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Chapter Author: Don Fullerton, Inkee Hong, Gilbert E. Metcalf

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A Tax on Output of the Polluting Industry Is Not a Tax on Pollution
The Importance of Hitting the Target

Don Fullerton, Inkee Hong, and Gilbert E. Metcalf

1.1 Introduction

A tax per unit of pollution can induce all the cheapest and most efficient forms of pollution abatement (Pigou 1932). To reduce its tax liability, the firm can switch to a less-polluting fuel, add a scrubber, change disposal methods, or otherwise adjust its production process. These methods of substitution in production reduce the pollution per unit of output. In addition, the tax raises the overall cost of production, so the higher equilibrium output price chokes off demand for the output. Thus the tax has a substitution effect that reduces pollution per unit, and an output effect that reduces the number of units.

Yet few actual taxes are targeted directly on pollution (Barthold 1994). Taxes on gasoline are prevalent around the world, and the use of gasoline is indeed correlated with vehicle emissions. This gas tax might provide some incentive to reduce emissions by driving less, but it provides no incentive to reduce emissions per gallon (such as by adding pollution-control equipment). The United States taxes chemical feedstocks associated with contaminated Superfund sites, and this tax may help reduce pollution, but

Don Fullerton is professor of economics at the University of Texas at Austin and a research associate of the National Bureau of Economic Research. Inkee Hong is a doctoral candidate in the Department of Economics at the University of Texas at Austin. Gilbert E. Metcalf is professor of economics at Tufts University and a research associate of the National Bureau of Economic Research.

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it provides no incentive to use a cleaner production process, to avoid spills, or to use any other method of reducing pollution per unit of chemical input (Fullerton 1996). In Europe, some industrial effluent taxes are calculated using an assumed industrywide rate of effluent per unit output, so the firm cannot reduce its tax by reducing its own effluent per unit (Hahn 1989). These taxes miss the substitution effect.

In this paper, we measure the welfare effect of improperly targeted instruments. We build a simple analytical general equilibrium model with substitution in production and demand by consumers, and we derive second-best optimal tax rates on emissions or on output. These rates are based on preference parameters, technological parameters, and preexisting tax rates. We discuss these optimal tax rates, and then we choose plausible values of the parameters to calculate the effects of a small change in each tax rate. For alternative initial conditions, we use the model to calculate the cost of missing the target: the welfare gain from a targeted tax on emissions minus the gain from an imperfectly targeted tax on output of the polluting industry.

Actual taxes may miss the target for several reasons. First, actual policy may not fully appreciate the importance of hitting the target. Policymakers may have been concerned primarily with equity considerations, trying to ensure that polluting industries are made to pay for pollution—without realizing that the form of these taxes affects incentives to reduce pollution. Second, actual emissions may be difficult or impossible to measure. In these cases, the best available tax may apply to a measurable activity that is closely correlated with emissions. To reduce vehicle emissions, for example, the gasoline tax may be the best available instrument. Third, the technology of emissions measurement is improving over time. Policymakers may be slow to adjust the tax base to reflect the newly reduced cost of measuring a particular pollutant.

We do not measure or model the costs of targeting the tax on pollution, that is, the costs of measurement, monitoring, and enforcement. We only measure the benefits of properly targeting the tax. Thus our results can be taken as a measure of the importance of developing new measurement or enforcement technologies and of reforming the law to take advantage of those technologies. That is, we calculate the improvement over an output tax that can be obtained by a targeted tax on pollution that can capture the substitution effect as well as the output effect.

The next section reviews actual environmental taxes around the world and describes the extent to which they miss the target. Section 1.3 reviews existing economic literature on this subject. Most early economic models ignored the substitution effect, assuming that pollution was associated only with output. More recently, others model substitution in production, but assume that the emissions tax is fully available. Schmutzler and Goulder (1997) provide a partial equilibrium model of the difference between an output tax and an emissions tax. Our paper contributes to this literature by providing a general equilibrium model to compare the welfare effects of these taxes.

If emissions cannot be monitored at reasonable cost and policy is limited to a tax on the output of the polluting industry, then how should that tax rate be set? One might think that the imperfection of this blunt instrument would reduce the optimal rate of tax. In our results section, we show that is not the case: The second-best output tax should be set to capture exactly the same output effect that would have been captured by the emissions tax. If the unavailable emissions tax would have raised output price by 12 percent, for example, then the output tax should be set to 12 percent. We also solve for the optimal emissions tax in a second-best world with some fixed preexisting output tax.

Finally, we use plausible parameters to calculate the incremental effects on welfare of slight increases in any preexisting output tax or emissions tax, and we show the welfare gap. We find that the welfare gain from an initial emissions tax is more than twice the gain from an initial output tax. This cost of missing the target does not depend on the size of the preexisting output tax or on the size of the elasticity of substitution in utility, but it does depend on the elasticity of substitution in production. A larger ability to substitute between emissions and other inputs in production substantially raises the importance of hitting the target.

1.2 Environmental Taxes around the World

While the economics literature has long championed the use of market-based instruments (e.g., environmental taxes and tradable permits), most countries have long relied on a system of regulations, including command and control regulations. In the past 10 years, however, countries have begun to shift to the use of environmental taxes of some sort. In this section, we review the types of taxes that are typically used and consider to what extent these taxes "hit the target."[1]

As we noted previously, the problem of targeting environmental taxes accurately in most cases follows from a difficulty in monitoring emissions. This has led Eskeland and Devarajan (1996) to distinguish between direct and indirect instruments to control pollution. Direct instruments require knowledge of actual emissions, while indirect instruments do not. A Pigouvian tax, as developed in textbooks, is a tax on emissions themselves. The difficulty with direct taxes is that monitoring emissions is technologically difficult and administratively complex. Thus, most actual policies fall back

1. Roughly speaking, market-based instruments may be either price-based or quantity-based instruments. Taxes are a form of price-based instrument, while tradable permits are a quantity-based instrument. This paper compares various kinds of taxes, while Fullerton and Metcalf (1997) use a similar model to consider quantity instruments.

on indirect approaches to reduce emissions; the problem of hitting the target can be reframed as a problem of the administrative need to use indirect instruments.

1.2.1 Air Pollution

A variety of taxes are employed around the world to combat air pollution. Sweden applies a charge on actual nitrous oxide (NO_X) emissions of large heat and power producers (final sale only) at a rate of roughly 40 Swedish crowns per kilogram of NO_X ($7.17 per kg) (OECD 1994). For companies without emissions measurement equipment, standard emissions rates (in grams of NO_X per joule) exceed typical average actual emissions. The higher assumed emissions rate provides an incentive for companies to install measurement equipment. Tax collections are rebated to firms on the basis of final energy production. Thus the combination is revenue neutral because it provides a subsidy to low-emitting firms and a tax on high-emitting firms. The Swedish experience suggests that technological limitations on the use of directly targeted taxes may fall with technological progress. Moreover, this tax provides an interesting example of allowing firms to choose whether to be subject to a direct or an indirect tax. For firms that do not adopt monitoring equipment, the tax becomes a tax on fuel consumption; the actual NO_X emissions are irrelevant.

Japan levies a charge on SO_2 emissions, with the rate varying across regions. The tax is based partly on historic emissions (1982–86) and partly on emissions from the previous year. The tax rate in 1992 was 124 yen per cubic nanometer for historic emissions, and it was between 95 and 860 yen per cubic nanometer depending on the geographic region in which emissions occurred (OECD 1994). Allowing the rate to vary across geographic region provides the possibility of linking the rate more closely to marginal environmental damages. Whether Japan does in fact link the rates closely to marginal environmental damages is a question beyond the scope of this paper.

Taxes on coal illustrate how technological differences can significantly affect the ability to target emissions directly. A number of European countries levy a tax on the sulfur content of various fuels. Norway levies a charge on the sulfur content of oil. Sweden levies a charge on the sulfur content of oil, coal, and peat. A strict sulfur-content tax is an indirect tax in that it does not require any monitoring of emissions. It also does not provide any incentives to use scrubbers or otherwise reduce sulfur emissions (other than by shifting from high- to low-sulfur-content fuel). Sweden rebates the tax to firms that can demonstrate significant reductions in SO_2 emissions from the use of technologies such as flue gas cleaning. As of 1993, Finland levied a tax differential between standard and sulfur-free oil.

A tax on carbon content can be viewed as a direct tax on CO_2 emissions in the sense that it is economically infeasible to alter the ratio of carbon emissions to carbon content of the fuel in the industrial process.[2] Thus, whatever carbon is embodied in a fuel will be released to the atmosphere upon burning. As of 1992, six Organization for Economic Cooperation and Development (OECD) countries had either explicit or implicit carbon taxes (Denmark, Finland, Italy, Netherlands, Norway, and Sweden). Most of the countries tax different sectors at different rates, with some sectors exempted altogether. These taxes, to our knowledge, do not provide any incentive for carbon scrubbing.

The Montreal Protocol of 1989 required the eventual phasing out of halons and chlorofluorocarbons (CFCs). In the United States, Congress imposed taxes on these ozone-depleting chemicals at the same time that it implemented quantity regulations. The tax rate depends to some extent on the degree of ozone depletion. Merrill and Rousso (1991) note that the purpose of this tax was to capture monopoly rents arising from quantity restrictions. While the tax rate is not explicitly set equal to social marginal damage, it is a direct tax in that these chemicals have a direct relationship to the ozone-depletion damage stemming from their use. They are indirect and thus imprecisely targeted, however, in the sense that CFC emissions to the atmosphere are assumed rather than measured. No distinction is made in the use of CFCs regarding circumstances in which release to the atmosphere is more or less likely.

1.2.2 Water Pollution

Taxes related to water pollution are of two general types: user charges for sewage treatment and wastewater effluent charges. The latter is of more concern to us than the former. Better-targeted taxes would be based on "load," a measure of the pollutants contained in the wastewater. It can be measured on an instantaneous basis (so many parts per million) or on a flow basis (so many grams per hour or day). Sewage-treatment charges for households are based on water consumption rather than load on the treatment plant, and so they serve as an indirect charge. Industry is more likely to be metered with charges based on load. In 1992, for example, Denmark, Finland, Norway, and Sweden all levied charges on firms based on pollution loads exceeding some minimum amount.

In 1976, Germany implemented a water effluent charge for firms (to go into effect in 1981), with different rates for different pollutants (e.g., chemical oxygen demand [COD] and heavy metals). Firms are taxed on the basis of "damage units," defined approximately as the amount of pollution generated by one individual. Damage units are defined in terms of the amount

2. Processes for carbon scrubbing are described in Astarita, Savage, and Bisio (1983), but these technologies generate such a vast amount of solid waste (e.g., carbonic acid or forms of carbonates) that disposal costs become prohibitive. Sulfur scrubbing, on the other hand, involves a small amount of sulfur per ton of coal (or barrel of oil) and so does not lead to such significant sulfur-disposal problems.

of discharge of various pollutants.[3] While the tax is a tax on emissions, certain features of the system make it more an enforcement mechanism for technology standards. In particular, firms get a 75 percent reduction in rates if they can demonstrate compliance with specific technology standards. Thus, the tax might be viewed as a tax on old technology rather than on pollution. To the extent that the tax induces a shift to new, less polluting technology, however, these standards may improve targeting relative to standards that do not induce technology improvement.

1.2.3 Solid and Hazardous Waste

The OECD distinguishes between municipal-waste user charges and waste-disposal taxes. Municipal-waste user charges may be collected as a flat rate, but they are increasingly based on actual waste, and they are used to finance the cost of collection and disposal. In contrast, waste-disposal taxes generate revenues that either go into the general budget or are earmarked for environmental expenditures (e.g., subsidies for recycling). Since no effort is made to monitor the contents of waste, any pollution to groundwater from solid waste in a landfill does not affect the charge to households or to firms producing the waste. In other words, these taxes are indirect taxes with no incentive for shifting the composition of the waste stream.

As of 1992, five OECD countries had some form of tax that they characterize as hazardous-waste taxes. As the U.S. experience makes clear, these taxes may be described only very loosely as taxes on hazardous waste. The United States levies a number of Superfund taxes detailed in Fullerton (1996). These are taxes on petroleum ($0.097 per barrel) as well as on 42 organic and inorganic chemical feedstocks—with rates ranging from $0.22 to $4.87 per ton in 1992. The chemicals to be taxed were chosen to some extent on the basis of their presence in hazardous-waste sites to be cleaned up under the Superfund law. In particular, the tax rates are set to raise a specified sum necessary to clean up Superfund sites, where required collections on oil and chemicals are based on their relative importance in waste sites. These are indirect taxes at best, and, like many of the taxes discussed here, they do not provide incentives for emissions reduction. They might reduce the purchase of the petroleum or chemical products, but they do not influence their handling, their use, or the amount that becomes waste.

For hazardous waste, the form of disposal affects the marginal environmental damages quite dramatically. This fact suggests that a tax on the disposal of hazardous waste could reduce welfare if it shifts the mode of disposal from safe, monitored disposal sites to illegal dumping in unmonitored, unsecured sites. The welfare impact of a tax on hazardous-waste disposal will depend in an important way on the cost of monitoring dis-

3. The following amounts of effluents (in addition to others not listed) each add up to 1 damage unit: 50 kg of organic matter (COD), 3 kg of phosphorus, or 1 kg of copper and copper compounds (Anderson and Lohof 1997).

posal activities as well as the cost of enforcement and illegal disposal activities. The more costly it is to monitor disposal activities and enforce rules for proper disposal, the more likely it is that a tax on hazardous-waste disposal will reduce welfare.

As of 1992, several countries levied taxes on the disposal of automobile batteries (Canada, Denmark, Portugal, and Sweden) with differing rates based on the type of battery. Some countries levy charges on waste-oil disposal (Finland, France, Italy, Norway, and the United States). Numerous countries levy charges on packaging. Other taxes are levied on disposable diapers (Canada), car tires (Canada and the United States), and plastic shopping bags (Italy).

1.2.4 Taxes on Products Associated with Pollution

Product taxes are indirect taxes by definition. As of 1992, 10 OECD countries levied some form of one-time sales tax differential on cars based on weight (Canada), degree of compliance with emissions standards (Belgium, Greece, Japan, Netherlands, and Sweden), fuel efficiency (Canada, Japan, and the United States), or the lack of a catalytic converter (Finland, Germany, and Norway).

In 1992 some OECD countries levied higher annual taxes on vehicles that lack a catalytic converter (Austria and Denmark) and on average emissions for major pollutants for each class of car (Germany). All OECD countries levy excise taxes on gasoline. In addition, many OECD countries levy a higher tax on leaded than unleaded fuel. For example, Denmark, Finland, and Norway levied a surtax on leaded fuel of $0.11 per liter in 1992.

1.2.5 Summary

This brief survey of environmental taxes suggests that few taxes anywhere are precisely targeted taxes on emissions. The failure to target emissions precisely may follow from significant costs associated with measuring emissions, from costs associated with monitoring point- and non-point-source emissions at reasonable cost, and—as a consequence—difficulties with preventing tax evasion and illegal disposal activities.[4] To some extent, however, the imprecise targeting may result when policymakers do not fully appreciate the costs of missing the target.

1.3 Prior Literature

The literature on environmental taxes is extensive. Most papers, however, do not focus on the distinction between taxes on emissions and taxes on inputs or outputs that are imperfectly correlated with emissions. In an early example that is typical of this literature, Sandmo (1975) carries out

4. Siniscalco et al. (chap. 8 in this volume) discuss the possibilities of voluntary compliance with pollution control rules.

an optimal tax exercise in the presence of externalities. One of the consumption goods enters the utility function directly as a negative externality. Because of the one-for-one relation between the good itself and pollution, a tax on the good corresponds exactly to a tax on pollution. If the good itself is associated with pollution, instruments to discourage pollution can only operate through an output effect (as discussed previously). Actually, the tax on output can still perfectly correct for pollution associated with an input—if output must be produced using a fixed amount of pollution per unit.[5] With substitution in production, however, the output tax is no longer equivalent to a tax on pollution.

A recent paper by Cremer and Gahvari (1999) extends the Sandmo analysis to allow pollution to be associated with one of several inputs in the production of a "dirty good." In a standard optimal tax analysis, Cremer and Gahvari show first that emissions taxes and output taxes are not equivalent and, second, that both emissions and output taxes may be needed to achieve optimality in a second-best world. In effect, the emissions tax corrects externalities, while the output tax rates handle tax collections for general revenue needs in an optimal fashion. While it is an important extension of the original Sandmo analysis, the Cremer and Gahvari paper does not consider the loss from using an output tax instead of an emissions tax. That is, it still assumes that taxes on emissions are feasible.

A paper by Schmutzler and Goulder (1997) directly examines the tradeoff between the use of emissions taxes and output taxes in the presence of imperfect monitoring of emissions. They note that previous authors (e.g., Cropper and Oates 1992) have recognized that output taxes may be preferable to emissions taxes if emissions are difficult to monitor, and they attempt to make more precise what it means to be "difficult to monitor." They enumerate four factors that affect the choice between emissions and output taxes: (1) monitoring costs, (2) technological factors, (3) the regulator's information structure, and (4) social preferences for consumption goods versus environmental quality. As the costs of monitoring emissions rise, the advantage of precisely targeted emissions taxes falls. This effect relates to evasion possibilities, as discussed in the previous section about hazardous-waste-disposal taxes. Technological factors come into play by determining the scope of substitution in production away from pollution. If emissions are a fixed proportion of output, then an output tax would be equivalent to an emissions tax without the need to measure emissions di-

5. See, for example, the recent paper by Sandmo and Wildasin (1999). This statement is true as long as emissions per unit of output are constant across firms. Nichols (1984) notes that the cost of using an output tax rather than an emissions tax rises with variation across firms in the emissions-to-output ratio (even if this ratio is fixed for each firm). Nichols also notes that targeting emissions per se is not precisely correct because the tax should distinguish among emissions according to their marginal damages. This point justifies, for example, time-varying emissions taxes where marginal damages vary during the day.

rectly. The regulator's information structure determines what it can monitor. Regulators face difficulty monitoring emissions, but they may face even more difficulty trying to tax certain inputs or output (thereby affecting the relevant target). Finally, the loss from poorly targeted instruments is a loss in the value of output, while the loss from the high cost of monitoring may be a loss in environmental quality, so the trade-off in utility between consumption and the environment may also affect the choice of instruments. Smulders and Vollebergh (chap. 3 in this volume) explore many similar issues.

Policy can miss the target in another important sense that we note here, but do not pursue in this paper. In the presence of multiple pollutants, targeting one pollutant may cause the substitution of other pollutants for that pollutant. Devlin and Grafton (1994) explore this topic in the context of determining the optimal number of tradable permits for a pollutant when multiple pollutants coexist.[6]

All of these papers ignore general equilibrium considerations. A large literature starting with Bovenberg and de Mooij (1994) explores the welfare consequences of environmental taxes and other instruments in a general equilibrium context with preexisting taxes.[7] These papers have typically focused on the interactions among taxes rather than on the issue of emissions taxes versus output taxes (or otherwise imperfectly targeted taxes). In the model that we present here, we allow for general equilibrium considerations as well as the existence of other distorting taxes.[8] We turn now to that model.

1.4 A General Equilibrium Model of Production and Consumption

The review of environmental taxes in section 1.3 indicates a slow movement away from output taxes and toward emissions taxes. However, the predominant existing environmental taxes still miss the target in that they tax a purchased input to production or an output sold, but not emissions per se. In this section, we carry out a general equilibrium analysis of the costs and effects of using mistargeted environmental instruments. The model allows us to investigate the welfare effects of a commodity or emissions tax in a second-best world with a preexisting labor distortion. We allow for choices in production and consumption, using the same notation

6. A similar idea is analyzed by Metcalf, Dudek, and Willis (1984), who consider the effect of controlling one form of disposal medium for a pollutant in a situation with multiple disposal media.

7. A very partial list includes Bovenberg and Goulder (1996), Parry (1995), Goulder (1995), Goulder, Parry, and Burtraw (1997), and Fullerton and Metcalf (1997). This literature is surveyed in Fullerton and Metcalf (1998).

8. The paper by Schmutzler and Goulder (1997) is closest in spirit to our paper. Their analysis is explicitly partial equilibrium, however, and they do not consider other preexisting tax distortions.

Table 1.1 **Policy Experiments**

1. Preexisting tax on Y only
A. Increase tax on Y
B. New tax on Z
2. Preexisting tax on Z only
A. New tax on Y
B. Increase tax on Z

as in Fullerton and Metcalf (1997). The model has a homogeneous population (of size N) and the possibility of substituting inputs in production. We assume perfect competition, complete information, and perfect factor mobility. The model has a clean good (X) and a dirty good (Y) that is produced using labor (L_Y) and emissions (Z).

A number of policies can be analyzed with this model. We can solve for the optimal second-best tax rate (either on emissions, Z, or on output, Y) as a function of preference and production parameters as well as preexisting tax rates. In addition, we can consider various incremental tax reforms. With respect to the latter, we consider the four possible scenarios listed in table 1.1.

Most actual taxes fall into category 1, as noted in our review, and the relevant policy reform is either an increase in one of these taxes or the introduction of a new, more targeted tax. Taxes on gasoline are an output tax, for example, so proposals in the United States to increase the gasoline tax are an example of scenario 1A. On the other hand, proposals for a new carbon tax in the context of current taxes on gasoline are an example of scenario 1B. As an example of a preexisting tax on emissions, a carbon tax was implemented in the Scandinavian countries in the early 1990s. Policy reforms to implement new taxes in those countries on goods associated with pollution are examples of scenario 2A, while proposals to increase the carbon taxes are examples of scenario 2B. We begin by developing the model in the case with preexisting taxes on either emissions or output, but we first consider only an incremental tax on output (t_Y).

1.4.1 Production

The clean good is produced in a constant-returns-to-scale technology using only labor (L_X) as an input:[9]

$$X = L_X . \tag{1}$$

9. Our model assumes one factor of production, for simplicity called "labor," but under some circumstances this factor can be taken to represent a homogeneous composite of all clean resources used in production.

For convenience, the numeraire is taken to be labor (or, equivalently, the clean good). The dirty good (Y) is produced in a constant-returns-to-scale production function using labor (L_Y) and emissions (Z):

(2) $$Y = F(L_Y, Z).$$

Also, emissions entail some private cost in terms of resources (labor), and we can define a unit of emissions as the amount that requires one unit of resources:[10]

(3) $$Z = L_Z.$$

Aggregate emissions adversely affect environmental quality:

(4) $$E = e(NZ) \quad e' < 0.$$

Finally, a public good is produced using labor:

(5) $$G = NL_G.$$

The amount of this public good is held constant in revenue-neutral reforms later.

1.4.2 Consumption

In this model, the N identical households derive utility from the two private goods (X and Y), leisure (L_H), the public good (G), and environmental quality (E):

(6) $$U = U(X, Y, L_H; G, E).$$

The household budget constraint is given by

(7) $$X + (p_Y + t_Y)Y = (1 - t_L)L,$$

where

(8) $$L = L_X + L_Y + L_Z + L_G.$$

Government finances the public good with a preexisting tax on labor income (t_L) and possibly a tax on output (t_Y). The nominal net wage is $1 - t_L$. A fixed amount of time ($\overline{L}$) can be allocated between work (L) and leisure (L_H).

10. Note that emissions are positively related to the use of these resources: L_Z is not to clean up or reduce emissions, but just to cart it away. Abatement is undertaken by substituting L_Y for Z. This overall production function is still constant returns to scale, since Z is a linear function of L_Z. The private cost for emissions helps justify our assumption of an internal solution with a finite choice for Z, even without corrective government policy.

1.4.3 Comparative Statics

Later we consider the effect of changing various prices through the use of taxes. We employ a log-linearization technique for the analysis, an approach that is appropriate when considering small changes. This technique allows us to capture important behavioral attributes of producers and consumers with a few key parameters. It also makes for a tractable analysis by allowing us to solve a system of linear equations. The goal in this section is to develop the various equations that trace through the impacts of a tax change on prices, quantities, and welfare. We begin by noting how any changes affect utility:[11]

$$\text{(9)} \qquad \frac{dU}{\lambda L} = t_L \hat{L} + t_Y \left(\frac{Y}{L}\right) \hat{Y} + (t_Z - \mu)\left(\frac{Z}{L}\right)\hat{Z},$$

where dU is the change in a representative agent's utility and λ is the private marginal utility of income. The term μ equals $-NU_E e'/\lambda$ and is the marginal social damage from pollution. A hat over a variable indicates a percentage change (e.g., $\hat{Z} = dZ/Z$). The left-hand side of this expression is the change in welfare (in dollars) as a fraction of the total resource in the economy. The right-hand side is composed of three parts. The first two parts are the welfare effect of the environmental policy through its impact on labor supply and the amount of the dirty good. Since labor is already discouraged as a result of the tax on wage income, any policy that further discourages labor supply will reduce welfare. A similar effect holds for any preexisting tax on the dirty good. If either t_L or t_Y is 0, the corresponding welfare effect on labor or the dirty good disappears from the equation. The third term is the welfare impact resulting from the change in pollution.

In order to find tractable solutions to the welfare equation (9), we make some simplifying assumptions about consumer preferences. In particular, we assume that environmental quality and the public good are separable from the consumption goods and that the consumption goods enter utility in a homothetic subutility function:[12]

$$\text{(10)} \qquad U(X, Y, L_H, E, G) = U(V(Q(X, Y), L_H), E, G),$$

where V and Q are both homothetic. For later use, define p_Q as a price index on $Q(X, Y)$ such that

11. This equation follows from totally differentiating the utility function and substituting in the consumer's first-order conditions. Details are available from the authors.

12. The assumption of separability is standard in this second-best tax literature because it is tractable and because it is a central case with neither complements nor differential substitutes. We only have two private goods (X and Y). With more disaggregation, particular private goods would undoubtedly be complements to leisure or to the environment and receive unique tax treatments for those reasons.

(11) $$p_Q Q = X + (p_Y + t_Y)Y,$$

and let w be the real net wage,

(12) $$w = (1 - t_L)/p_Q.$$

Thus the change in the real net wage ($\hat{w} \equiv dw/w$) will be related to the change in the labor tax ($\hat{t}_L$, defined as $dt_L/(1 - t_L)$) and the change in $p_Q(\hat{p}_Q \equiv dp_Q/p_Q)$. From equation (11), the change in p_Q depends on the change in the producer price p_Y and the change in the output tax ($\hat{t}_Y \equiv dt_Y/(1 + t_Y)$). Finally, let c_Y be the consumer price for Y,

(13) $$c_Y = p_Y + t_Y.$$

Our assumptions about consumer preferences allow us to characterize the general equilibrium response to a change in the tax on Y with four equations:

(14) $$\hat{Y} - \hat{X} = \sigma_Q(\hat{p}_X - \hat{c}_Y) = -\sigma_Q \hat{c}_Y,$$

(15) $$\hat{L} = \varepsilon \hat{w},$$

(16) $$\hat{w} = -\hat{t}_L - \phi \hat{t}_Y,$$

(17) $$(1 - \phi)\hat{X} = \hat{L} - \hat{t}_L - \phi(\hat{Y} + \hat{t}_Y).$$

In these equations, σ_Q is the elasticity of substitution in consumption between X and Y, ε is the uncompensated labor supply elasticity, and ϕ is the share of the consumer's after-tax income spent on Y. Equations (14) and (15) follow directly from our definition of σ_Q and our assumptions about consumer preferences. Equation (16) follows from totally differentiating equation (12) and using equation (11), while equation (17) follows from differentiating the consumer's budget constraint.

We totally differentiate the government budget constraint, hold G fixed, and assume that the revenue from the change in t_Y is offset by a change in t_L. These assumptions provide the fifth equation in our system:

(18) $$\hat{t}_L = -\left(\frac{t_L}{1 - t_L}\right)\hat{L} - \left(\frac{t_Z Z}{(1 - t_L)L}\right)\hat{Z} - \phi\left[\hat{t}_Y + \left(\frac{t_Y}{1 + t_Y}\right)\hat{Y}\right].$$

This is the change in t_L necessary for government to balance the budget when changing t_Y. Next, we turn to the equations implied by production. As yet, we do not allow for a change in the tax on emissions. Thus any change in inputs or output comes entirely from an output effect. Because of constant returns to scale in production, we have

$$\hat{Y} = \hat{Z} = \hat{L}_Y. \tag{19}$$

Also, the producer price is fixed,[13] and so

$$\hat{c}_Y = \hat{t}_Y. \tag{20}$$

Equations (14)–(20) represent eight linear equations that can be solved for the eight variables ($\hat{Y}$, $\hat{X}$, $\hat{w}$, $\hat{t}_L$, $\hat{c}_Y$, $\hat{L}$, $\hat{L}_Y$, and $\hat{Z}$), all as functions of the exogenous $\hat{t}_Y$.

After we solve for changes in Y, L, and Z as functions of the change in t_Y, we substitute these expressions into equation (9) and express the welfare change as a function of the incremental tax reform:[14]

$$\frac{dU}{\lambda L} = -\left\{\frac{\sigma_Q(1-\phi)\left\{(1-t_L)\left[t_Y\left(\frac{Y}{L}\right) + (t_Z-\mu)\left(\frac{Z}{L}\right)\right] + \varepsilon t_L \mu\left(\frac{Z}{L}\right)\right\}}{(1-t_L-\varepsilon t_L) - (1+\varepsilon)\left[t_Y\left(\frac{Y}{L}\right) + t_Z\left(\frac{Z}{L}\right)\right]}\right\}\hat{t}_Y. \tag{21}$$

Despite the complexity of this equation, we can make some general observations about the welfare impact of an incremental tax reform. First, note that the welfare impact does not depend on the ability to substitute other inputs for emissions in production (σ_Y). Since we have limited our instrument to a tax on the dirty output, the only welfare gain comes about from an equilibrium output effect (arising from substitution in consumption). The change in the output tax provides no substitution effect in production.

Second, the first term in the denominator must be positive to ensure that the government is on the upward-sloping side of the Laffer curve for wage taxation. We will assume that this is always the case. A condition for the entire denominator to be positive is for $\varepsilon < (NL - G)/G$, or that ε be bounded above by the ratio of private output to government output.[15] We will also assume that this condition holds throughout.

Third, note that the formula simplifies considerably with no preexisting taxes:

13. We normalize the initial producer price of Y to be 1, for any given emissions tax. In this section, where we do not allow for the emissions tax to change, the producer price will be unaffected by changes in the output tax.

14. Details are available from the authors upon request.

15. This follows from the fact that government spending is financed entirely by taxes: $G/N = t_L + t_Z Z + t_Y Y$.

$$\frac{dU}{\lambda L} = \sigma_Q(1 - \phi)\mu\left(\frac{Z}{L}\right)\hat{t}_Y. \tag{21'}$$

Welfare is unambiguously increased by an initial output tax, as long as consumers can substitute X for Y.[16]

Next we turn to a model for the case where the policy shock is a change in the tax on emissions rather than on output. The relevant equations (14) and (15) are unchanged, and other equations change, as noted by primes:

$$\hat{Y} - \hat{X} = \sigma_Q(\hat{p}_X - \hat{c}_Y) = -\sigma_Q\hat{c}_Y, \tag{14}$$

$$\hat{L} = \varepsilon\hat{w}, \tag{15}$$

$$\hat{w} = -\hat{t}_L - \left(\frac{(1 + t_Z)Z}{(1 - t_L)L}\right)\hat{t}_Z, \tag{16'}$$

$$(1 - \phi)\hat{X} = \hat{L} - \hat{t}_L - \phi\left[Y + \left(\frac{(1 + t_Z)Z}{Y}\right)\hat{t}_Z\right], \tag{17'}$$

$$\hat{t}_L = -\left(\frac{t_L}{1 - t_L}\right)\hat{L} - \phi\left(\frac{t_Y}{1 + t_Y}\right)\hat{Y} - \frac{(1 + t_Z)Z}{(1 - t_L)L}\left[\hat{t}_Z + \left(\frac{t_Z}{1 + t_Z}\right)\hat{Z}\right], \tag{18'}$$

$$\hat{L}_Y = \hat{Z} + \sigma_Y\hat{t}_Z, \tag{19.1'}$$

$$\hat{Y} = \left(\frac{L_Y}{Y}\right)\hat{L}_Y + \left(\frac{(1 + t_Z)}{Y}\right)\hat{Z}, \tag{19.2'}$$

$$\hat{c}_Y = \left(\frac{(1 + t_Z)Z}{(1 + t_Y)Y}\right)\hat{t}_Z. \tag{20'}$$

Equations (19.1′) and (19.2′) require a bit of explanation. The first equation is the behavioral relationship in production given by the elasticity of substitution in production (σ_Y). Then the second equation follows from the first-order conditions in production.

Combining these equations and using the zero-profits condition, we can solve for the welfare impact of a change in the tax on emissions:

16. The output effect disappears if σ_Q equals 0, because then consumers do not substitute X for Y when the latter's price rises. In addition, if ϕ equals 0 or 1, then the consumer is at a corner and again does not substitute X for Y (note that $\phi = 0$ implies $Z = 0$).

$$(22)\quad \frac{dU}{\lambda L} = - \left\{ \frac{\sigma_Q(1-\phi)(1+t_Z)\left(\frac{Z}{Y}\right)\left\{(1-t_L)\left[t_Y\left(\frac{Y}{L}\right) + (t_Z-\mu)\left(\frac{Z}{L}\right)\right] + \varepsilon t_L \mu\left(\frac{Z}{L}\right)\right\} + \sigma_Y\left(\frac{L_Y}{Y}\right)(1+t_Y)\left\{(1-t_L)(t_Z-\mu)\left(\frac{Z}{L}\right) + \left[\varepsilon t_L + (1+\varepsilon)t_Y\left(\frac{Y}{L}\right)\right]\mu\left(\frac{Z}{L}\right)\right\}}{(1+t_Y)\left\{(1-t_L-\varepsilon t_L) - (1+\varepsilon)\left[t_Y\left(\frac{Y}{L}\right) + t_Z\left(\frac{Z}{L}\right)\right]\right\}} \right\} \hat{t}_Z .$$

The first term in the numerator of equation (22) is very similar to the whole numerator in equation (21) and reflects substitution in consumption (i.e., the effect on output). The second term in the numerator reflects the substitution effect in production because we now have the possibility of changing relative input prices. With no preexisting taxes of any kind, the expression simplifies to

$$(22') \qquad \frac{dU}{\lambda L} = \left[\sigma_Q(1-\phi)\left(\frac{Z}{Y}\right) + \sigma_Y\left(\frac{L_Y}{Y}\right)\right]\left(\frac{\mu Z}{L}\right)\hat{t}_Z .$$

The first term in equation (22′) corresponds to equation (21′), adjusted for the fact that the tax is on emissions rather than output. It represents the output effect from the emissions tax. In addition, a substitution effect is captured by the second term.

1.5 Model Analysis

1.5.1 Optimal Tax Rates

We begin the analysis by considering the optimal tax in the various scenarios described. First consider the optimal emissions tax in the case with a preexisting tax on labor, but no tax on output. This is, we ask what is the tax t_Z in equation (22), where $t_Y = 0$, such that no further change $\hat{t}_Z$ can affect welfare ($dU = 0$). We set equation (22) to 0 and solve for the tax rate on emissions:

$$(23) \qquad t_Z^* = \mu\left[1 - \left(\frac{t_L}{1-t_L}\right)\varepsilon\right].$$

Unless the tax rate t_L or the uncompensated labor supply elasticity is 0, the term in brackets is less than 1, and the optimal emissions tax is less than the social marginal damages ($t_Z^* < \mu$). This result is consistent with Bovenberg and de Mooij (1994).

To see how our expression (23) relates to other results in the literature, let ψ be the partial-equilibrium marginal cost of public funds for the labor tax. Goulder and Williams (1999) show that

$$\psi = 1 + \frac{t_L(\partial L_H / \partial t_L)}{L - t_L(\partial L_H / \partial t_L)}. \tag{24}$$

Then some simple manipulation of this formula provides

$$\psi = \left[1 - \left(\frac{t_L}{1 - t_L}\right)\varepsilon\right]^{-1}. \tag{25}$$

With a positive tax rate and positive labor supply elasticity ε, the marginal cost of funds is $\psi > 1$. Thus equation (23) can be rewritten as

$$t_Z^* = \frac{\mu}{\psi}, \tag{23'}$$

as noted by Sandmo (1975) and Bovenberg and van der Ploeg (1994).[17]

Analogously, if the emissions tax is unavailable ($t_Z = 0$), we can solve for the second-best tax on output as the t_Y in equation (21) such that a change $\hat{t}_Y$ does not raise welfare ($dU = 0$). We set the numerator of equation (21) to 0 and find

$$t_Y^* = \left(\frac{\mu}{\psi}\right)\left(\frac{Z}{Y}\right). \tag{26}$$

A striking result is that the optimal tax on output is very similar to the optimal tax on emissions.[18] This tax is second-best in two respects. First, this t_Y is reduced when divided by $\psi > 1$, to account for the preexisting tax on labor. Second, one might think that it should be reduced even more, to account for missing the target. The output tax is a blunt instrument for dealing with pollution. On the other hand, perhaps t_Y should be increased to get more of an output effect, since it misses the substitution effect. Yet equation (26) shows that the output tax should be set to generate exactly the same output effect as the ideal emissions tax. To see this, note that the

17. This result is also consistent with Cremer and Gahvari (1999). They solve for optimal second-best tax rates on emissions and on outputs in the general case without separability, but in our case with separability, their emissions tax would be μ/ψ and their output tax would be 0 (using t_L for revenue).

18. For the special case where $Y = Z$, equation (26) collapses to (23′).

second-best emissions tax ($t_Z^* = \mu/\psi$) would raise production costs by $(\mu/\psi)Z$. Divide this amount by Y to get the extra cost per unit of output, which is exactly the amount that t_Y^* would raise the price of output.[19]

In other words, the fact that the output tax cannot achieve the desired substitution effect should not deter policymakers from its use to achieve the desired output effect. The optimal t_Y^* is the damage per unit of output—calculated as the desired tax per unit of emissions (t_Z^*) times emissions per unit output (Z/Y).

If the ideal t_Z^* were unavailable, could the authorities set t_Y^* and enforce it? If firms differ, one might think that authorities would need to know each firm's Z (or equivalently Z/Y) to set that firm's output tax rate using equation (26). Yet, if authorities knew Z, it seems they could employ an emissions tax directly. However, authorities only need to measure (or estimate) Z/Y once to set the output tax rate. The tax can then be enforced simply by counting units of output. In contrast, the emissions tax requires continuous measurement of Z, especially after firms change their Z/Y ratio in response to the tax. Moreover, if firms are similar, authorities need only the average Z/Y to set the output tax rate. Even if firms are similar, the emissions tax requires authorities to measure (or at least threaten to measure) each firm's emissions.

Next, consider the possibility of preexisting taxes either on emissions or on output. Equation (26) generalizes readily in the presence of a preexisting tax on Z:

$$t_Y^* = \left(\frac{\mu}{\psi}\right)\left(\frac{Z}{Y}\right) - t_Z\left(\frac{Z}{Y}\right). \tag{27}$$

The first term in equation (27) is the output effect from the optimal output tax if t_Z is 0. The second term adjusts the tax rate to account for the output effect already obtained from taxing emissions. If the emissions tax is fixed suboptimally, then the additional required output tax is simply the additional desired output effect to account for the undertaxation of emissions. If emissions are taxed optimally ($t_Z = \mu/\psi$), then (27) shows that the optimal tax on output is 0.

To find the optimal tax on emissions (t_Z^*) in the case of a preexisting tax on output, we find the tax rate on emissions that cannot raise utility. That is, we find t_Z in equation (22) such that $dU = 0$. The solution to this equation is more complicated:

19. Actually, the optimal t_Y^* in equation (26) uses the Z/Y without any t_Z, without any substitution effect, so that Z/Y is higher than the optimal Z/Y. The rule in equation (26) gives the same output effect, but the level of t_Y^* in equation (26) is higher than the output effect of t_Z^* (at optimal Z/Y).

$$(28)\quad \sigma_Q(1-\phi)(1+t_Z^*)Z\{(1-t_L)[t_Y Y+(t_Z^*-\mu)Z]+\varepsilon t_L \mu Z\}$$
$$+\sigma_Y L_Y(1+t_Y)\left\{(1-t_L)(t_Z^*-\mu)Z+\left[\varepsilon t_L+(1+\varepsilon)t_Y\left(\frac{Y}{L}\right)\right]\mu Z\right\}=0.$$

While solving for t_Z^* is not possible, we can rewrite equation (28) to make a basic point:

$$(28')\quad t_Z-\mu=$$
$$-\left\{\frac{(1-t_L)\sigma_Q(1-\phi)(1+t_Z)t_Y Y+\left\{[\sigma_Q(1-\phi)(1+t_Z)Z]\varepsilon t_L+\left[\sigma_Y L_Y(1+t_Y)\varepsilon t_L+(1+\varepsilon)t_Y\left(\frac{Y}{L}\right)\right]\right\}\mu}{(1-t_L)[\sigma_Q(1-\phi)(1+t_Z)Z+\sigma_Y L_Y(1+t_Y)]}\right\}.$$

While we have not explicitly solved for the optimal emissions tax (since t_Z appears on both sides), we can show that the right-hand side is less than 0. Thus the optimal emissions tax rate is less than the social marginal damages ($t_Z^* < \mu$), with preexisting t_Y and t_L. A sufficient condition for the emissions tax rate to equal the social marginal damages is that ε and t_Y both equal 0.[20] Note that if either t_L or ε is 0 (so $\psi = 1$), then a nonzero t_Y still means that the optimal tax on emissions is less than μ.

For the special case where $Y = Z$ and $\sigma_Y = 0$, equation (28) collapses to

$$(28'')\qquad t_Y + t_Z = \frac{\mu}{\psi}$$

In this case, we need not distinguish between taxes on emissions or output, since the production function is such that output itself is polluting. Once again, the optimal tax is marginal social damages divided by the marginal cost of public funds.

1.5.2 Incremental Tax Reforms

We now turn to a numerical analysis of tax reforms. We measure the impact on welfare of a small change in either t_Z or t_Y. In order to carry out these calculations, we need values for a number of key parameters. Table 1.2 presents the assumed values for our base-case calculations; justification for these selections appear in Fullerton and Metcalf (1997).

Little evidence exists on some of these parameters, especially σ_Q and σ_Y, and so we present a sensitivity analysis in subsection 1.5.3. Also, marginal environmental damages (μ) could be considerably higher for some pollut-

20. Alternatively, the optimal tax rate equals μ if t_Y and t_L are 0 (i.e., a first-best world).

Table 1.2 Parameter Assumptions

Parameter	Value
μ	0.3
ε	0.3
σ_Q	1.0
Y/L	0.3
σ_Y	1.0
Z/L	0.15
t_L	0.4

ants (and lower for others). Tax rate results are proportional to μ, however, so it is easy to see how results change with that parameter.

Consider scenario 1, with no preexisting tax on emissions, but with a preexisting tax on labor and (perhaps) on output. With these values, the first-best Pigouvian tax would be $\mu = 0.3$, but the marginal cost of funds is $\psi = 1.25$, so the second-best tax on emissions is 0.24, from equation (23′). Then, since emissions constitute half of output, equation (26) says that the second-best tax on output is 12 percent. For our measure of welfare, we use $dU/\lambda L$, the monetary value of the change in utility as a fraction of total income.

Figure 1.1 depicts the general welfare effects of a small change in either the output tax or the emissions tax, assuming no preexisting emissions tax, for alternative values of a preexisting output tax. The horizontal axis indicates the level of the output tax prior to the reform, and the vertical axis shows the net change in welfare as a proportion of national income. The absolute welfare change may be in billions of dollars, but dividing by GDP makes the relative gains look small on the vertical axis. Consider the lower line, which indicates the change in welfare for a change in t_Y. First note that it crosses the horizontal axis at $t_Y = 0.12$. Since the optimal output tax with this configuration of parameters is 0.12, welfare does not change when the tax rate is altered from this level. At tax rates below this optimum, welfare rises when the tax on Y is increased a small amount. The maximum gain occurs with no preexisting tax on output.[21] The line falls below the horizontal axis in the region where t_Y exceeds 12 percent, indicating that a further increase in the tax rate would reduce welfare.

The upper line shows the welfare gain from introducing a small emissions tax. First, note that this line is everywhere above the line for raising

21. It is tempting to integrate under this curve to measure the welfare impact of a large change in t_Y, say from 0 to 12 percent. This would be a legitimate exercise if the private marginal utility of income were constant across this interval. In general, λ is not constant, however, so the increments to welfare are measured in different units of income and are not additive.

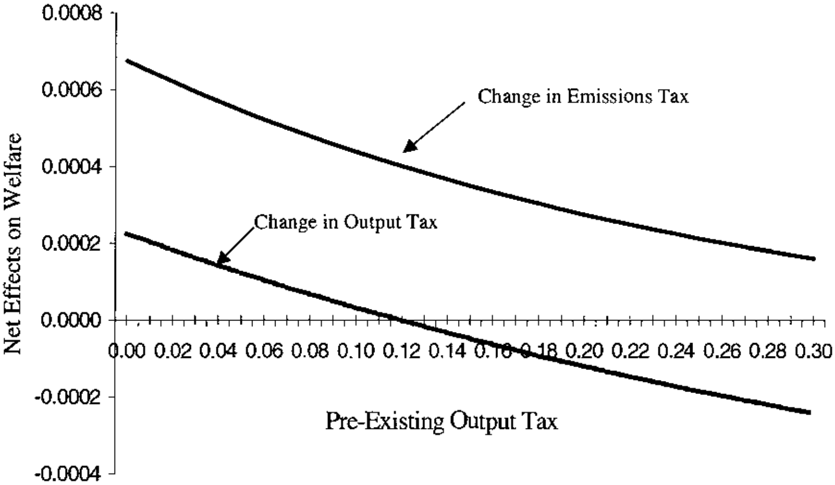

Fig. 1.1 Scenario 1: proportional change in welfare from a change in emissions tax or output tax (with preexisting labor and output taxes)

the output tax. For any preexisting tax on output, welfare is raised more by introducing a tax on emissions than by increasing the tax on output. Recall that the major distinguishing difference is that the emissions tax provides both output and substitution effects while the output tax only provides an output effect. As an approximation, then, the substitution effect is the gap between these two lines. With no initial taxes, the welfare gain from a small output tax is less than half that of a small emissions tax: More than half of the gain from an emissions tax comes from the shift in production processes as emissions become more expensive. This decomposition depends directly on σ_Y because the crucial distinction between an output tax and emissions tax is the ability of the latter to operate through the substitution effect. Later we provide a sensitivity analysis of this parameter.

Second, the welfare gain from introducing an emissions tax is everywhere positive. At high preexisting output tax rates, the additional output effect reduces welfare, but the initial substitution effect from the first introduction of t_Z is sufficiently strong to overwhelm any negative output effect.

Figure 1.2 corresponds to scenario 2 (no preexisting output tax). The horizontal axis now indicates the level of a preexisting emissions tax. The optimal emissions tax for this set of parameter assumptions is 24 percent, so the line measuring the incremental gains from an incremental emissions tax crosses the horizontal axis at 0.24 (where welfare cannot be raised by any change in t_Z). Interestingly, the output tax curve also crosses the horizontal axis at 24 percent. In other words, if the preexisting emissions tax is already at the second-best optimal rate of 0.24, then the initial intro-

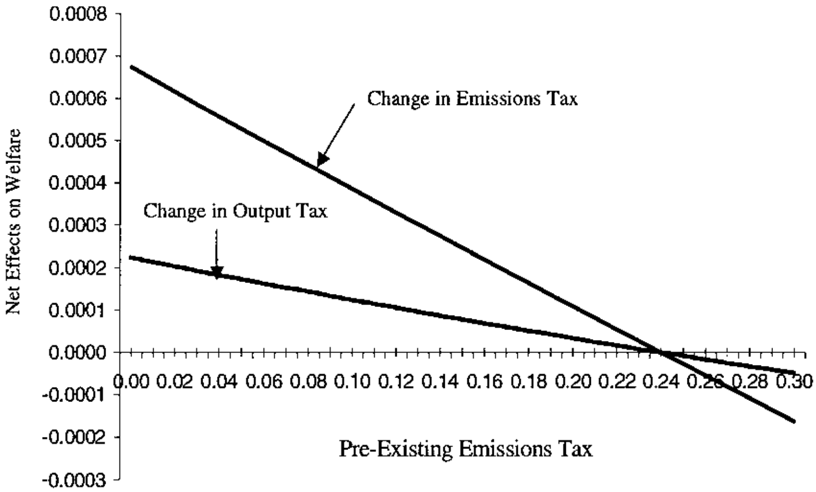

Fig. 1.2 Scenario 2: proportional change in welfare from a change in emissions tax or output tax (with preexisting labor and emissions taxes)

duction of t_Y has no first-order effect on welfare. Back at the vertical axis, where the initial t_Y and t_Z are both 0, the introduction of an initial t_Z dominates the introduction of an initial t_Y (since t_Z has both substitution and output effects). In other words, the emissions-tax curve starts out higher than the output-tax curve, and they must both cross the horizontal axis at 0.24 (the second-best optimum). If the emissions tax rate exceeds the second-best optimum, a further increase in this tax is more welfare reducing than an increase in the output effect, since the increase in the emissions tax has both an unwanted substitution effect and an unwanted output effect.

1.5.3 Sensitivity Analysis

Figures 1.1 and 1.2 are drawn using one set of preference parameters and technological parameters. Clearly, however, the size of the substitution effect depends on the elasticity of substitution in production (σ_Y), and the size of the output effect depends on consumer demand (the elasticity of substitution in utility, σ_Q). We vary those parameters in figures 1.3 and 1.4, but we still show the effect of missing the target—the welfare gap—defined as the gain from adding a tax on emissions minus the gain from adding to the tax on output.

Figure 1.3 shows this welfare gap (on the vertical axis) for different values of the elasticity of substitution in utility (on the horizontal axis). The three curves in the figure correspond to three initial values of t_Y (0.0, 0.12, and 0.24). Since σ_Q most directly affects the output effect, and not the substitution effect, it does not much affect the cost of missing the target.

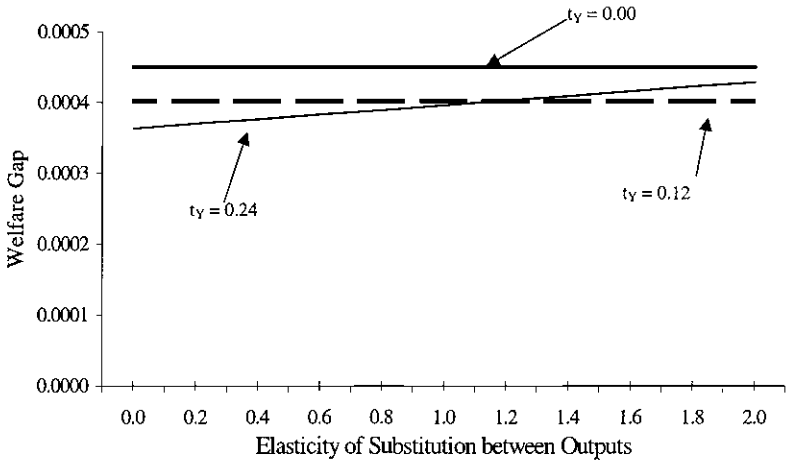

Fig. 1.3 How the welfare gap depends on substitution between outputs: the proportional gain from adding a tax on emissions minus the gain from adding to the tax on output

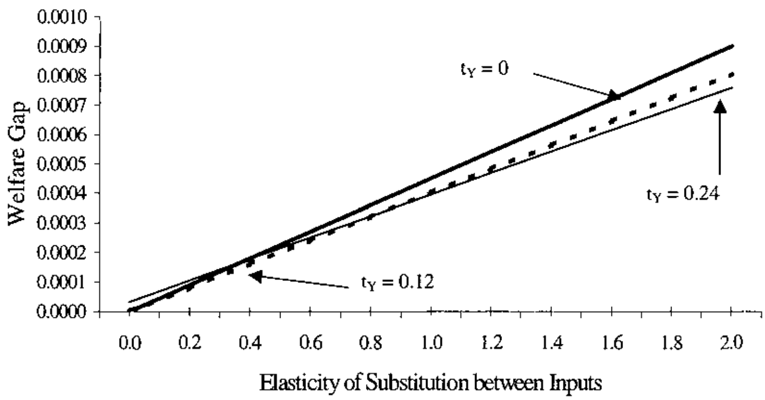

Fig. 1.4 How the welfare gap depends on substitution between inputs: the proportional gain from adding a tax on emissions minus the gain from adding to the tax on output

When the initial tax rate is 12 percent or lower, the welfare gain from the emissions tax exceeds the gain from the output tax by a relatively constant amount. At higher levels of preexisting t_Y, a higher σ_Q raises this amount.

Figure 1.4 shows the welfare gap for different values of the elasticity of substitution in production (again for initial t_Y equal to 0.0, 0.12, or 0.24). The assumed value of σ_Y clearly affects the size of the welfare gap. For any initial tax on output, the ability to substitute in production dramatically increases the importance of hitting the target.

1.6 Conclusion

A tax on pollution has been suggested by Pigou (1932) and thoroughly analyzed in the economics literature ever since, but a true Pigouvian tax is essentially never employed by actual policy. Most actual environmental taxes apply to the output of a polluting industry or to an input that is correlated with emissions, rather than directly to emissions. Perhaps policymakers think that the "polluter pays" principle is satisfied, since the polluters bear the burden of the output tax, but this paper shows the loss in welfare from missing the target in this fashion. Using plausible parameters, the introduction of a tax on emissions raises welfare by more than twice as much as a tax on the output of the polluting industry. We find that the ability of producers to substitute away from emissions directly affects the cost of missing the target, but it does not affect the second-best optimal tax on output. In the case in which emissions cannot be taxed, perhaps for technological reasons, we find that the second-best output tax should still be set to obtain the same effect on output price as would occur with the desired but unavailable emissions tax.

Other research directions are not explored in this paper but represent important avenues for further study. First of all, we ignore the administrative cost of trying to monitor emissions. If the ability to measure and tax emissions is a matter of degree, then we would expect a trade-off at the margin between the falling marginal benefits of hitting closer to the target and the rising marginal costs of doing so. The optimum might then involve some optimal degree of effort to measure and tax emissions.

Second, our model considers a tax on the output of the polluting industry for comparison with the ideal emissions tax, but some of the actual environmental taxes apply to an input to production that is correlated with pollution. To analyze such a tax, our model would have to be modified such that the polluting industry uses three inputs to production: labor, emissions, and some other input that is correlated to emissions.

Third, our model is rather stylized, with one clean output, one dirty output, and one very general technology of switching from emissions to the other input in production. Our results are valuable for a conceptual understanding of the importance of hitting the target, but specific policy problems should be analyzed for particular industries with carefully specified technologies of pollution abatement.

Fourth, as indicated in our review of actual taxes, some programs may allow the firm to choose between paying an output tax or purchasing abatement and monitoring equipment to pay a lower emissions tax. In addition, waste taxes may be earmarked for public spending on abatement. Hazardous-waste taxes may increase illegal, unmonitored activities.

Finally, we note that our model relies on many other standard simplifying assumptions and thus could be extended to consider the effects of uncertainty, imperfect competition, heterogeneity among firms, distributional effects among consumers, traded goods, transboundry pollution, and many other interesting problems.

References

Anderson, Robert, and Andrew Lohof. 1997. The United States experience with economic incentives in environmental pollution control policy. Washington, D.C.: U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation.

Astarita, Giovanni, D. Savage, and A. Bisio. 1983. *Gas treating with chemical solvents.* New York: Wiley.

Barthold, Thomas A. 1994. Issues in the design of environmental excise taxes. *Journal of Economic Perspectives* 8:133–51.

Bovenberg, A. Lans, and Ruud de Mooij. 1994. Environmental levies and distortionary taxation. *American Economic Review* 84:1085–89.

Bovenberg, A. Lans, and Lawrence H. Goulder. 1996. Optimal environmental taxation in the presence of other taxes: General equilibrium analyses. *American Economic Review* 86:985–1000.

Bovenberg, A. Lans, and Frederic van der Ploeg. 1994. Environmental policy, public finance, and the labor market in a second-best world. *Journal of Public Economics* 55:349–90.

Cremer, Helmuth, and Firouz Gahvari. 1999. What to tax: Emissions or polluting goods? University of Illinois. Mimeo.

Cropper, Maureen, and Wallace Oates. 1992. Environmental economics: A survey. *Journal of Economic Literature* 30:675–740.

Devlin, R. A., and R. Q. Grafton. 1994. Tradable permits, missing markets, and technology. *Environmental and Resource Economics* 4:171–86.

Eskeland, Gunnar S., and Shanta Devarajan. 1996. *Taxing bads by taxing goods: Pollution control with presumptive charges.* Washington, D.C.: World Bank.

Fullerton, Don. 1996. Why have separate environmental taxes? *Tax Policy and the Economy* 10:33–70.

Fullerton, Don, and Gilbert E. Metcalf. 1997. Environmental controls, scarcity rents, and pre-existing distortions. NBER Working Paper no. 6091. Cambridge, Mass.: National Bureau of Economic Research.

———. 1998. Environmental taxes and the double dividend hypothesis: Did you really expect something for nothing? *Chicago-Kent Law Review* 73 (1): 221–56.

Goulder, Lawrence H. 1995. Environmental taxation and the "double dividend": A reader's guide. *International Tax and Public Finance* 2:157–83.

Goulder, Lawrence H., Ian Parry, and Dallas Burtraw. 1997. Revenue-raising vs. other approaches to environmental protection: The critical significance of preexisting tax distortions. *RAND Journal of Economics* 28:708–31.

Goulder, Lawrence H., and Roberton Williams. 1999. The usual excess-burden approximation usually doesn't come close. Stanford University. Mimeo.

Hahn, Robert. 1989. Economic prescriptions for environmental problems: How the patient followed the doctor's orders. *Journal of Economic Perspectives* 3: 95–114.

Merrill, Peter R., and Ada S. Rousso. 1991. Federal environmental taxation. In

Proceedings of the eighty-third annual conference of the National Tax Association, ed. Frederick D. Stocker, 191–98. Columbus, Ohio: National Tax Association, Tax Institute of America.
Metcalf, Gilbert E., Daniel Dudek, and Cleve Willis. 1984. Cross-media transfers of hazardous wastes. *Northeast Journal of Agricultural and Resource Economics* 13:203–9.
Nichols, Albert. 1984. *Targeting economic incentives for environmental protection.* Cambridge, Mass.: MIT Press.
OECD. 1994. *Managing the environment: The role of economic instruments.* Paris: Organization for Economic Cooperation and Development.
Parry, Ian. 1995. Pollution taxes and revenue recycling. *Journal of Environmental Economics and Management* 29:S64–S77.
Pigou, Arthur C. 1932. *The economics of welfare.* 4th ed. London: Macmillan.
Sandmo, Agnar. 1975. Optimal taxation in the presence of externalities. *Swedish Journal of Economics* 77:86–98.
Sandmo, Agnar, and David E. Wildasin. 1999. Taxation, migration, and pollution. *International Tax and Public Finance* 6:39–59.
Schmutzler, Armin, and Lawrence H. Goulder. 1997. The choice between emission taxes and output taxes under imperfect monitoring. *Journal of Environmental Economics and Management* 32:51–64.

Comment Gilbert H. A. van Hagen

Introduction

In their contribution to this conference volume, Don Fullerton, Inkee Hong, and Gilbert Metcalf explore the difference between a tax on the output of a polluting industry and a direct tax on emissions. According to their numerical estimates, the welfare gain from the introduction of an emissions tax may be twice the welfare gain from an (imperfectly targeted) output tax. Thus, they emphasize the importance of looking for direct taxes on emissions that can replace the currently employed taxes on the output of polluting industries and on inputs that are imperfectly correlated with emissions.

In addition, the analysis of Fullerton, Hong, and Metcalf provides an important guideline for the design of taxes on the output of the polluting industry in the case that an emissions tax is unavailable. They indicate that the second-best output tax would still be set to obtain the same effect on output price as would occur with the desired but unavailable emissions tax. In this comment, I shall focus on this conclusion. In particular, I will provide some additional insight into the relationship between the second-

Gilbert H. A. van Hagen is an economist at the CPB Netherlands Bureau for Economic Policy Analysis in The Hague, and a research associate of the OCFEB Research Centre for Economic Policy at the Erasmus University in Rotterdam.

best tax on the output of a polluting industry and the second-best emissions tax.

Restrictions on the Availability of Tax Instruments

The central idea behind the analysis of second-best taxation is that policymakers are faced with various restrictions on the availability of tax instruments. In particular, let us assume that the objectives of the tax system are threefold: (1) to finance an exogenous level of public expenditure; (2) to redistribute income from high-wage to low-wage households; and (3) to internalize the external effects from production and consumption activities on the level of pollution and, thereby, on environmental quality. Ideally, the government should use a set of personalized lump-sum taxes and transfers to achieve the first two goals and an emissions tax to achieve the third objective. However, both a set of personalized lump-sum taxes and a precisely targeted emissions tax are generally unavailable to the policymaker.

First, households differ in terms of their earnings capacity and, thereby, their abilities to pay taxes. Fairness considerations prescribe that individuals with relatively low earning capacity ought to pay less taxes than people with higher levels of ability. The government faces great difficulties, however, in determining the precise ability level (e.g., the hourly wage rate) of each person. Moreover, private agents lack an incentive to truthfully disclose this information if they can reduce their tax bill by lying; that is, by claiming to possess a lower earnings capacity than their true hourly wage rate. As a result, a set of lump-sum, nondistortionary ability taxes is generally unavailable to the policymaker.

In contrast, observations of annual earnings levels (rather than implicit hourly wage rates) are relatively straightforward to obtain. Moreover, differences in earnings levels across households can be expected to feature a strong correlation with underlying differences in earning capacities. Consequently, policymakers typically rely on distortionary income taxes (and transfers) to finance public outlays and redistribute income across households.

Second, environmental taxes often cannot be targeted directly on emissions, as evidenced by the comprehensive review of Fullerton, Hong, and Metcalf of actual environmental taxes employed by various governments around the world. Instead, taxes are usually imposed on commodities that are imperfectly correlated with the level of emissions. Such levies raise the price of, and thereby lower the demand for, dirty inputs and outputs. As a result, their introduction will generally succeed in reducing the total level of emissions. These output and input levies fail, however, to provide an incentive for the polluting firms to reduce the ratio of the level of emissions to the level of the taxed input or output.

A Simple Rule for the Second-Best Tax on Output of a Polluting Industry

How should the tax system be designed if we take into account (1) the restriction that income taxes rather than lump-sum taxes are used to finance public expenditures, and (2) the constraint that an imperfectly targeted tax on the output of the polluting industry is used rather than an emissions tax? Fullerton, Hong, and Metcalf provide a preliminary answer to this question by analyzing the welfare effects of a tax on output of the polluting industry in an illustrative general equilibrium model with a single representative firm and household, and a preexisting distortionary tax on labor income. In particular, they find that when an emissions tax is unavailable, the constrained efficient solution requires setting the tax on output of the polluting industry equal to the social marginal damages from pollution divided by the marginal cost of public funds and multiplied by the emissions-output ratio.

This is a particularly simple and useful tax rule, as a numerical implementation by Fullerton, Hong, and Metcalf illustrates. Environmental economists have developed a number of methods, such as contingent valuation analysis, to provide an empirical estimate of the social marginal damages from (different sorts of) pollution. Similarly, public finance economists have developed methods to estimate the value of the marginal cost of public funds, which measures the marginal excess burden from the preexisting tax on labor income. Finally, an estimate of the average emissions-output ratio in the particular industry under consideration is required.

The Second-Best Emissions Tax versus the Second-Best Output Tax

The Fullerton-Hong-Metcalf (FHM) rule for the second-best output tax implies that the output tax should still be set to obtain the same effect on the output price as would occur with the desired but unavailable emissions tax, *for given values of the social marginal damages from pollution and of the marginal cost of public funds.* Fullerton, Hong, and Metcalf emphasize this result, but without the proper qualification that I have added in italics. The values of the social marginal damages from pollution and of the marginal cost of public funds are not given, however.

Let us start from the situation in which no tax on emissions or on output of the polluting sector has been imposed, while a proportional income tax is used to finance an exogenous level of public expenditures. Now let us compare the effects from the introduction of a tax on emissions versus the introduction of an (imperfectly targeted) output tax, where both have the same effect on the output price.

The introduction of a tax on emissions will induce a larger increase in the level of environmental quality than the introduction of an output tax. A tax on output reduces the level of pollution only through an increase in the price of, and an associated reduction in demand for, the output of the polluting industry. In addition to the effect on the demand for output of the polluting industry, an emissions tax generates a further reduction in pollution by encouraging firms to switch to a cleaner production technology and a lower emissions-output ratio. Hence, environmental quality will be greater after the introduction of an emissions tax than after the introduction of an output tax that has the same effect on the output price as the emissions tax.

A higher level of environmental quality implies a lower value for the social marginal damages from pollution (measured in terms of private income). As environmental quality expands, people start to care less for the environment relative to income. Since an emissions tax is more successful in reducing the level of pollution than an output tax, the introduction of a tax on emissions will lead to a larger decline in the value of the social marginal damages from pollution than the introduction of an output tax with the same effect on the output price as the emissions tax.

The FHM rule for the optimal second-best tax states that the emissions tax or, if unavailable, the output tax should be raised until its rate corresponds to the social marginal damages from pollution divided by the marginal cost of public funds (multiplied, in the case of an output tax, by the emissions-output ratio). Ignore the value of the marginal cost of public funds for the moment. We have seen that an increase in the emissions tax will lower the value of the social marginal damages from pollution more rapidly than an equivalent increase in the output tax. Hence, the FHM rule must be satisfied at a lower rate of the emissions tax than of the output tax (multiplied by the emissions-output ratio).

That is, even though the second-best tax *rules* for the emissions and output taxes correspond, their second-best tax *rates* differ. In particular, the second-best output tax will have a greater effect on the output price than the desired but unavailable second-best emissions tax, while the optimal level of environmental quality will be lower in the case of an output tax. If the government lacks access to an emissions tax, the efficient level of environmental quality is lower because a tax on output of the polluting industry is less efficient than a tax on emissions in achieving the same reduction in the level of pollution. Yet the output price should be raised more strongly in the case of the second-best output tax in order to partially compensate for missing the target (which results in a higher level of pollution and therefore in a larger value of the social marginal damages from pollution).

Interaction with the Preexisting Income Tax

The FHM rule for the optimal second-best environmental tax reveals that due to the presence of a distortionary income tax, the social marginal damages from pollution must be divided by the marginal cost of public funds in the calculation of the second-best tax rate. This result holds both in the case of an emissions tax and in the case of an output tax. This result appears to suggest that the quantitative adjustment to the environmental tax in order to account for the presence of a preexisting, distortionary income tax is the same in both cases. In other words, the unavailability of lump-sum taxation does not seem to interact with the unavailability of a direct tax on emissions.

In the previous section, however, we arrived at the conclusion that the second-best output tax will have a greater effect on the output price than the desired but unavailable second-best emissions tax. This implies that the tax revenue from the second-best output tax exceeds the revenue from the second-best emissions tax. These surplus tax revenues could then be returned to households through an additional cut in the rate of the proportional income tax, at a given level of public expenditure. Then the income tax rate, and hence the marginal cost of public funds, is smaller in the case of a second-best output tax than in the case of a second-best emissions tax.

Intuitively, the output price should be raised more strongly in the case of an output tax in order to partially compensate for missing the target. As a result, the total revenues from environmental taxation expand, and the income tax and the size of the marginal cost of public funds (MCPF) can be reduced. In other words, the unavailability of a direct tax on emissions appears to somewhat alleviate the welfare losses from the unavailability of lump-sum taxation, as reflected in a lower value of the MCPF (although, of course, an emissions tax, if available, is still preferable to a tax on output of the polluting sector).

Conclusion

In my comments on the contribution of Fullerton, Hong, and Metcalf, I have explored some of the implications of the tax rule that they derive for the optimal second-best tax on the output of a polluting sector. In particular, the government's inability to tax emissions implies a lower level of environmental quality because a tax on output of the polluting industry is less efficient than a tax on emissions in achieving the same reduction in the level of pollution. However, the efficient output price would be raised more strongly in the case of the (second-best) output tax, in order to partially compensate for missing the target. As a result, the total revenues from environmental taxation expand, so that the rate of the income tax and consequently the size of the MCPF can be reduced relative to the case of a second-best tax on emissions.

These implications show that relevant lessons can be learned from a study of the optimal design of a second-best tax system, in which we take into account (1) the constraint that income taxes rather than lump-sum taxes are used to finance public outlays, and (2) the restriction that an imperfectly targeted tax on the output of the polluting industry is used rather than an emissions tax. Fullerton, Hong, and Metcalf provide an important first contribution to this subject. Nevertheless, it should be noted that their analysis rests on a number of simplifying, unrealistic assumptions (as they acknowledge in the conclusion of their paper). For example, their model abstracts from the heterogeneity of firms (regarding the emissions-output ratio) and from the heterogeneity of households (in terms of wage rates). Hence, ample room is still available for extensions and improvements to the study of the optimal design of a second-best tax on output (and inputs) of a polluting sector in the presence of a distortionary income tax.