involves no cost. They find that, depending on the scope of monitoring costs, the input-substitution effect, and the output-demand effect, the optimal policy will involve either pure emissions taxes, pure output taxes, or a mix of the two. Higher (lower) costs of monitoring emissions, a smaller (larger) input-substitution effect, and a larger (smaller) output-demand effect contribute toward the optimality of pure output (emissions) taxes. If marginal monitoring costs are not too high, a mix of output and emissions taxes may be optimal. This can be seen if one considers starting with a pure emissions tax and then reducing slightly the emissions tax rate while incrementing the output tax (from zero) in a way that keeps emissions constant. The initial substitution of the output tax for the emissions tax does not change the cost (ignoring monitoring costs) of achieving emissions reductions because the significance of losing the input-substitution effect is initially zero. At the same time, substituting the output tax for part of the emissions tax yields a first-order saving in monitoring costs. Hence the mixed policy is superior to the pure emissions tax.[54]

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[53] Specifically, it is optimal for the firm to choose a level of emissions such that marginal abatement costs (or the marginal benefit from emissions) equal the marginal expected penalty. It is also optimal to equate the marginal expected penalty with the tax rate. By transitivity, marginal abatement costs should equal the tax rate at the optimum.

[54] Introducing an output tax instead of an emissions tax is just one example of how regulators can tax activities related to, but imperfectly associated with, emissions. A general examination of this issue is provided by Wijkander (1985), who emphasizes that efficiency depends not only on how taxed (and subsidized) activities are related to emissions but also on how they are related to each other. Cross-effects between related goods can yield counterintuitive results. In particular, a subsidy (rather than a tax) on a complement to emissions may be optimal. The reason is that it alleviates the distortions due to the imperfect link between emissions and another complementary good, which is taxed.

Using two-part instruments to overcome monitoring problems

Monitoring costs can be reduced, and efficiency enhanced, by employing two-part instruments. In subsection 4.1.4 we observed that a performance standard is equivalent to an emissions tax plus a subsidy to output. This implies that a performance standard, combined with an appropriately scaled tax on output, is equivalent to an emissions tax. The output-tax component of this two-part instrument neutralizes the efficiency disadvantage of the performance standard relative to the emissions tax.

Eskeland and Devarajan (1995) analyze an option like this in the context of air pollution in Mexico City. They demonstrate that adding a tax on gasoline to a system involving mandated automobile pollution-reduction technologies yields efficiency gains, and that the resulting two-part system approximates the impact of a tax on automobile emissions.[55] The addition of the gasoline tax is equivalent to the removal of the mandated technology's implicit subsidy to automobile use; hence it helps remove the efficiency disadvantage of the mandated technology relative to a tax on emissions.

A deposit-refund system is another important example of a two-part instrument designed to overcome monitoring problems. Under such a system, consumers pay a surcharge when purchasing products whose improper disposal would lead to environmental harm. The deposit is refunded if the consumer returns the product to an approved center for recycling or proper disposal. Thus the refund component helps overcome the difficulty of monitoring improper disposal.[56]

Fullerton and Wolverton (1997) show that difficulties of monitoring "dirty" inputs can be overcome through the combination of a tax on output and subsidy to "clean" inputs. This two-part instrument is equivalent to a tax on the "dirty" input. Thus, for example, if the use of coal by electric power plants is difficult to monitor, the effect of a coal tax can be duplicated by the combination of a tax on electricity output and a subsidy to all inputs to electricity other than coal. Fullerton and Wolverton point out that a deposit-refund system is much like this combined tax and subsidy. The deposit on batteries is like an output tax, and the refund for property battery disposal is akin to a subsidy to a clean "input" (a clean method for using and disposing of the battery).

Liability Rules as Alternatives to Taxes in the Presence of Uncertainty

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[55] Some of the differences between their two-part instrument and an emissions tax may be due to the fact that they combine an output tax with a mandated technology rather than a performance standard. The mandated technology does not provide the same incentives for input-substitution inherent in a performance standard. For further analysis of this issue see Goulder, Parry, Williams, and Burtraw (1999).

[56] For a theoretical exposition of deposit-refund systems, see Bohm (1981). Such systems have been implemented in the U.S., Canada, and some European countries through "bottle bills" intended to control litter from beverage containers and reduce the flow of solid waste from landfills. See Menell (1990). In the U.S. a deposit-refund system has been applied to lead-acid batteries as well.

One can think of environmental damages as a function of various activities by households or firms. Consider in particular the case where the damage or harm, *h*, is a function of the vector ***x*** of actions taken by a firm: $h = f(x)$. The vector ***x*** might represent productive inputs; it could also represent a vector of emissions or other by-products from production. The important distinction is between various firm-level phenomena (given by ***x***) and the harm *h* that results from them. If the function *f* is known by the regulator, then in principle the regulator could achieve the same outcome either by taxing the harm *h* or by taxing different vectors ***x*** according to the harm that they generate.

Typically, regulators will not know the function *f* with certainty. Moreover, the harm *h* associated with a given vector ***x*** might have a stochastic component. In this case, one can associate with each ***x*** a distribution of harms, *H*, where $H = g(\mathbf{x})$.

In this situation the regulator could discourage harm through a tax on ***x*** (for example, a tax on fuel inputs or on emissions). The regulator will succeed in bringing about efficient choices of ***x*** if the tax equals the expected harm associated with ***x***: that is, if $t(\mathbf{x}) = E(g(\mathbf{x}))$ for all ***x***,[57] and economic agents (firms and potential victims) are risk-neutral.

However, the regulator may have very little information as to the distribution of harms associated with each ***x***. An alternative is to implement liability rules: penalties based on the actual harm, *h*.[58] A potential advantage of such rules is that they do not require the regulator to observe ***x*** or know the function *g*. The regulator only needs to be able to observe the harm *h* when it occurs and trace it to the responsible firm. In contrast, to achieve efficient regulation through a tax on ***x***, the regulator must be able to monitor ***x*** perfectly and must know the function $E(g(x))$.

One can imagine circumstances when liability rules will be considerably more attractive to the regulator. For example, when ***x*** is a large vector -- as when potential harm derives from activities of the firm along a great many dimensions (safety, personnel, upkeep, etc.) – it might be especially difficult to devise a tax that captures expected harm. This is the case both because the regulator would not be able to observe ***x*** and because it would have a very inexact idea of how this complicated behavior affects the probability of harm. Circumstances of this sort are fairly common, which may help explain why liability rules sometimes can be more important in dealing with externalities (in environmental contexts and elsewhere) than environmental taxes. At the same time, in some circumstances liability rules may be less attractive than taxes. Such circumstances seem to apply in the paradigmatic case of pollution-generation -- where the source of harm is an identifiable pollutant stemming from a production plant. In this case, it may be easier to track ***x*** (which may be a scalar) than the produced harm (which may be difficult to trace back to its source). In this case a pollution tax has an advantage over a liability rule.

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[57] We abstract from the issue of prior distortionary taxes. In the presence of such taxes, efficiency is achieved when $t(x) = E(g(x))/MCPF$.

[58] For a further discussion of the economics of liability rules, see Section 2 of the chapter by Kaplow and Shavell in this volume and the references cited therein. This discussion concerns what are termed *strict* liability rules. These contrast with negligence rules and other legal provisions assigning liabilities based on harm. See Kaplow and Shavell (2001) for a discussion.

4.2.2 Uncertainty about costs and benefits and the choice between price-based and quantity-based instruments

We have analyzed how, in a second-best setting, the ability of emissions taxes to raise revenue and exploit the revenue-recycling effect yields an important efficiency advantage of such taxes over non-auctioned emissions quotas. In the presence of uncertainty about abatement costs or environmental damages, further issues arise that can either weaken or strengthen the case for emissions taxes relative to emissions quotas.

[Figure 6 about here]

These issues were first addressed formally by Weitzman (1974)[59], who considered the setting where regulators are uncertain as to the marginal costs and marginal benefits of pollution abatement, and must choose between a price-based instrument (that is, a pollution tax) and a quantity-based instrument (that is, a pollution quota or an imposed level of pollution abatement). Weitzman's basic results are heuristically presented in figures 6a and 6b. Figure 6a displays the case where regulators are uncertain as to the costs of emissions abatement. In the diagram, MC_E and MC_R respectively stand for the expected and actual (or realized) marginal costs of abatement, and *MB* represents the known marginal benefits (avoided damages) from abatement. Regulators must must either set an emissions tax t or require a given quantity of abatement, a. (Setting the quantity a is the same as specifying the emissions quota $\bar{e}$, where $\bar{e} = e_o - a$ and e_o represents emissions in the absence of regulation.) Regulators are regarded as risk-neutral and aim to maximize expected net benefits from emissions reductions.

If the uncertainty as to the position of the *MC* schedule is symmetric, the tax rate that is optimal *ex ante* is the rate t^* in the diagram, and the quantity of abatement that is optimal *ex ante* is a^*. These levels equate marginal benefits with the expected marginal costs. *Ex post*, however, neither the tax nor the restriction on the quantity of abatement (or emissions quota) is optimal, since neither promotes abatement at a level that equates *realized* marginal costs (MC_R) with marginal benefits. With the realized marginal cost schedule MC_R in Figure 6a, the optimal level of abatement is a^{**}, which differs from a^* and from a_t, the level of abatement that results under the tax t^*. (When the tax is t^*, a_t is optimal because it equates firms' actual marginal abatement costs to this tax rate.) In Figure 6a, the efficiency losses relative to the *ex post* optimum are shown by the shaded triangles. The tax implies the loss represented by the triangle ABC; the quantity regulation implies the loss given by the triangle CDE. In this case, the loss is substantially larger under quantity-based regulation than under the tax. This reflects the relative steepness of the *MC* curve in comparison with the *MB* curve. When the *MB* curve is relatively flat, the tax avoids especially large (and costly) errors in the quantity dimension. It is easy to show diagrammatically that if the *MC* curve is relatively flat in comparison with the *MB* curve, the quota leads to smaller expected losses (relative to the *ex post* optimum) than the tax. These results are confirmed and generalized in Weitzman's mathematical analysis. The

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[59] Weitzman's central results were anticipated in earlier papers by Lerner (1971) and Upton (1971), who employed somewhat less formal analyses. Additional analyses include Adar and Griffin (1976), Fishelson (1976), Roberts and Spence (1976), and Stavins (1996). Newell and Pizer (1998) extend this uncertainty framework to a dynamic setting that considers connections between pollution emissions (flows) and concentrations (stocks).

case of a relatively steep MB curve applies in the neighborhood of serious threshold effects. If global climate change, for example, is characterized by a threshold where small increases in emissions would cause significant climate change, then near this threshold the marginal benefit curve will be very steep. In such a situation quotas or other quantity-based instruments may be preferred.

In contrast, uncertainty on the benefit side does not discriminate between taxes and quotas (quantity-based regulation) if this is the only uncertainty or if benefit uncertainty is uncorrelated with the cost-side uncertainty. This is illustrated in Figure 6b, which assumes no uncertainty on the cost side. Here the efficiency loss is ABC under both policies. When there is no uncertainty as to marginal costs, the abatement level a_t chosen by firms under the tax is the same as a^*. Hence the choice of instrument has no bearing on the efficiency loss. If the uncertainty and cost uncertainty are correlated, however, uncertainty on the benefit side affects the relative attractiveness of quotas and taxes.[60]

This analysis has ignored the second-best issues discussed earlier. Second-best considerations have no bearing on the choice, under uncertainty, between emissions taxes and *auctioned* quotas, since auctioned quotas and emissions taxes are equivalent in terms of their tax-interaction and revenue-recycling effects. Thus, Weitzman's analysis provides a useful guide to the choice between taxes and auctioned quotas in both first- and second-best settings.[61] On the other hand, second-best considerations give a premium to emissions taxes over *grandfathered* quotas, for reasons discussed earlier. Uncertainty considerations of the sort we have just discussed could either reinforce or offset this premium.

It is important to recognize that the Weitzman analysis assumes that the government must impose a linear tax on emissions. The choice between taxes and quotas is different when the government can make use of nonlinear taxes. As shown by Roberts and Spence (1976) and Kaplow and Shavell (1997), a nonlinear tax on emissions dominates an emissions quota in the presence of uncertainty about abatement costs and emissions damages. *Ex ante*, it is optimal for the government to introduce a tax schedule which duplicates the schedule of expected marginal damages as a function of emissions. The nonlinear tax schedule expresses a more complex relationship between emissions and damages than can be expressed under either a linear tax or a quota, and this helps it reduce the errors associated with the uncertainty about the actual position of marginal cost curve. Although nonlinear tax schemes are seldom introduced in practice, Kaplow and Shavell contend that such schemes need not be difficult to administer.

5. Distributional Considerations

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[60] This point was briefly noted by Weitzman. Stavins (1996) explores this issue in detail.

[61] Second-best considerations could influence the choice between emissions taxes if they affected the slopes of the relevant marginal cost or marginal damage curves. However, in a partial equilibrium framework Schöb (1996) shows that pre-existing taxes do not alter the relevant slopes, so that Weitzman's first-best choice rule between price and quantity regulation remains valid in a second-best setting.

5.1 Efficiency-equity trade-offs

By assuming homogeneous households, the previous sections abstracted from distributional considerations. Policies were analyzed mainly in terms of efficiency. Now we consider the case where the government is concerned with distributional impacts as well as efficiency.

In environmental policy making, a trade-off often emerges between efficiency and distribution (equity). To illustrate this, we expand the model from Section 2 to include two types of households. The first type, which will be called the "active" household, relies entirely on labor income. The second type, the "inactive" household, obtains income only from government transfers. We assume that transfers are not subject to the tax on labor income but are subject to taxes on consumption.[62] Under these circumstances, higher taxes on consumption reduce the purchasing power of "inactive" households. The relative changes in the demands for the two commodities (45) and (46) become:

$$\tilde{C} = (1-\alpha_Y)(\tilde{w}_R + \tilde{L}) - \alpha_Y(1-\alpha_C)\tilde{t}_D + (1-\alpha_C)\sigma_J\tilde{t}_D \tag{60}$$

$$\tilde{D} = (1-\alpha_Y)(\tilde{w}_R + \tilde{L}) - \alpha_Y(1-\alpha_C)\tilde{t}_D - \alpha_C\sigma_J\tilde{t}_D \tag{61}$$

where α_Y denotes the share of non-labor income in aggregate household income (after labor taxes). Abstracting from pollution taxes on intermediate inputs, we arrive at the following expression for employment:

$$\tilde{L} = \frac{\varepsilon_{LL}^{U}}{\Delta_T}[-\theta_D\,\alpha_C(1-\alpha_C)\,\omega_L(1-t_L)\sigma_J + \alpha_Y S(1-\alpha_C)]\,\tilde{t}_D \tag{62}$$

where:

$$\begin{aligned}\Delta_T \equiv\ & (1-\alpha_Y)(1-\theta_L)\,\omega_L[1-\theta_D(1-\alpha_C)] \\ & - \varepsilon_{LL}^{U}\,[\theta_L\,\omega_L(1-\alpha_Y) + \omega_L\,\alpha_Y + \theta_D(1-\alpha_C)\,\omega_L(1-\theta_L)(1-\alpha_Y)]\end{aligned} \tag{63}$$

Expression (62) indicates that in the absence of government transfers, an incremental environmental tax reform does not affect employment if the initial pollution tax is zero. This corresponds to the earlier results from Section 3. However, if transfers are positive such a reform boosts employment (see (62) with $\theta_D = 0$). In this case the government is able to more than compensate workers for the real income loss due to a higher environmental tax because the tax reform ends up shifting the tax burden from workers to transfer recipients. Thus, real wages and the labor supply increase. Accordingly, the increase in environmental quality is accompanied by a higher level of employment, thereby improving efficiency and reducing the

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[62] Transfer recipients are not compensated for consumption taxes because the price index used to determine real transfers does not include consumption taxes.

labor-market distortion due to the labor tax.[63]

Bovenberg and de Mooij (1994b) offer further analysis of this issue and consider in particular a reform that begins with positive initial taxes (i.e. $\theta_D > 0$). They show that the environmental tax reform can increase employment (and produce the double dividend) only if the reform involves a reduction in the real value of transfers and thus redistributes purchasing power from transfer recipients to wage earners. Their analysis points up a rather robust trade-off between efficiency and equity.[64]

The analysis above abstracted from the distribution of environmental benefits. Environmental taxes differ from other taxes because they not only finance ordinary public goods but also augment the supply of the environmental public good. The distribution of environmental benefits can be such as to create scope for an efficiency-enhancing reform, even when the government must meet the constraints of revenue- and distributional neutrality. For example, if environmental benefits accrue especially to the "inactive" household, these benefits can offset the welfare impact associated with a reduction in the real value of transfers. Hence, under these circumstances, the government might be able to introduce a policy that reduces the real value of transfers while still satisfying the distributional constraint that the overall welfare of this household be maintained. This example illustrates how the distribution of environmental benefits from pollution taxes can potentially "grease the wheels" of tax reform.

5.2 The Pigovian rule reconsidered

The Pigovian rule -- to set taxes equal to marginal environmental damages -- applies the Samuelson condition to the public good of the environment. As noted, if governments have access to individual-specific lump-sum taxes, the Samuelson condition holds: it is optimal for the marginal rate of transformation between the public and private goods to be equal to the sum of the marginal rates of substitution.

5.2.1 Conditions that would resurrect the Pigovian rule

In practice, governments do not have access to individual-specific lump-sum taxes because they cannot observe individual abilities. Instead, they have to rely on observable behavior (i.e., labor income) to distinguish between various households.[65] The previous analysis suggested that in the absence of lump-sum taxes, the Samuelson condition (Pigovian rule) is no longer optimal. However, in an expanded analysis that considers distributional

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[63] Here an efficiency improvement is identified with a potential Pareto improvement.

[64] This model indicates, more generally, that efficiency gains can be reaped only by reducing the real value of transfers. The government need not employ the environmental tax reform to achieve such gains. In this model, the government could reap these efficiency gains more directly by cutting nominal transfer payments, by subjecting transfers to the labor-income tax, or by replacing a tax on labor income by a broad-based tax on consumption.

[65] Specifically, the government observes only labor income and cannot separately observe the wage rate or hours worked.

concerns, the Samuelson condition may apply after all in some special circumstances (see Christiansen (1981), Boadway and Keen (1993), Kaplow (1996), Pirttilä and Tuomala (1997), and Slemrod and Yitzhaki (2000)). The literature on public goods provision has derived the following three conditions which together assure that the Samuelson rule continues to hold even if governments cannot employ individual lump-sum taxes:

-- The government can impose a nonlinear income tax system whose rates can be adjusted to offset the distributional effects of the provision of additional public goods.

-- Households have identical tastes.

-- In homogeneous utility, leisure is weakly separable from (public and private) goods.

When these conditions hold, the optimal level of provision of the public good is given by the Samuelson rule. The reason is as follows. Suppose the government applies the Samuelson condition to determine the level of provision of a public good, and that it provides this good in a way that is distributionally neutral; that is, the (nonlinear) tax system is adjusted so that the benefit enjoyed by any individual from higher environmental quality is exactly offset by the additional taxes paid. If the three conditions hold, then financing the public good in this way leaves each person's incentives unchanged on the labor-leisure margin, and thus it introduces no additional distortion. Thus the Samuelson rule (which, in the context of environmental public goods, is the Pigovian rule) is optimal. The separability condition is necessary to ensure that the ratio between private and public goods does not alter the marginal utility of leisure.[66]

Kaplow (1996) points out the optimality of the Pigovian rule in the special case where the third condition above is satisfied because environmental quality and private goods are separable from leisure in utility. This case is a natural benchmark because it provides the conditions under which efficiency and equity can be separated by perfectly matching targets and instruments. In this case, the income tax takes care of distributional concerns, which allows pollution taxes to be aimed solely at internalizing externalities. Under the conditions specified by Kaplow, the impacts on leisure demand from the provision of the public good and from the taxes that finance it exactly offset one another. Hence financing the public good has no distortionary impact, and the "first-best" Pigovian rule applies.

The Samuelson condition also continues to apply if public goods enter production as a separable intermediate input (i.e., the marginal products of other inputs are unaffected by the level of public goods) and if consumption taxes can be set set optimally (see Christiansen (1981)). This result is closely related to the result derived by Diamond and Mirrlees (1971) that distributional concerns do not justify violating production efficiency if the government can optimally adjust consumption taxes. Intuitively, distributional issues are more efficiently addressed with consumption taxes, which directly affect consumer prices, than with taxes on

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[66] This is closely related to the familiar result derived by Atkinson and Stiglitz (1976) that commodity taxes should be uniform if produced goods are weakly separable from leisure in utility. Intuitively, this latter condition ensures that, compared to the income tax, commodity taxes are less efficient instruments for redistribution. Accordingly, these taxes can be targeted at efficiency, implying uniform commodity taxes.

intermediate goods, which influence consumer prices only indirectly.

5.2.2 Difficulties in meeting those conditions

In practice, however, the conditions that would restore the Pigovian rule are difficult, if not impossible, to obtain. The following issues seem especially relevant.

Imperfect Compensation

Because of information problems and associated administrative costs, the type of nonlinear tax system described above may be infeasible. Governments may find it difficult to identify the workers that suffer inordinately from environmental taxation and to calculate the required adjustment of the income tax to leave the distribution unaffected. The nonlinear tax system prescribed above would thus face serious information problems. These systems may be difficult to administer as well, in part because of the complexities involved in adjusting the tax schedule in the face of new information.[67] Moreover, a nonlinear income tax will not be able to compensate all agents for the effects of the pollution tax if environmental preferences vary within income classes. Finally, governments may not be able to adjust income taxes to offset the distributional effects of environmental policy because of political and institutional constraints.

The absence of sufficient instruments to compensate distributional effects implies that pollution taxes cannot be targeted solely at internalizing pollution. Indeed, the inability to offset the distributional effects of pollution taxes is one of the main obstacles to the introduction of pollution taxes.[68]

Non-separability of utility

If the environmental public good and private goods are not separable from leisure, the Pigovian rule is no longer optimal. Under such circumstances, additional provision of the environmental public good affects the marginal rate of subsitution between leisure and consumption and thereby influences labor supply.[69] If, in particular, environmental quality is a weaker complement to leisure than private goods are, an improvement in environmental quality

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[67] In the absence of nonlinear income taxes, commodity taxation must play a redistributive role. Deaton (1977) investigates how in this case the optimal commodity tax structure should strike a balance between equity and efficiency considerations.

[68] As pointed out by Feldstein (1976), the distributional issues associated with a reform of an existing tax system are rather distinct from those associated with designing a tax system from scratch.

[69] Cremer *et al.* (1998) explore how externalities affect the optimal structure of the nonlinear income tax. They show that externalities may change the formula for the optimal marginal income tax rates if commodity transactions are anonymous and the government therefore cannot levy nonlinear commodity taxes. Intuitively, in the absence of sufficiently rich instruments to control the externality directly through a tax on pollution, it is second-best optimal to address the externality indirectly through the nonlinear income tax.

makes work relatively more attractive, yielding an increase in labor supply and a reduction in the labor market distortion. Hence, under these circumstances the environmental public good should be provided at a higher level than that endorsed by the Pigovian rule.[70]

To consider this more closely, note that if environmental quality is less complementary to leisure than private consumption goods are, the marginal willingness to pay for the environment (i.e. the marginal rate of substitution between environmental quality and private goods) declines with the amount of leisure. This relaxes the self-selection constraint that restricts the amount of redistribution (see Boadway and Keen (1993)). In particular, if high-ability households mimic the low-ability households by collecting the same income, the only difference between the households is that the high-ability households enjoy more leisure. Their marginal willingness to pay for the environment is lower than that of low-ability households - because this willingness to pay declines with leisure. Accordingly, raising the ratio of environmental quality to private commodities raises utility of low-ability households compared to that of the mimicking high-ability households. By relaxing the self-selection constraint, a higher environmental tax allows for a less progressive tax system -- that is, a lower (distortionary) marginal labor tax. In this way, distributional concerns promote a higher level of provision of the environmental public good."[71] However, these concerns negatively affect the provision of environmental quality if, compared to private consumption of produced commodities, environmental quality is more complementary to leisure.

The environment as an intermediate input

The Pigovian rule also is suboptimal if environmental quality and productive inputs are not separable. Under these circumstances, the provision of the environmental public good has distributional implications through effects on the relative wages of workers of different skills. If, in particular, environmental quality is more complementary to labor provided by low-ability households ("unskilled" labor) than to labor provided by high-ability households ("skilled" labor), enhancing environmental quality redistributes well-being in favor of unskilled labor. To the extent that society values this redistribution, it would support a higher level of environmental quality than that prescribed by the Pigovian rule. This circumstance could conceivably apply to policies that improve water quality in marine fisheries. This improves the productivity of fishermen, and the resulting distributional impact could support a higher level of regulation than otherwise would be considered justified.[72]

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[70] This result is consistent with expression (25). According to this expression, the lower tax should be imposed on the commodity that is less complementary to leisure. Hence, this commodity should be 'overprovided' in the sense that its marginal rate of transformation should exceed its marginal rate of substitution.

[71] A similar argument holds if preferences are not homogeneous but instead vary with unobservable ability (see Mirrlees (1976)). In particular, the environment should be '"overprovided" if low-ability households feature relatively strong preferences for the environment.

[72] For further analysis of this issue, see Boadway and Marchand (1995).

5.3 Reexamining instrument choice in light of distributional issues

If the three sufficient conditions for the optimality of the Samuelson rule hold (see subsection 5.2.1), efficiency and distributional concerns are best addressed by separate policy instruments. The choice of environmental policy instrument, in particular, need be based only on efficiency considerations. Under these circumstances there is a clear combination of instruments that best meets efficiency and distributional objectives. The optimum here involves providing the level of environmental quality dictated by the Pigovian rule, supplying other public goods according to the Samuelson condition, and employing a nonlinear income tax system that deals with distributional concerns.[73]

In general, the three conditions are unlikely to hold, however. Yet the analyses that identified these conditions provide important lessons relevant to other circumstances. They reveal the importance of considering factor supply effects stemming from the changes in the level of the environmental public good. In addition, they indicate that, where possible, it is useful to assess efficiency impacts subject to the constraint of "distributional neutrality" – the requirement that the distribution of individual well-being remain unchanged across the policies under consideration. Moreover, they suggest that when the policies under consideration are not distributionally neutral -- a typical situation when actual policy alternatives are involved -- differences in distributional effects are relevant to the choice of environmental policy instrument. The relative attractiveness of a given policy instrument will depend not only on efficiency effects but also on distributional impacts and the weights given to those impacts in the social welfare function.[74]

Much will depend on whether the government has sufficient instruments to meet both distributional and efficiency objectives. Environmental taxes, in particular, may become more attractive to the extent that they are part of a larger tax reform package. When it combines new environmental taxes with other reforms that address distributional issues, the government utilizes a large number of policy instruments and the potential for Pareto-improving outcomes increases.

Potential trade-offs between efficiency and distribution (equity) become relevant to the choice among policy instruments identified in Section 4. We observed that in a second-best setting, revenue-raising instruments such as environmental taxes have a potential efficiency advantage over policies like freely offered tradeable permits that do not raise revenue. The former policies exploit this advantage to the extent that revenues are used to finance reductions in the rates of pre-existing distortionary taxes.

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[73] When the three sufficient conditions hold, the optimal level of environmental quality can be provided by emissions taxes or emissions quotas. Adjustments to the nonlinear income tax would offset what otherwise would be an efficiency disadvantage of quotas, namely, their inability to exploit the revenue-recycling effect.

[74] If, in particular, the government previously achieved an optimal distribution of income, then an incremental lump-sum redistribution to any individual has a value equal to the MCPF. Under these conditions, the quota policy's rents also have an incremental value equal to the MCPF. Hence the efficiency disadvantage of the quota would be exactly offset by the value of its distributional impact. See Kaplow (1996) for discussion of related issues.

Buchanan and Tullock (1975) showed that environmental policies, by causing restrictions in output, have the potential to generate significant rents to the regulated firms. The potential to enjoy significant rents has distributional significance and thus is relevant to the choice among environmental policy instruments. Consider, for example, two policies involving tradeable emissions permits. Under one policy, all of the permits are auctioned out to industrial sources of pollution; under the other, the permits are freely provided to these firms. The latter policy enables firms to retain as private rents what otherwise would be government revenue. Buchanan and Tullock pointed out that the latter policies can cause firms' profits to be higher than they would be in the absence of regulation. In keeping with this observation, Bovenberg and Goulder (2000) found that very modest grandfathering (free provision) of emissions permits is consistent with preserving profits. Under a policy in which tradeable permits are employed to limit U.S. emissions of carbon dioxide, only a small percentage (around 10 percent) of the permits must be given out free in order to preserve profits of the regulated fossil fuel industries; a very large percentage can be auctioned. When most of the permits are auctioned, the government's sacrifice of revenue is small and thus the sacrifice of efficiency (relative to the case of 100% auctioning -- the most cost-effective case) is small as well. Only a small share of the permits must be freely provided because the policy produces large potential rents. Firms only need to retain a small share of the potential rents to maintain profits.

Thus, policy makers can address distributional and efficiency objectives by deciding what fraction of potential revenues from an environmental policy will actually be collected. More generally, by introducing more complex policies (including policies in which more than one instrument is invoked), the government gains flexibility in attending to both efficiency and distributional concerns. This may help policies come closer to achieving Pareto improvements and thereby enhance political feasibility.

6. Summary and Conclusions

This chapter has analyzed economic issues surrounding the use of taxes and other instruments for environmental protection. It attests to the importance of general equilibrium effects – in particular, interactions between environmental policy initiatives and pre-existing distortionary taxes. Because of these interactions, some of the most important efficiency impacts of environmental policies take place outside of the sector, industry, or market that is targeted by the regulation.

Two central ideas explain these interactions and form the basis of many of the results discussed in this chapter. First, environmental taxes and other forms of environmental regulation act as implicit taxes on factors of production because they raise the costs and prices of produced goods relative to the prices of factors, thereby lowering real factor returns. Second, insofar as they function as implicit taxes on factors, environmental taxes and regulations compound distortions posed by pre-existing factor taxes.

6. 1 Optimal tax issues

These ideas underlie, for example, the main results on the optimal setting of environmental taxes. In a second-best setting where distortionary taxes represent a necessary source of revenue, the optimal rate for an environmental tax typically is less than the Pigovian rate. This reflects the fact that environmental taxes compound the distortions of pre-existing taxes -- even after accounting for the value of the revenues raised by these taxes. Consequently, a given environmental tax rate entails a higher cost than it would in a first-best world. Hence the optimal tax rate is lower.

6.2 Costs of revenue-neutral reforms

Tax interactions also explain why revenue-neutral environmental tax reforms (as opposed to optimal tax policies) tend to be more costly in a second-best setting than in a first-best world. In examining revenue-neutral reforms, it was useful to decompose the overall impact on gross cost into a *tax-interaction* effect and a *revenue-recycling* effect. Typical revenue-neutral environmental tax reforms produce a negative (in efficiency terms) tax-interaction effect by raising overall output prices and thereby lowering returns to factors. Such reforms also produce a positive revenue-recycling effect to the extent that they finance reductions in marginal tax rates of pre-existing distortionary taxes. A main lesson from analyses of revenue-neutral environmental tax reforms is that the tax-interaction effect tends to be larger in absolute magnitude than the revenue-recycling effect; hence, revenue-neutral reforms are more costly in a second-best setting than in a first-best world. The intuition behind this result is that environmental taxes generally are more narrow than factor taxes; hence, they are less efficient mechanisms for raising revenue (or more costly in terms of consumption of non-environmental goods) than factor taxes are. The very characteristics of environmental taxes that make them attractive for achieving environmental goals — namely, their focus on particular, pollution-generating activities or processes — make them unattractive as instruments for raising revenue.

The dominance of the tax-interaction effect over the revenue-recycling effect bears on the double-dividend claim about revenue-neutral reforms. The double (i.e., second) dividend arises only if the costs of revenue-neutral environmental reforms are zero or negative, that is, if such reforms reduce the overall gross costs of the tax system. This is an even stronger requirement than the requirement that revenue-neutral reforms be less costly in a second-best world than in a first-best setting. Thus, *a fortiori*, the dominance of the tax-interaction effect over the revenue-recycling effect refutes the double-dividend argument. An important caveat is in order, however. As we have discussed, if the existing tax system is highly inefficient along other, non-environmental dimensions (for example, if capital is excessively taxed relative to labor), there may be scope for the double dividend after all. A double dividend is possible if "green" tax reform helps eliminate pre-existing inefficiencies of this sort. The question arises as to why green tax reform is necessary to deal with these inefficiencies, since in principle they could be addressed more directly through "ordinary" tax reform. This raises difficult political issues that lie beyond the scope of this chapter.

6.3 Instrument choice

Tax interactions are also crucial to the choice between environmental taxes and other, non-tax instruments for environmental protection. Non-auctioned pollution quotas produce the same costly tax-interaction effect that environmental taxes do. But, in contrast with environmental taxes whose revenues are used to finance cuts in distortionary taxes, such quotas fail to enjoy the beneficial (in efficiency terms) revenue-recycling effect. As we have seen, the absence of the revenue-recycling effect puts quotas at a significant efficiency disadvantage: the net efficiency gains (incorporating environmental benefits) from quotas may be much lower than those under environmental taxes. Indeed, in some circumstances the inability to exploit the revenue-recycling effect may make it impossible to generate efficiency improvements through non-auctioned pollution quotas.

The presence of uncertainty about abatement costs and benefits, and the associated costs of monitoring and enforcement, complicate the problem of instrument choice. Once we account for these issues, the efficiency ranking of taxes, quotas, and other instruments (such as performance standards and mandated technologies) becomes less clear. As we have noted, much depends on the nature of the uncertainty and the monitoring and enforcement costs. These complications can at least partly explain why policy makers often have persisted in favoring command-and-control approaches over incentive-based policies.

6.4 Distributional issues

Distributional considerations also complicate instrument choice. Quotas and taxes differ in their distributional impacts, and one of the potential attractions of non-auctioned quotas is that they involve a smaller transfer of wealth from polluters[75] to taxpayers. This distributional aspect has powerful political implications, and helps explain why the political process tends to favor grandfathered permits over auctioned permits or taxes. These distributional attractions need to be weighed against the efficiency disadvantages of quotas. The present chapter could not provide the weights to be assigned to these competing goals, but it was able to clarify the efficiency cost of meeting the distributional objectives.

Some authors have attempted to examine jointly the distributional and efficiency issues. They consider, in particular, how the government might employ a nonlinear tax system to meet all of its distributional objectives (including ironing out the distributional effects of environmental public goods), and employ environmental taxes to serve the goal of providing the optimal amount of environmental quality. If the government has access to a nonlinear tax and if other, special conditions obtain, the Pigovian rule for optimal environmental taxation can apply after all. These conditions are unlikely to prevail in the real world, however. Generally, it is unrealistic to expect that distributional consequences will be ironed out through adjustments to a nonlinear income tax. This means that the Pigovian rule usually will not apply and that distributional consequences of environmental policies have to be accounted for in the choice of environmental policy instruments.

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[75] Or, more precisely, the owners, workers, and consumers that ultimately bear the burden of pollution taxes.

6.5 Areas for Future Research

Although no one can predict with certainty the returns from academic research, the discussion above suggests to us some areas where further research explorations might yield significant payoffs. The analysis of environmental taxation often lacks attention to real-world complications, so that the prescribed remedies become irrelevant to policy discussions. Two key complications are information problems and associated implementation issues; a closer attention to these complications might bring substantial rewards. In the past two decades, progress on the design of marketable pollution permits programs and on deposit-refund systems proved to be very useful to policymakers: tradeable permits helped overcome significant information burdens encountered by regulators in the face of heterogenous producers, and deposit-refund systems helped overcome significant monitoring problems that sometimes bedeviled environmental taxes. Unfortunately, information, monitoring, and enforcement problems persist in many areas where tradeable permits or deposit-refund systems are not feasible. New instruments are needed to deal with these problems.

Another key difficulty with current work is that, too often, efficiency assessments are made in isolation, without attention to distributional impacts. Distributional considerations carry a great deal of political force, and thus studies that integrate efficiency and distributional assessments seem especially valuable. A major challenge to environmental policy making seems to be the design of policies that achieve efficiency goals without producing unacceptable distributional outcomes. Public economics textbooks often suggest that distributional activities should be carried out only by the "distribution arm" of the public sector, leaving regulatory authorities free to concentrate exclusively on efficiency. This separation of functions is intellectually appealing, but unfortunately the political process does not seem to allow such separation of impacts when policy proposals are debated. This suggests a value to research that helps design transfer mechanisms to accompany environmental policies that otherwise would have undesirable distributional consequences.

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Table 1

Marginal Damages from Pollution in the U.S.

(1) Pollutant	*(2) Major Associated Damages*	*(3) Region for Which Damage Is Calculated*	*(4) Marginal Damage (1995 dollars per ton)*	*(5) 1996 Emissions (millions of short tons)*	*(6) Damage as Percent of GDP in 1996 (assuming constant marginal damages)*[a]
Volatile Organic Compounds (VOCs)	health effects, agricultural losses, worsened visibility, materials damage	Northeast U.S.	427 - 2,828	19.09	0.107 - 0.707
Particulate Matter	increased mortality, increased morbidity, soiling	U.S.	505 - 12,819	3.29[b]	0.022 - 0.552
Sulfur Oxides	health effects, agricultural losses, worsened visibility, materials damage, soiling	U.S.	375 - 2,087	19.11	0.094 - 0.522
Nitrogen Oxides	worsened visibility, acute health effects, agricultural losses, materials damage	U.S.	10 - 122	23.39	0.003 - 0.037

[a] Figures in this column apply numbers from column (5) to the ranges in column (4), and express this product as a percentage of 1996 GDP ($7636 billion).

[b] Particulate matter of size 10 microns or less. Excludes "miscellaneous and natural" emissions.

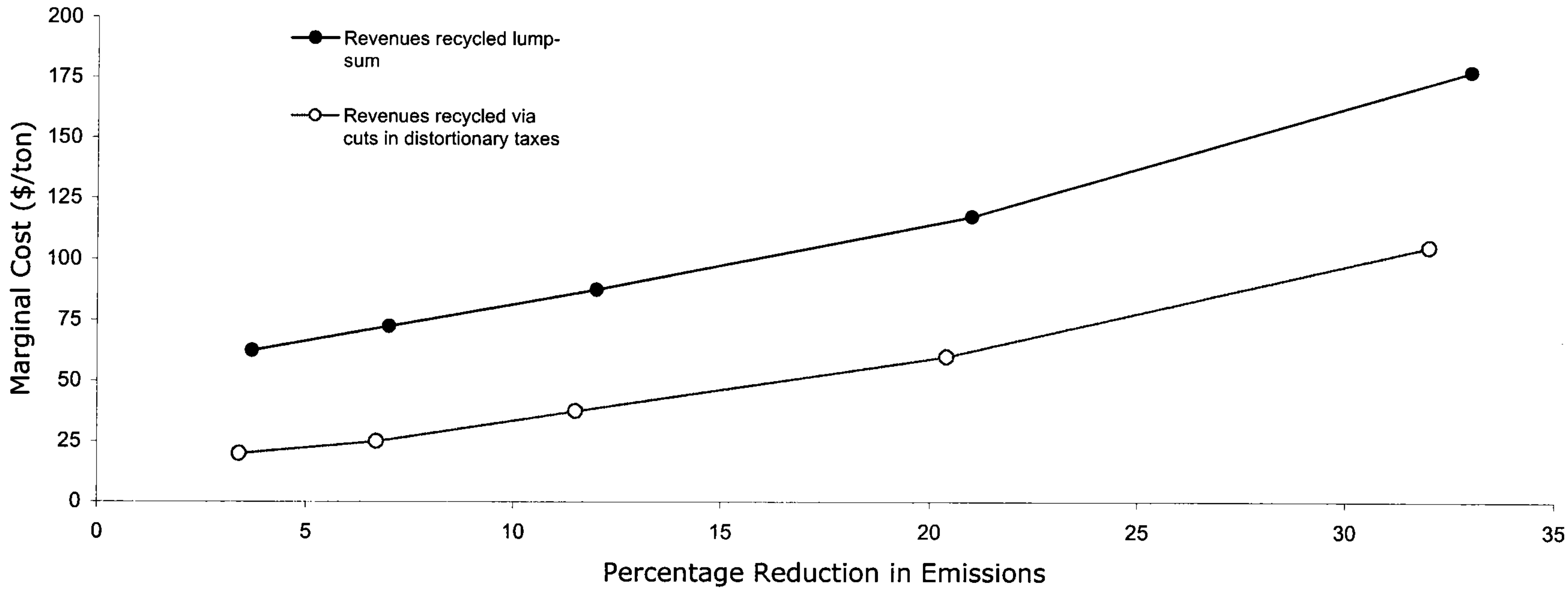
Sources: Climate and Policy Assessment Division, Office of Policy, Planning & Evaluation, U.S. Environmental Protection Agency; National Air Quality and Emissions Trends Report (EPA Document Number 454/R-97-013), U.S. Environmental Protection Agency, 1996.

Table 2

MCPF Estimates

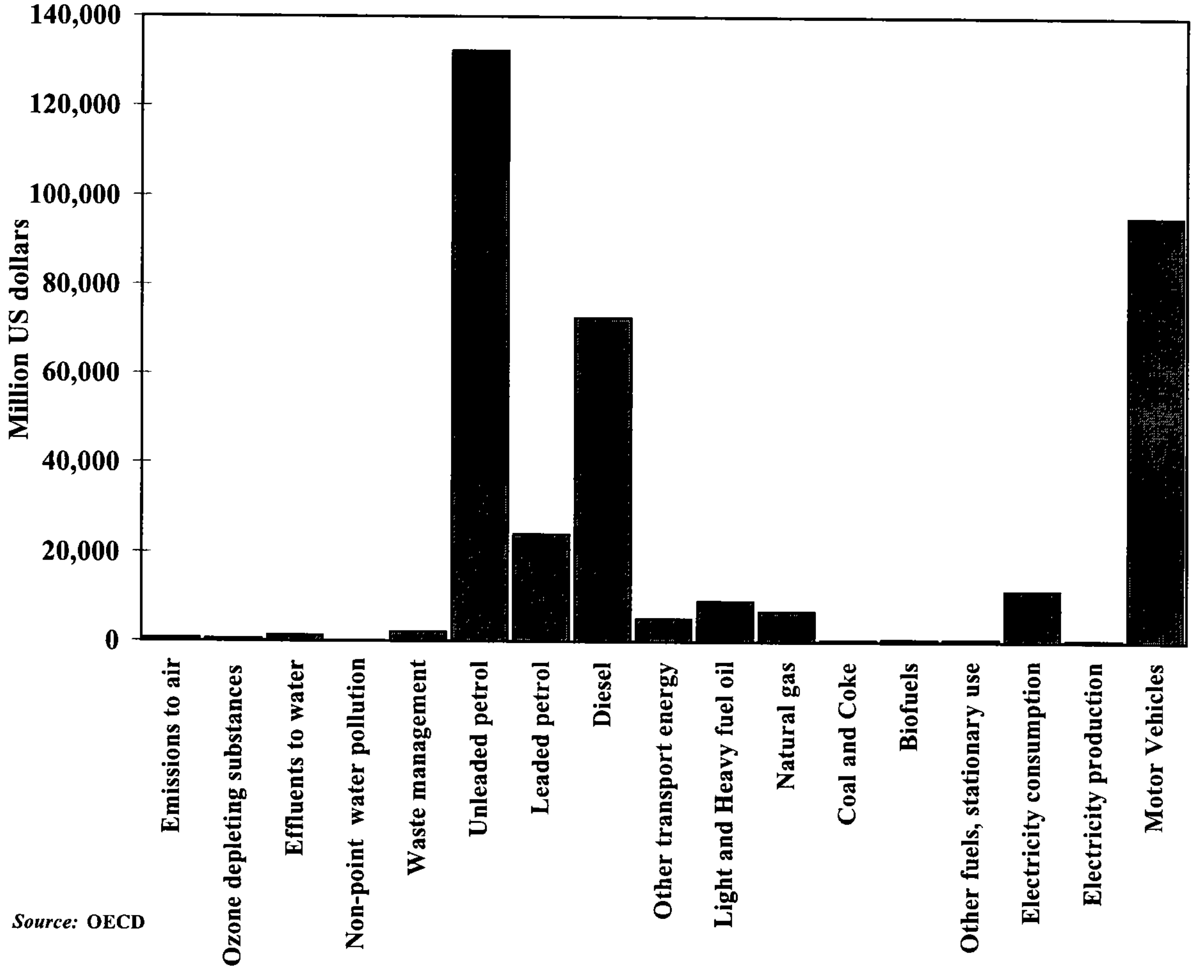
Study	*Taxes Considered*	*Estimate (MCPF per Dollar of Revenue)*
Browning (1987)	U.S. taxes	1.32-1.47
Hannson and Stuart (1985)	Swedish taxes	1.69
Ballard, Shoven and Whalley (1985)	U.S. taxes	1.17-1.56
Bovenberg and Goulder (1996)	U.S. taxes	1.11-1.41

Figure 1
General Equilibrium Marginal Costs of Carbon Dioxide Emissions Reductions*



*These are gross costs: they do not net out the benefits from avoided environmental damage.

Figure 2
Environment-Related Tax Revenue in 21 OECD Member Countries in 1995



Source: OECD

Table 3: Contributions of Environment-Related Taxes to Overall Tax Revenues for OECD Countries in 1997

Country	Environment-Related Tax Revenue (millions of US dollars)	Total Tax Revenue (millions of US dollars)	GDP (billions of US dollars)	Environment-Related Tax Revenue as Percent of Total Tax Revenue	Environment-Related Tax Revenue as Percent of GDP
Austria	4,865	91,297	206.7	5.33	2.35
Belgium	5,715	111,411	243.6	5.13	2.35
Canada	13,242	236,225	640.0	5.61	2.07
Czech Republic	1,501	20,460	53.0	7.33	2.83
Denmark	7,780	84,233	168.4	9.24	4.62
Finland	3,963	56,526	122.5	7.01	3.23
France	30,156	635,746	1,406.0	4.74	2.14
Germany	46,382	782,305	2,114.5	5.93	2.19
Greece	4,746	40,504	120.0	11.72	3.95
Hungary	1,292	17,868	45.8	7.23	2.82
Iceland		2,377			
Ireland	2,381	25,772	78.5	9.24	3.03
Italy	37,790	515,237	1,159.5	7.33	3.26
Japan	71,388	1,202,355	4,195.3	5.94	1.70
Korea	13,333	101,880	476.9	13.09	2.80
Luxembourg	504	7,303	17.5	6.89	2.88
Mexico		67,763			
Netherlands	13,668	158,109	376.7	8.64	3.63
New Zealand	1,108	23,553	64.9	4.70	1.71
Norway	5,570	65,676	155.0	8.48	3.59
Poland	2,350	55,936	143.2	4.20	1.64
Portugal	3,670	34,919	104.3	10.51	3.52
Spain	11,964	188,355	558.6	6.35	2.14
Sweden	7,276	122,252	237.5	5.95	3.06
Switzerland	5,020	86,729	256.3	5.79	1.96
Turkey	5,846	53,007	190.2	11.03	3.07
United Kingdom	38,247	464,383	1,315.7	8.24	2.91
United States	77,333	2,299,136	8,121.0	3.36	0.95
Total	417,090	7,551,318	22,571.6	5.52	1.85

Source: **OECD**

Figure 3

Typical First-Best, Partial Equilbrium Framework
For Analyzing Efficiency Effects of an Environmental Tax

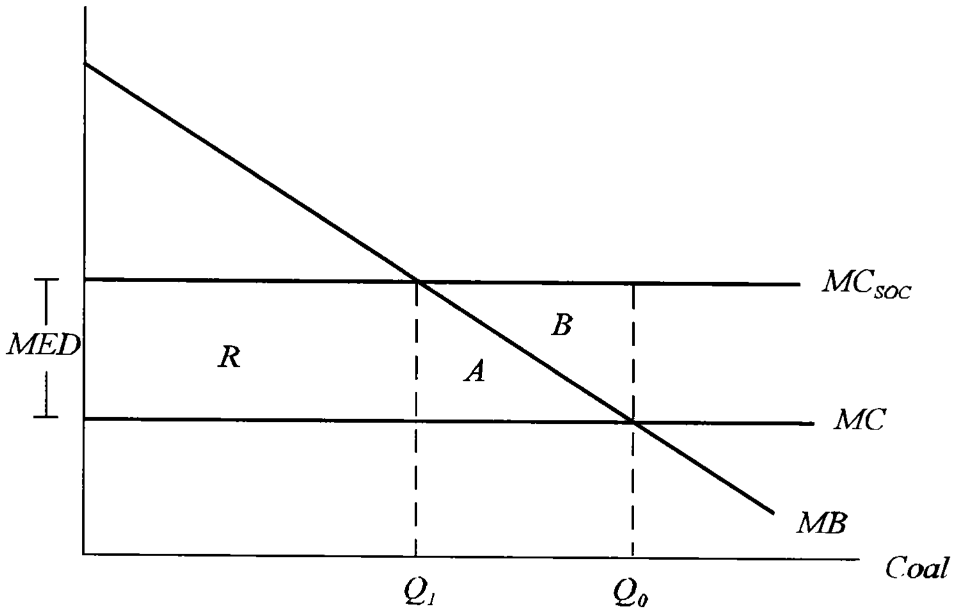


Figure 4

Marginal Costs of Pollution Abatement in Second-Best Setting

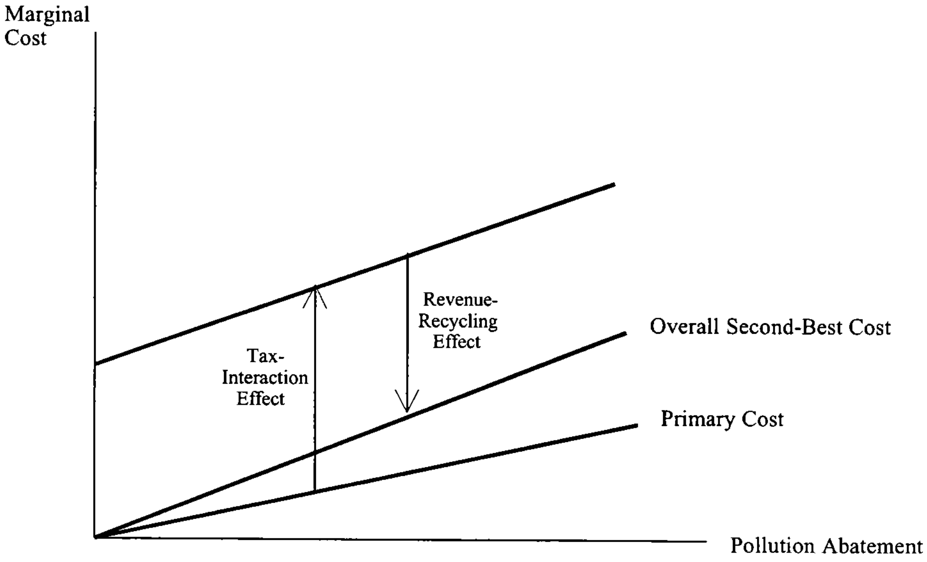


Table 4: Numerical Assessments of Welfare Impacts of Revenue-Neutral Environmental Tax Reforms

Model	Reference	Country	Type of Environmental Tax	Method of Revenue Replacement	Welfare Effect
DRI	Shackleton *et al.* (1996)	U.S.	Phased-in Carbon Tax[a]	Personal Tax Cut	-0.39[b]
Goulder	Goulder (1995b)	U.S.	$25/ton Carbon Tax	Personal Tax Cut	-0.33[c]
"	Goulder (1994)	U.S.	Fossil Fuel Btu Tax	Personal Tax Cut	-0.28[c]
Jorgenson-Wilcoxen	Shackleton *et al.* (1996)	U.S.	Phased-in Carbon Tax[a]	Capital Tax Cut	0.19[d]
LINK	Shackleton *et al.* (1996)	U.S.	Phased-in Carbon Tax[a]	Personal Tax Cut	-0.51[b]
Proost-van Regemorter	Proost and van Regemorter (1995)	Belgium	Hybrid of Carbon and Energy Tax	Payroll (Social Security) Tax Cut	-3.45[d]
Shah-Larsen	Shah and Larsen (1992)	U.S.	$10/ton	Personal Tax Cut	-1049.[e]
"	"	India	"	"	-129.
"	"	Indonesia	"	"	-4.
"	"	Japan	"	"	-269.
"	"	Pakistan	"	"	-23.

Notes: (a) Beginning at $15/ton in 1990 (period 1), growing at five percent annually to $39.80 per ton in 2010 (period 21), and remaining at that level thereafter. (b) Percentage change in the present value of consumption; the model does not allow for utility-based welfare measures. (c) Welfare cost per dollar of tax revenue, as measured by the equivalent variation. (d) Equivalent variation as a percentage of benchmark private wealth. (e) Compensating variation in levels (millions of U.S. dollars).

Figure 5

Total Costs of Auctioned Permits (Emissions Tax) And Grandfathered Permits in a Second-Best Setting

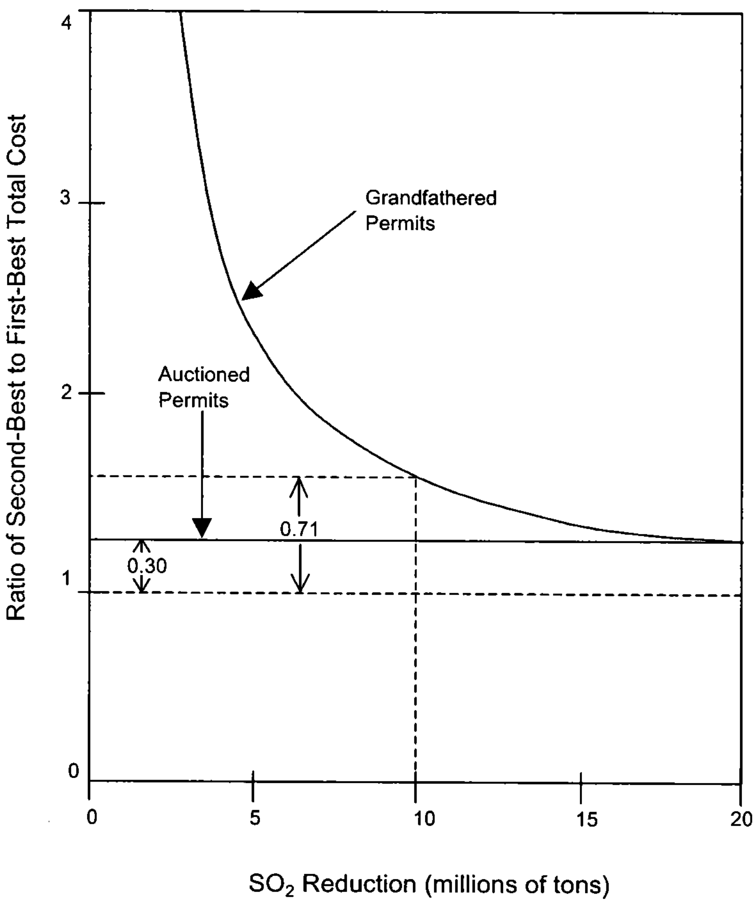
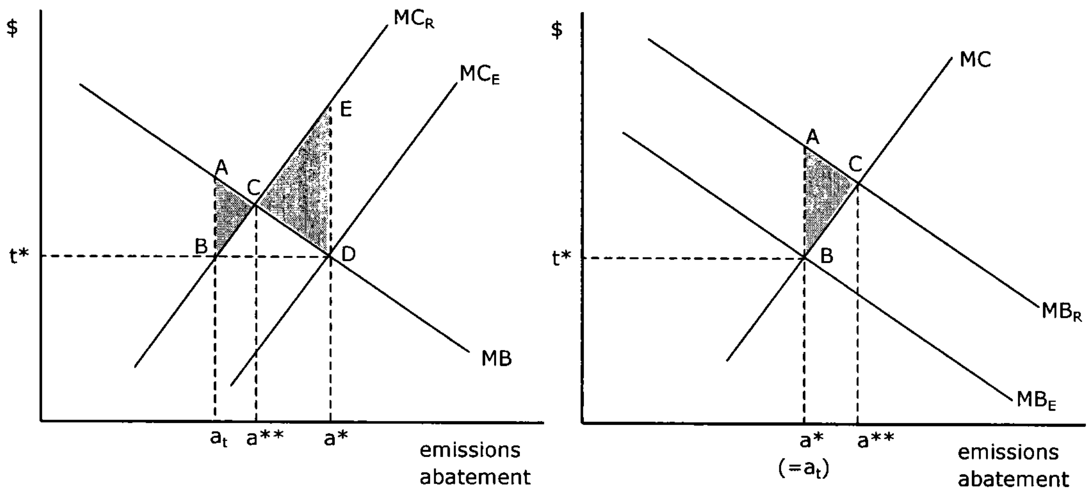


Figure 6
Uncertainty and the Choice of Policy Instrument



6a: Cost Uncertainty

6b: Benefit Uncertainty