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A Presumptive Pigouvian Tax on Gasoline

Analysis of an Air Pollution Control Program for Mexico City

Gunnar S. Eskeland

Taxing a variable input in polluting activities makes sense when abatement is induced indirectly, rather than by a pollution tax. By including a gasoline tax in an otherwise well-composed control program for Mexico City, one saves 11 percent of the welfare costs of the program, because — keeping emissions constant — costly technical abatement measures are replaced by cheaper demand conservation.

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Without continuous monitoring of emissions, a pollution control agency needs to evaluate abatement options itself. Apart from making activities cleaner, it should also stimulate reductions in the level of activity in polluting sectors.

Eskeland develops an analytical framework to show that a tax on a variable input, such as gasoline, is useful for this purpose. It encourages individuals and firms to sacrifice trips when they would prefer those sacrifices to those of higher spending on abatement. The instrument exploits privately held information about which trips can be saved at a low social cost.

Other weaknesses of a program based on indirect instruments — as opposed to one induced by a theoretically conceived pollution tax — remain. One of these is that the agency may have poorer information than individuals and firms about the status of vehicles and the effectiveness of individual abatement options. Such an information gap — which could be bridged by a true pollution tax — is abstracted from the analysis.

Eskeland shows that the tax rate that belongs in a cost-effective pollution control program is independent of the price elasticity of demand for the polluting good. But the higher the demand elasticity, the higher are the costs of not including a presumptive tax on the polluting good in the tool kit of the pollution control agency.

Eskeland estimates the cost savings available when an optimal gasoline tax is included in an otherwise well-composed program, appropriately accounting for the welfare costs of demand consumption. He shows that the targeted emission reductions can be obtained at 11 percent lower costs, saving $64 million annually, when the demand conservation induced by the gasoline tax allows some other, more expensive abatement options to remain unused.

He proposes an ad valorem gasoline tax of about 25 percent, when no separate value is associated with the collection of revenue or with avoidance of noise, congestion, accidents, and road damage. In Mexico City alone, the tax would collect $350 million a year. After recent price increases, implicit tax rates in Mexico City are higher than suggested by Eskeland's analysis. Higher rates may or may not be justified due to the benefits of demand conservation not accounted for in the analysis.

A Presumptive Pigouvian Tax on Gasoline

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1 Introduction

The topic of this paper is prompted by a prosaic, but practical challenge: how to reduce air pollution from transport in a metropolitan area like Mexico City, while keeping an eye at the welfare costs of doing so. A least cost solution to such a problem could involve behavioral change, such as modified travel patterns, as well as a number of technical modifications, whether in the form of tune-ups or retrofitting of existing capital equipment, or in the form of new configurations of machinery (e.g. catalytic converters), fuels, etc.

These details have not been of great interest to economists in the public finance tradition (with some notable exceptions), since a proposed tax levied on individual emissions would provide perfect incentives. Firms and households exposed to such a tax would self-select, taking (only) those measures that are most effective from society's point of view, irrespective of whether they could be categorized as technical modifications, changes in input mix or changes in the consumption basket. Using such a tax, or tradeable pollution permits, the agency charged with protecting the environment need know nothing but *aggregate* marginal costs and benefits of abatement, since the detailed actions that can be taken to reduce pollution need be known only by the economy's micro agents[2].

Indeed, had a social planner possessed data on how much pollution each individual caused through the year, then a year-end tax bill based on related damages would have provided appropriate incentives to pollution reduction from all kinds of activities. Had emission monitoring been feasible, the planner would not need to know what options individuals and firms in different activities have to reduce emissions, nor how those options compare in terms of costs. In particular, he would not have needed to design special programs for each sector. Sectors, firms and individuals would have been affected by his tax scheme simply in accordance with how much they polluted, and would each have responded with socially optimal effort. When continuous monitoring of individual emissions is not feasible, however (and it is not yet for motor vehicles), the planner needs to ask himself which sectors are polluting, what options exist within the sector,

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[2] The general results are well presented in Baumol and Oates (1988). Special treatment of the information economy of the market is found in Weitzman (1974). Notice that if the planner assesses individual marginal abatement costs with errors that are not perfectly correlated across polluters, he can assess aggregate abatement costs with less error than he can assess individual abatement costs.

and how he can best stimulate each of them. It is in this context the analysis of *a program to control air pollution from motor vehicles in Mexico City* takes place.

Pollution taxes, rare and still fairly unimportant exceptions in the real world, have been criticized on many grounds, and in this article we discuss one of those: For many types of polluting sources, and automobiles among them, technology does not yet allow continuous monitoring of individual emissions. Feasible monitoring -- annual testing of individual *rates* of emissions (say, grams per liter or vehicle kilometer)[3] -- leaves the environmental agency in a totally different situation, having to use regulation and incentives in a detailed program aimed at mimicking the least cost program that a pollution tax would have induced.

In section 2, we briefly review the theoretical literature on the use of imperfect corrective taxes, to provide a basis for our analysis. In section 3, we develop the theoretical background for *cost-effectiveness* analysis in a very simple, general equilibrium, welfare economic perspective. We use this framework to show that any program employing inducements to make an activity cleaner also should contain taxes on the main (polluting) input or output used in the activity, since containing the level of the activity is justified as long as abatement is costly and some pollution remains[4]. We show that the tax that should accompany any given level of abatement (say, a three way catalytic converter) in a cost-effective program is easily calculated; it does not depend on the demand elasticity for the polluting good and it does not depend on knowledge about the benefits of emission reductions.

Lastly, in section 4, we apply the analysis to a detailed program of measures to contain pollution in Mexico City, and show how inclusion of a gasoline tax in the tool-kit would reduce the costs of attaining the targeted emission reductions. The savings provided by the proposed tax are conservatively assessed, since we have not assumed any premium for transfer of revenue to

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[3] Apart from providing a poor proxy for actual in-use emission rates (see, among others, Lawson et al. 1990), the method does not combine data on emission rates with data on vehicle utilization (it could). Thus, utilization is not discouraged, unless abatement expenditures raise the relevant marginal costs, and, even then, the method does not discourage use optimally and cheaply, as complementary instruments could.

[4] We use the term *polluting activity* about a consumption or production activity associated with emissions. Taxes on goods or inputs used in the activity or outputs from the activity can reduce emissions through reduced activity levels. Also, they can make the activity cleaner, per unit, if there is substitutability and one can tax a particularly *polluting input* or *polluting good*.

the public sector (a premium would be appropriate in a context where revenue generation has social costs), nor any value to reducing other effects of gasoline use that are not charged for, such as accidents, congestion and road damage.

2 Theoretical Background

Optimal taxation theory has mainly been concerned with the minimization of the *distortionary* costs of revenue-raising taxes (See, for instance, Mirrlees, 1976). The broader normative public finance literature has also taken on the task of providing the case for an authoritative government and intervention through public expenditures, taxation and regulation, where the two main classes of objectives are market failure and concerns about income distribution (Atkinson and Stiglitz, 1980, and Starrett, 1988, both provide broad coverage). The result of greatest relevance for this study was provided by Pigou (1920), whose recommendation that pollution problems could best be taken care of by taxes gave rise to the term *Pigouvian taxes*[5].

On Pigouvian (or corrective) taxes, theory prescribes that individuals should be confronted with the full marginal social costs of their activities. Moreover, theory states that if they did, and if the definition of social costs included such effects as the problems caused by pollution, then pollution control would be efficient, in the sense that there would be no net benefits to society either to further (or different) prevention of pollution or to more pollution.

Sandmo, 1975, combines two motives for taxation, when he analyzes how a revenue-motivated optimal tax structure would be modified when a negative external effect, like pollution, is associated with one of the commodities. He shows that traditional, distortion-minimizing revenue formulas will prevail, but that a Pigouvian element will be contained in the formula for the for the polluting good. As a special case, if the revenue requirement is sufficiently low, taxation of the polluting good may be sufficient, so that revenues can be raised without causing distortions.

[5] The position that authoritative intervention, for instance through Pigouvian taxation, is necessary for efficiency when there are external effects, was later challenged by Coase (1960). Coase argued that voluntary negotiations between those causing and those affected by an external effect could provide for efficiency. Later literature has emphasized that negotiations may be costly and inefficient, as may an intervening bureaucrat (See Farrell, 1987, for a simple exposition and discussion).

Other theoretical contributions concerned with Pigouvian, or corrective taxes, have generally abstracted from the need to generate revenues through distortionary taxes. This could be interpreted as effectively assuming that it is not costly to fund the public sector, or simply that the two topics can be analyzed separately[6]. Many have been concerned with the distortionary effects *of* Pigouvian taxes, however, in analyzing such taxes when they are not ideal from the perspective of correcting for external effects.

The most notable among these are Sandmo, 1976, Balcer, 1980, and Wijkander, 1985, all asking whether taxes and subsidies levied on complements and substitutes can be helpful when taxation of the polluting good is either not feasible or not perfect, in terms of emission generation. They find that such supportive instruments can be helpful when, respectively: i) the polluting good is used both in a polluting and in a non-polluting activity; ii) some users of the polluting good cause more harm per unit consumed than others, and; iii) taxing the polluting good directly is not feasible. These results can all be read as special explorations of a point made by Greenwald and Stiglitz (1986); that market equilibria in economies with market failures are not constrained Pareto optimal, and that a demand system, with all its own- and cross price elasticities, can provide opportunities to seek Pareto improvements.

In this essay, we examine a situation where resources can be spent on making the consumption of a good less polluting[7]. The availability of options in *pollution abatement* implies that taxation of the *polluting good* would not provide ideal incentives, since it would encourage only the subset of abatement options that reduce the use of the polluting good. Indeed, mandated abatement, rather than demand management, has been at the heart of pollution control programs worldwide. We make the simple point that an efficient program exploits opportunities to reduce activity levels in polluting activities as well as opportunities to make each activity cleaner. If emission monitoring were feasible, optimal exploitation of both avenues would have been implemented by one single instrument: an emission tax.

[6] Sandmo, 1975, could be read as providing some support for such a separation, although the pollution control agency would need to coordinate with the revenue generating agency.

[7] We shall use the term polluting rather than the more general (but clumsier) *externality causing*. Our model is equally valid for a problem with positive external effects.

In the theoretical literature, the distinction between optimal scale of polluting activities and optimal abatement has been treated only tangentially: The point has been made that pollution taxes are superior to abatement subsidies since the latter may lead to "too much" of the polluting activity (See, for instance, Baumol and Oates, 1988)[8]. In our model, we apply two instruments, an abatement requirement and a tax on a variable input (the one most strongly associated with pollution generation) in the polluting activity. We show that, unless the polluting good is taxed, the polluting activity is "too large", even when polluters pay for abatement[9].

The use of more than one instrument to deal with only one negative external effect is commanded by a monitoring problem. When monitoring of individual contributions to pollution is costly, one will want to use indirect instruments to affect the different choices that can affect pollution (See Eskeland and Jimenez, 1992).

There are many weaknesses of a program of mandated abatement requirements, as compared to one implemented by a true pollution tax. The improvement proposed here, through the taxation of a major input or output in the polluting activity, merely removes one of these weaknesses -- that abatement requirements do not effectively discourage demand for polluting goods. Our gasoline tax proposal is an indirect instrument which reveals privately held information about which trips can be sacrificed at a low social cost, and encourages firms and individuals to sacrifice those[10]. As an example of weaknesses that remain (as compared to a program induced by a true pollution tax) in the proposed air pollution control program, we have preserved the assumption that the agency has all the knowledge that exists about the status of vehicles and the efficiency of various abatement options. Consequently, the proposed program is poorer than a theoretically conceivable program -- in which the pollution tax would have revealed

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[8] While subsidizing abatement would give too high activity levels in polluting activities, making polluters pay for abatement does not imply optimal discouragement; making polluters pay for *damages* would. The polluter pays principle, as advocated by OECD, regretfully, usually applies to payment for abatement, but not for damages (see OECD 1975, and Opschoor and Vos, 1989).

[9] Some insight into the role that can be played by changes in the level of activity in polluting sectors is provided by Jorgenson and Wilcoxen (1990) and Hazilla and Kopp (1990). They explore changes in sectoral activity levels as result of abatement costs, however, rather than as a result of pollution taxes, input taxes or output taxes.

[10] We use the *sacrifice of trips* figuratively for options that reduce pollution through reduced demand for the polluting good. An important category of such options are more efficient cars; the social costs will often consist of items such as higher capital costs (for instance through accelerated replacement) or loss in terms of some other quality dimensions (size, power).

and exploited *all* relevant privately held information[11]. How much poorer the program is depends on how important these remaining information gaps are, assuming that the agency exploits rationally the information that it holds.

3 A simple model with demand management and abatement

Background for choice of model What should a model look like, to facilitate the comparison of emission control options within a sector, to the possibility of shrinking the overall level of activity in the sector? The aim in our analysis has been to apply a modelling framework which is simple enough to communicate central ideas, but rich enough to compare the most relevant implications of options that are *so different that they cannot be analyzed without a modelling framework*. Traditional pollution control programs have emphasized the technical options that can make production and consumption activities less polluting. The model we propose emphasizes that manipulation of demand for polluting goods *could* represent an interesting alternative or complement to abatement (the latter reduce pollution per unit of polluting good consumed). In the model, abatement expenditures are dealt with only in a very superficial way, since we only need to know the incremental costs per unit of emission reductions provided.

We thus need a model which not only allows for behavioral responses to policies that can influence demand, but which also provides a measure of the social costs of such demand manipulation. The models proposed in the welfare economic literature are tailored for those purposes, and, ideally, one would want to apply a model with many consumers or groups of consumers. This would allow for analysis of the distribution of costs and benefits across economic agents, apart from efficiency aspects.

Our focus is on efficiency implications, using a model with a representative consumer. Such a framework has two principal shortcomings. First, it cannot be helpful in analyzing the effects on income distribution. This abstraction can be justified only by assuming that the effects

[11] In revealing and exploiting which trips can be sacrificed at the lowest social costs, the gasoline tax is superior to the present regulation that each car is banned from driving a specific weekday. The higher social costs of saving trips through the regulation is partly reflected by the fact that households buy *driving permits*, implicitly, by registering additional vehicles.

of the air pollution control strategy on income distribution is not of major interest, for instance because the planner has available other instruments that can cheaply transfer income between groups[12]. Second, in practice, consumers differ along other dimensions, for instance by owning unevenly polluting vehicles. Our model can best be interpreted as one in which a representative consumer owns a composite of the vehicle fleet in Mexico City[13].

We shall employ a model with separability along two lines in the direct utility function, as do Balcer and Wijkander, and a representative consumer model, as do Sandmo and Wijkander. Finally, we assume that public revenue generation is not in itself costly. This assumption is reasonable only if the public sector revenue requirement does not exhaust the potential of instruments available for costless revenue generation and transfers to the public sector.

<u>The consumer's maximization problem:</u> Let individual j's emissions e^j of pollutants depend on her consumption of the polluting good, x^j, and the abatement she applies, a^j. Let her utility u^j depend on quantities consumed, y^j, x^j, of non-polluting goods and polluting goods, respectively, as well as the total amount of emissions from all n individuals[14]:

(1)

$$u^j = u^j\left(y^j, x^j, \sum_{i=1}^{n} e^i(x^i, a^i)\right).$$

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[12] We shall here use the concepts *welfare cost* and *social cost* to describe net costs, totalled over individuals, firms and the public sector, thus valuing costs equally across agents. We define the concept of *costs* sharply in the section *cost effectiveness*.

[13] An emission coefficient, representing grams of weighted emissions per liter of gasoline consumed, is central in our analysis of a gasoline tax. Thus, the emission coefficient used in this analysis shall be interpreted as the marginal emission coefficient for a fleet of heterogenous vehicles, when the gasoline price is adjusted [illegible] tly.

[14] We shall assume that the utility function satisfies the traditional regularity assumptions: it is quasiconcave, continuous and twice differentiable. Further, we assume that x, y and a are constrained to non-negative values. We shall assume that the individually optimal solution does not involve either of the corners y = 0 or x = 0. We shall further, in this analytical section, assume that initial expenditures on abatement are very productive (abatement is produced at constant returns to scale, but its effect on emissions is declining), so that the corner a = 0 does not occur in the planner's optimum unless in combination with $t_x = 0$. The latter assumption is relaxed in the applied section, where discrete measures are investigated in the surroundings of the analytically determined optimum.

Individual j takes consumer prices as given and maximizes u^j subject to an individual budget constraint which we shall assume is binding, and a constraint for abatement. The individual budget constraint is:

(2)

$$y^j + (p_x + t_x)x^j + p_a a^j = I^j + \frac{1}{n}t_x\sum_{i=1}^{n} x^i.$$

where the price of the non-polluting good is normalized to one, p's with subscripts are producer prices, and a tax, t_x, is levied on the polluting good. I^j is j's lump sum income, and the last term on the right hand side is j's share of the tax revenues, all of which are returned to consumers as transfers. Also, a constraint defines a minimum of abatement, "a bar", which would be zero in the absence of regulation:

(3)

$$a^j \geq \bar{a}^j.$$

Maximization of (1) subject to (2) and (3) results in the following first order conditions for individual optimum:

(4)

$$u^j_{y^j} - \beta^j = 0,$$

(5)

$$u^j_{x^j} + u^j_e e^j_{x^j} - \beta^j(p_x + t_x - \frac{t_x}{n}) = 0,$$

(6)

$$u^j_e e^j_{a^j} - \beta^j p_a - \lambda^j = 0,$$

where β^j is the shadow price of j's budget constraint, λ^j is the shadow price of j's abatement requirement, and subscripts to the function symbols denote partial derivatives.

Now, let us make the assumption that the individual does not take into account the effect of her pollution on herself, and also that she does not take into account the share of her own tax payments that will be returned to her; both are either theoretically correct descriptions or minor approximations if n, the number of individuals which pollute each other and share public revenues (here assumed to be the same), is large[15]. Then, from the perspective of individual optimization, the second and the last left hand terms in equation (5) are zero, and the same holds for the first term in equation (6). Further, from (6), we can see that the consumer will adjust abatement to the lowest possible level, so that (6) can be reduced to:

(7)

$$a^j = \bar{a}^j.$$

Since there are superscripts for only one individual in the first order conditions, superscripts can be eliminated. Further, since the utility function is determined only to a

[15] Sandmo, 1975: "When maximizing utility"..."theindividual consumer, being very small compared to the market, will ignore the effect of a small change in his own consumption on the total quantity of good m consumed" (good m is the polluting good in Sandmo's model, Eskeland's remark).

monotone transformation, we can eliminate the shadow price of j's budget constraint from (5) and (4) without losing information, to characterize individual optimization by (7) and:

(8)

$$\frac{u_x}{u_y} = p_x + t_x.$$

We shall let the functions $x(a,t_x)$ and $y(a,t_x)$ represent the (Marshallian) demand functions consistent with the first order conditions (7) and (8). Further, since producer prices are fixed, equilibrium quantity changes will equal the partial derivatives of Marshallian demand functions.

The Planner's Maximization Problem Now, let us turn to the planner's problem. Let us assume there are constant returns to scale so that producer prices are given, and that the planner's objective is to maximize the sum of utility levels for the n consumers:

(9)

$$w = \frac{1}{n}\sum_{j=1}^{n} u^j(y^j,x^j,\sum_{i=1}^{n} e^i)$$

Working with a representative consumer in the following, we shall suppress individual superscripts, and describe the planner as maximizing the following welfare function, using mandated abatement, a, and a tax on the polluting good, t_x, as instruments:[16]

[16] With Marshallian demand functions substituted into the utility function, the objective function is an indirect utility function.

(10)

$$Max\ w_{a,t_x} = u(y(a,t_x),x(a,t_x),n{\cdot}e(x(a,t_x),a))$$

subject to a resource constraint which is the sum of the individuals' budget constraints:

(11)

$$y(a,t_x) + p_x x(a,t_x) + p_a a = I.$$

We can see that the difference between the individual's objective function, (1), and the planner's (10) is that the individual does not take into account her effect on emissions, since only a negligible amount affects herself, while the planner takes into account the effect of emissions on all individuals. A similar difference is present in their respective resource constraints (2) and (11); while the individual looks at tax payments as costs, the planner takes into account that they are all redistributed. Thus to the planner, taxes paid are not lost, and bear costs only to the extent that they distort resource use. Since we assume transfers are made without costs, only the former of these differences in the two optimization problems represent a challenge to policy in our model.

Maximizing (10) subject to (11), we have the following first order conditions for the socially optimal allocation:

(12)

$$y_a(u_y - \gamma) + x_a(u_x + nu_e e_x - \gamma p_x) + nu_e e_a - \gamma p_a = 0$$

(13)

$$y_{t_x}(u_y - \gamma) + x_{t_x}(u_x + nu_e e_x - \gamma p_x) = 0$$

We can differentiate society's resource constraint (11) with respect to a and t_x to obtain expressions for the equilibrium changes in demand:

(14)

$$y_a = -p_a - p_x x_a,$$

(15)

$$y_{t_x} = -\, p_x x_{t_x}.$$

Substituting (14) and (15) into (12) and (13), the first order conditions for social optimum are:

(16)

$$x_a(u_x + nu_e e_x - p_x u_y) + nu_e e_a - p_a u_y = 0,$$

(17)

$$x_{t_x}(u_x + nu_e e_x - p_x u_y) = 0.$$

Assuming that x_a and x_t are not zero[17], we can solve for the marginal rates of substitution, to find that the optimal allocation is characterized by:

[17] If consumption of polluting goods is completely insensitive to the instruments t_x and a (meaning that the consumer absorbs all costs of the tax and the abatement requirement via adjustments in consumption of non-polluting goods only), then $c_a/e_a = nu_e$ characterizes the optimal program, whereas t_x is not specified, since it has no allocative effect.

(18)

$$\frac{u_x}{u_y} + \frac{nu_e e_x}{u_y} = p_x$$

(19)

$$\frac{nu_e}{u_y} = \frac{p_a}{e_a}$$

As (18) and (19) shows, the sum across individuals of the marginal rates of substitution be equal to the marginal rates of transformation, consistent with Samuelson's (1954) result. Samuelson's definition of a public good, that it be non-exclusive in consumption, suits well for the quality of ambient air.

Rearranging, and using that marginal rates of substitution in consumption will equal consumer prices (8), we can get some additional intuition about the optimal abatement and tax rate:

(20)

$$t_x = -\frac{nu_e e_x}{u_y} ,or\ \frac{t_x}{p_x} = -\frac{nu_e e_x}{u_x + nu_e e_x}$$

(20) states that the tax levied on the polluting good should drive a wedge between the marginal rates of substitution equal to the part of the associated impact on welfare that the consumer does not take into account herself.

Eliminating nu_e, we can see that optimality requires:

(21)

$$\frac{t_x}{e_x} = -\frac{p_a}{e_a}$$

(21) states that the optimal tax rate on the polluting good, per unit of emissions from the polluting good, is equal to the direct marginal cost of abatement per unit of achieved emission reductions. (21) will prove a useful comparison when we, in the following, characterize a cost effective program.

Before proceeding, let us notice that the optimal program, as characterized by (18) and (19), could be implemented by *one* instrument, an emission tax, if it were available. This is easily checked by replacing the instruments in (10) with a tax levied on emissions, and modifying the individual budget constraint, (2), accordingly.

<u>Cost effective pollution control</u> The *optimal program*, above, is characterized by abatement and demand management being pursued to the point where marginal benefits equal marginal costs. If benefit estimates are unavailable, or in dispute, helpful results can be provided by asking how a given, targeted emission reduction can be achieved at lowest possible costs[18]. Such analysis is called cost effectiveness analysis. In the following, we will show how the concept of cost effectiveness fits into traditional framework of welfare economic analysis.

As we saw in the preceding, when producer prices are fixed, supply is infinitely elastic, and equilibrium marginal changes in quantities will equal the partial derivatives of the Marshallian demand functions. Starting from an arbitrary point a, t_x, with feasible quantities y, x and a, welfare is at the outset the following:

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[18] Estimates will often be found unavailable or of limited applicability for quantification of physical outcomes, such as the effects on ambient air quality of emission reductions, and the effects on health of improved ambient air, as well as for valuation of such outcomes. For a recent, brief, general discussion, see Cropper and Oates, 1992. Briefly on what is applicable for Mexico: Margulis, 1991.

(22)

$$w = u(y(a,t_x),x(a,t_x),\hat{n}e(x(a,t_x),a)),$$

where we have let "n hat", an uncertain estimate of how many individuals are affected by an individual's emissions, represent the uncertainty in the estimate of the benefits of emission control.

Rather than maximizing (22) subject to a constraint on emissions (which, in the end, we will do), let us ask the following question: Starting from an arbitrary point, t_x,a, what is the rate at which welfare changes if we change the tax rate slightly? Differentiating (22) with respect to t_x, we have:

(23)

$$\frac{\partial w}{\partial t_x} = u_y y_{t_x} + (u_x + \hat{n}u_e e_x)x_{t_x}$$

Using the partial derivative of the resource constraint, (15), and the first order condition for individual optimum, (8), we have:

(24)

$$\frac{\partial w}{\partial t_x} = (t_x u_y + n u_e e_x)x_{t_x}$$

Emissions will also change when we change the tax rate; from (1), we have:

(25)

$$\frac{\partial e}{\partial t_x} = e_x x_{t_x}$$

Dividing (24) by (25), the *marginal welfare impact*[19] of changing the tax rate, per unit of associated emission reductions is:

(26)

$$\frac{\partial w}{\partial t_x} / \frac{\partial e}{\partial t_x} = \frac{u_y t_x}{e_x} + \hat{n} u_e$$

While this is a (net) marginal cost expression, we can notice that if we were allowed to adjust only this instrument for the purpose of emission control, then setting (26) equal to zero would be optimal (consistent with (20)).

Following the same procedure as for the tax rate, we have the marginal impact on welfare when the abatement requirement is changed slightly from an arbitrary level, per unit of associated emission reductions:

(27)

$$\frac{\partial w}{\partial a} / \frac{\partial e}{\partial a} = \frac{(t_x x_a - p_a) u_y}{e_x x_a + e_a} + \hat{n} u_e$$

Composing a cost effective program requires the comparison of marginal costs of emission reductions across instruments. However, in comparing the cost expressions for the two instruments (26) and (27), no information would be lost if we were to use a cost measure which

[19] We will reserve the term *marginal welfare cost* for a measure that does not include the expected benefits, "n hat u_e", to conform with convention that marginal costs equal marginal benefits in optimum (see below).

does not include an assumed effect of emissions on welfare. Starting from an arbitrary point, eliminating "n hat u_o" would simply subtract the same amount from the cost expression for each instrument.

We can therefore define a measure of marginal welfare cost which only includes the sacrificed consumption of market goods. Subtracting "n hat u_o" from (26), the marginal cost at which tax rate adjustments provide emission reductions, in terms of sacrificed consumption of market goods, is:

(28)

$$\frac{\partial \hat{w}}{\partial t_x} / \frac{\partial e}{\partial t_x} = \frac{t_x \mu_y}{e_x}$$

Similarly, the marginal cost at which abatement requirements provide emission reductions, in terms of sacrificed consumption of market goods, is:

(29)

$$\frac{\partial \hat{w}}{\partial a} / \frac{\partial e}{\partial a} = \frac{(t_x x_a - p_a) u_y}{e_x x_a + e_a}$$

Using the measure "dw hat" for marginal costs, we can notice that optimal policies are characterized by marginal costs equal to "n hat u_o". This cost concept thus has the advantage of conforming to the convention that optimality be characterized by marginal costs being equal to marginal benefit. The main advantage of using this cost concept, however, is that the analysis of alternative emission reduction strategies can be isolated from the analysis of the benefits of emission reductions.

What, then, can we learn from these expressions? First, notice the simplicity of (28): marginal costs depend only on the tax rate on the polluting good (remember that we assume that other goods are priced at marginal costs) and on the marginal impact on emissions of consuming the polluting good (say, grams of pollutants emitted per liter of gasoline consumed)[20]. Second, let us notice what is not in (28): the marginal cost of using tax rate changes to reduce emissions does not depend on the elasticity of demand for polluting goods. The reason is, as we have seen, that the demand responsiveness, x_t, affects welfare through product markets multiplicatively, in the same way as it affects emissions. Consequently, it does not affect the ratio between the two. This result does not say that the amount of emission benefits offered by a given tax change is independent of the demand elasticity. What it says is that the marginal welfare costs, per unit of obtained emission reductions, is independent of the demand elasticity. As an example, if the elasticity were small, then the emission reductions would be small, but so would be the costs from sacrificed consumption, since changes in consumption would be small[21].

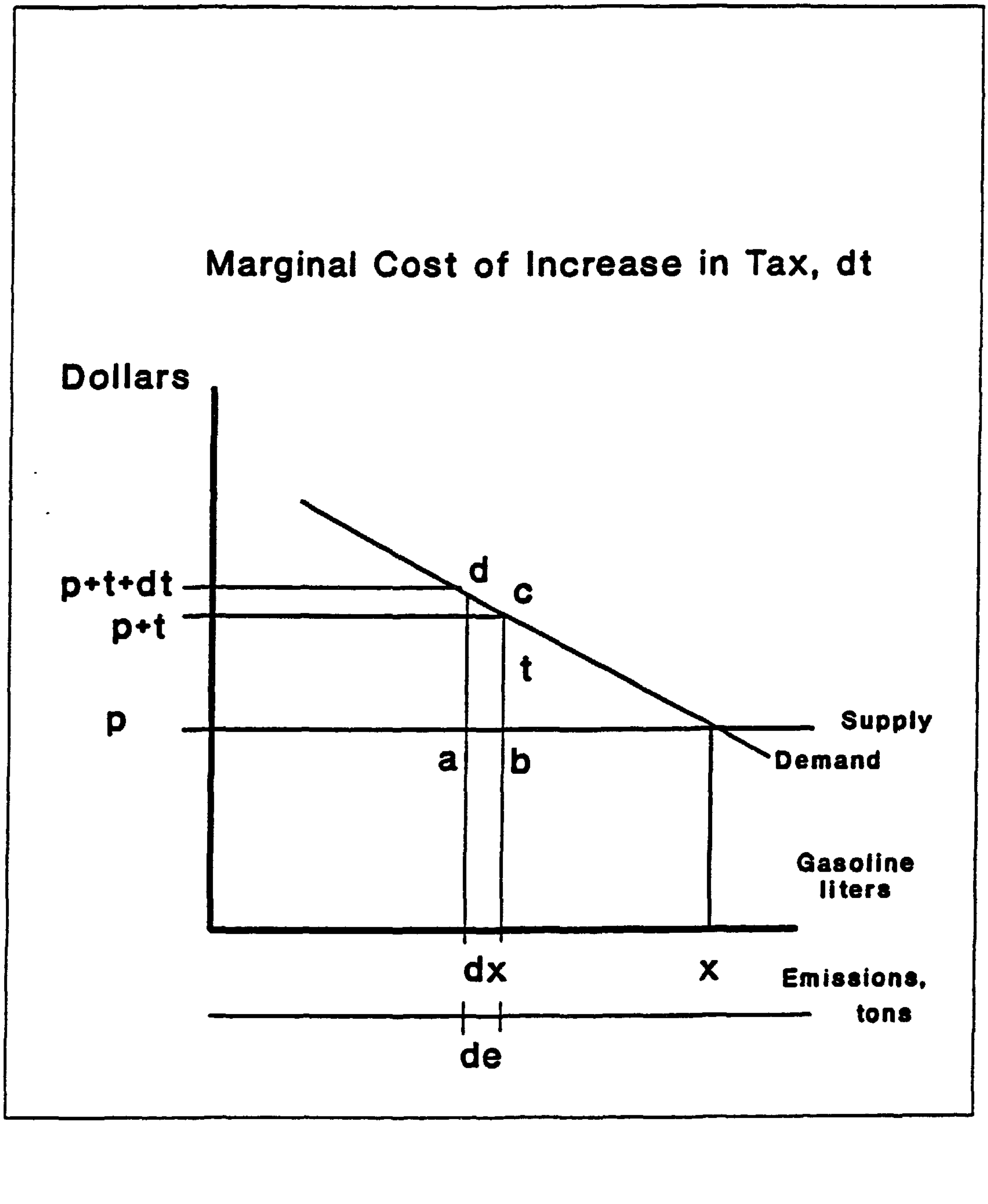
This result is illustrated in Figure 1, which is drawn for a given level of abatement, and, consequently, a given e_x. The welfare cost of a tax change "dt" is the trapezoid abcd, approximated by the rectangle $t \cdot dx$. Emission benefits, "de", will equal $e_x \cdot dx$, and "dx" cancels out in the ratio between the two, which is the expression for marginal costs.

---

[20] For practical purposes, the assumption that the responsiveness of emissions to a gasoline price change will be proportional to the responsiveness of gasoline consumption (i.e. $e_x = e/x$) is a fair, though probably conservative assumption (Krupnick, 1992, provides some analysis). With the caveat that the consumption pattern does not change (average trip length should stay constant, for instance, since cold-starts are very polluting), proportionality between fuel consumption and emissions is assumed in the main emission projection models, such as EPA's "Mobile 4" and "AP-42".

[21] The result should be of no surprise. The first basic theorem of welfare economics says that efficiency is ensured when agents face the marginal social costs and benefits of their actions, irrespective of elasticities.

Figure 1


Marginal Cost of Increase in Tax, dt
Dollars
p+t+dt
p+t
p
d
c
t
a
b
Supply
Demand
Gasoline
liters
dx
x
Emissions,
tons
de

From this, it is clear that the part of the gasoline demand curve which lies above the marginal cost of supply for gasoline is a supply curve for emission reductions, reading from right to left (we have used emissions per liter of gasoline, e_x, to produce an alternative unit of measurement along the x-axis).

The expression for marginal welfare costs of abatement requirements, (29), is considerably more complicated. In particular, the responsiveness of demand to stricter abatement requirements, x_a, remain a determinant both of the welfare costs (in the numerator) and of the emission reductions (in the denominator). Somewhat paradoxically, the cost effectiveness of technical abatement (changing emission coefficients) depends on the demand responsiveness, whereas the cost effectiveness of changes in the tax rate, the demand management instrument, does not![22] Also, we can notice that marginal welfare costs of additional abatement are equal to marginal benefits if policies are optimal. Too see this, use (20) and (21) to substitute for t_x and p_a in (29).

A cost effective program requires the two instruments to be utilized so that their marginal costs are equalized. Setting (28) and (29) equal to each other, we find that cost effective programs are characterized by:

(30)

$$\frac{t_x}{e_x} = -\frac{p_a}{e_a}\ .$$

(30) is also the solution to the maximization of welfare (22) subject to an emission constraint, and each of the expressions in (30) would equal the shadow price of the constraint (by

[22] Several authors have addressed the issue that abatement requirements affect emissions through demand responsiveness, most notably that the higher costs of new cars decelerate replacement of older, dirtier cars (Crandall et al., 1986, Berkovec, 1985). Equation (18) does not comprise such effects on "fleet demographics" (which will, to some extent, wash out in the long run), but emphasizes that demand responsiveness will influence costs, via utility lost due to sacrificed consumption, and emissions, via the same adjustments in consumption.

going this indirect way, we have also derived the marginal cost for each instrument when they are *not* exploited cost-effectively).

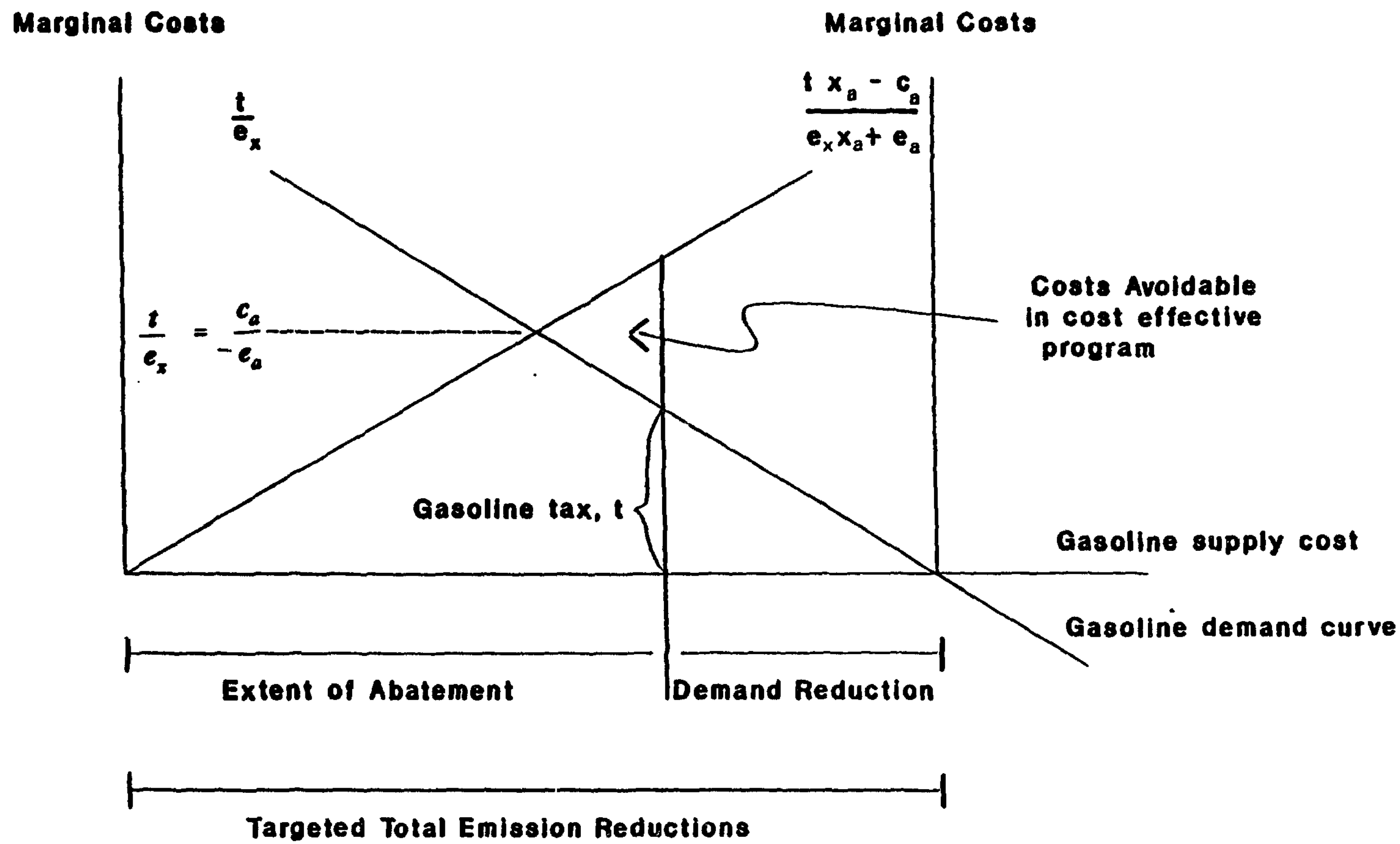
Thus, the set of cost effective programs can be characterized without estimates of demand responsiveness. Further, notice that the attractiveness of a tax on the polluting good does not depend on the availability of benefit estimates; the mere application of mandated abatement reveals that welfare costs can be saved, keeping emissions constant, if taxation of polluting goods is not applied accordingly[23]. Notice that the left hand side expression is the marginal cost measure for the tax on polluting goods, while the right hand expression is the simple, or direct marginal cost for abatement expenditures. Thus, we have shown that this simplistic measure of cost effectiveness, often applied in practical studies, is valid, but only if the polluting good is taxed accordingly! Notice also that (30), which is a complete characterization of the continuum of cost effective programs, is equal to (21), which, together with (19), characterize *the* optimal program. Thus, obvious to some, the optimal program is a special case amongst cost effective programs.

In figure 2, we have illustrated how one can think about a cost effective program. The horizontal axis is the amount of emission reductions targeted. From left to right, we have drawn a marginal cost curve for emission reductions via abatement expenditures (which we now know should include demand responsiveness, although in a cost effective program, as a special case, demand responsiveness cancels out). From right to left, we have drawn the part of the gasoline demand curve which lies above the marginal cost of supply, where the scale must be such that liters match tons emitted on the scale from right to left. A cost effective program is found where the two curves intersect. For any other combination of abatement and tax rate which satisfies the target, the difference between the two marginal cost curves can be saved by substituting, at the margin, the cheaper for the less expensive instrument.

[23] Direct emission taxes (or tradeable emission permits) optimally combine discouragement of the polluting activity and incentives to making it cleaner. Mandated abatement, on the other hand, needs to be accompanied by instruments discouraging activity levels to minimize welfare costs of emission reductions.

Figure 2

Abatement and Demand Reduction



There is another way of exploiting the results of this section, however. (30) states that if you know the marginal costs per unit of emissions reduced via technical controls, then you also know the gasoline tax rate with which it should be combined, for the program to be cost effective. We shall apply this perspective in the following application of our results to data on pollution control options in Mexico City.

4 Application to an air pollution control program

In an analysis of emission control options for motor vehicles in Mexico City, technical control options were ranked according to incremental costs per unit of weighted emission reductions provided (Table 1)[24]. The list is thus sorted in the sequence it would be implemented if willingness to pay were gradually increased. However, demand responsiveness is not incorporated in the figures; they simply show the direct incremental costs of abatement divided by the increment in emission reductions, c_a/e_a, and consequently do not provide the information we would want for marginal costs of abatement, as shown by formula (29). As (30) shows, however, demand responsiveness cancels out in the expression for marginal costs of abatement if a program is cost-effective. Thus, the figures are valid estimates of marginal costs if the abatement initiatives are accompanied by a gasoline tax that is optimal, conditional on the extent of abatement.

[24] See World Bank, 1992: Transport Air Quality Management for Mexico City Metropolitan Area: Sector Study". Weighted grams (or tons) of emissions refer to the following: Air pollution control programs will generally (and should) address several species of emitted pollutants simultaneously, and a prioritization is necessary. In the World Bank analysis of the Mexico City program, the following weights were applied, attempting to reflect the desirability to achieve ambient standards as well as the contribution by each emitted gram to ambient concentrations: Lead: 85/g, Nox: 4.7/g, PM10: 2.3/g, Dust: 0.9/g, Sox: 1.4/g, CO: 0.04/g (See Weaver, 1991).

Table 1: Mexico City: Abatement measures and matching gasoline tax rates

	Cost: Thousand Dollars per weighted ton	Cumulative Emission Reduction Mn wtd ton	Cumulative Costs Abatement Only (Mn USD)	Matching Gasoline Tax Cents/liter
Gas Truck LPG Retrofit	-379	90	0	-4.4
Minibus CNG Retrofit	-248	148	0	-2.8
Gas Truck CNG Retrofit	-225	231	0	-2.4
Gasoline Vapor Recovery	-80	275	0	-0.8
Re-engine Buses	140	299	3	1.4
Minibus 1992 Standards	181	391	20	1.7
I&M High-Use Vehicles	209	545	52	1.8
Gasoline Truck 1993 Standards	264	632	75	2.1
Taxis Tier 1 Standards	322	641	78	2.5
Re-engine R-100 Buses	482	651	83	3.7
Taxi Replacement, 1993 standards	510	714	115	3.7
Centr. Insp. & Maintenance, passenger cars	651	771	152	4.4
Passenger cars to 1993 standards.	669	883	227	4.0
Diesel Especial	699	893	234	4.2
Lower Regular R. Vapor Pressure to 7.5	836	904	243	4.9
Provide Regular Unleaded	923	954	289	5.1
Decentralized Insp. & Maint., Passenger cars	1034	1018	356	5.3
Replace Gasoline Trucks	1114	1096	442	5.0
5% MTBE in Regular Unleaded Gasoline	1201	1116	467	5.3
Lower RVP in Premium Unleaded. to 7.5	1313	1128	482	5.6
Road Paving (1000 km)	1335	1136	498	5.7
Passenger Car 1991 standards	1367	1180	508	5.4
Reduce Sulphur to .1% in Diesel	1371	1187	569	5.3
Passenger cars Tier 1 standards	1629	1201	578	6.2
US specifications for Diesel	2097	1207	601	7.9
11 % MTBE in Regular Unleaded Gasoline	2447	1219	613	9.0
5% MTBE in Premium Unleaded Gasoline	13487	1222	643	49.0
11% MTBE in Premium Unleaded Gasoline	14728	1226	686	53.2

Such a matching gasoline tax is shown in column 4 in Table 1. As an example, if the measure called "1993 standards for Passenger cars" were the costliest applied in a program, we would know that 669 dollars per weighted ton of emissions was the cost of abatement to be matched by the gasoline tax. Using the fact that with that and all the cheaper measures in effect, emissions per liter for the fleet as a whole would average 60 weighted grams, we can calculate that the gasoline tax should be 4 cents per liter, using (30)[25]. These tax rates represent optimal discouragement of gasoline use, given the burden placed on gasoline users to make their use cleaner. Any combination of technical controls with a lower gasoline tax than suggested implies that consumers could be made better off, keeping total emissions unchanged, by spending less on abatement, in return for lower gasoline consumption.

The observant reader will notice that the tax rate per liter of gasoline in Table 1 increases less than proportionally with the costs of applied technical measures. The explanation for this is that the technical measures reduce emissions per liter, so emissions per liter, e_x (the base for a presumptive Pigouvian gasoline tax), are declining as we climb the control cost curve[26]. Therefore, the gasoline tax also becomes an increasingly expensive instrument in pollution control; each liter carries less emissions as successive control measures are undertaken, so the sacrifice of a liter in consumption offers less in terms of emission reductions the cleaner is the average vehicle.

To provide an estimate of the additional emission reductions resulting from the gasoline tax, however, we need to apply an estimate of the elasticity of gasoline demand. Berndt and Botero (1985) estimated demand equations based on pooled regional (1973-78) as well as national times series data (1968-79) for gasoline sales in Mexico. Concluding, based on a number of models, they advise an "average" short run price elasticity of -.2, and a long run elasticity of -.7.

[25] 669 dollars per ton = (t_x dollars per liter/60 grams per liter) * 10^6 => t_x = \$ 0.04.

[26] Several approximations are employed in this calculation: First, technical measures are all assumed to reduce the average emission coefficients by the amount they reduce overall emissions. Secondly, the demand changes induced by the gasoline tax are assumed not to affect the costs or benefits of the technical measures.

In our calculations, since we are estimating the effects on the 1995 emission inventory, we have employed a price elasticity of -.4, assumed to hold in the medium term[27].

Using a demand elasticity estimate of -.4, we can calculate the additional emission reductions that will be provided by the gasoline tax at every level of the technical control cost curve. Since the gasoline tax will induce demand to contract, more emission reductions will be provided at every cost level, and the result is a more moderately sloped control cost curve. The two control cost curves are shown in figure 3, with the area between the curves representing the difference in total costs between a strategy based solely on technical controls and a strategy including demand management with the help of a gasoline tax.

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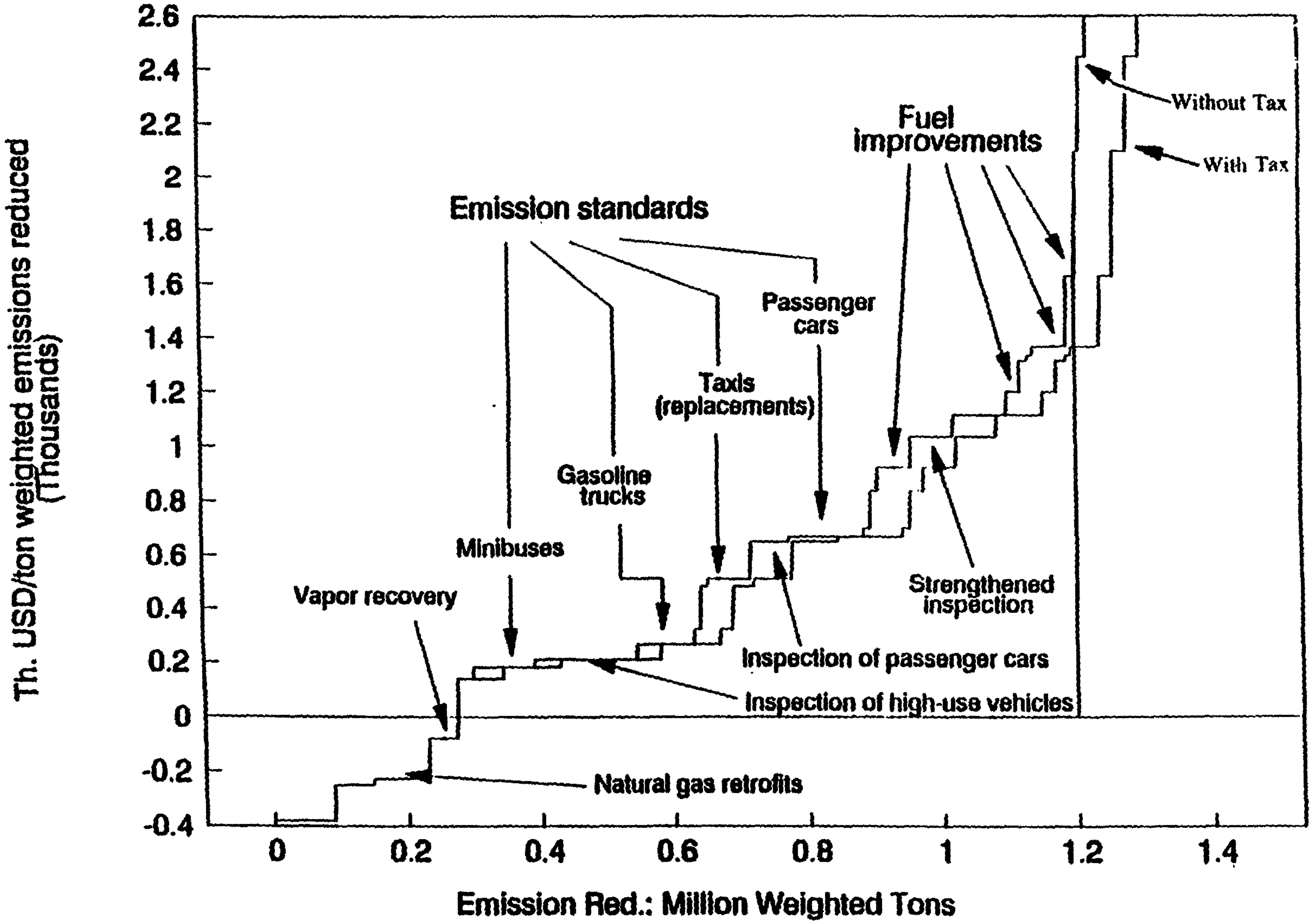
[27] Some other empirical studies indicate the same range. Pindyck, 1979, uses pooled data and finds: For OECD countries, the price elasticity exceeds -.4 when the time for adjustment is four years or more; for Brazil and Mexico, estimates are -.12 for the short run and -.55 for the long run. Sterner et al., 1992, report estimation of various models for 21 OECD countries (time series, and pooled), with an average of -.25 for short run elasticities and -.8 for long run elasticities.

Figure 3

Mexico City: Air Pollution, Transport

Control Costs, With and W/out Gas. Tax



Under these assumptions, a gasoline tax of 6.2 cents per liter (26%, ad valorem) reduces demand by about 10 percent for a program targeted to reduce weighted emissions by 1.2 million annual tons by 1995. Applying such a tax thus allows for 10% additional emission reductions at a willingness to pay of USD 1629/ton. We can notice that only a couple among all the abatement measures offer emission reductions of that magnitude. Alternatively, if settling for a target of 1.2 million tons, one can avoid employing measures escalating in costs from USD 1335/ton upwards to 1629. The cost savings would be an estimated 64 million dollars annually, or 11 percent of the estimated total control costs. An additional benefit would be that the gasoline tax, in Mexico City alone, would generate an estimated 350 million dollars in revenue.

The following can highlight the interdependency between the two sets of instruments. When control costs reach 1629 dollars per ton, average emission coefficients have been reduced by 70 percent, reducing the base for the presumptive emission tax on gasoline to 30 percent of its pre-control level. Thus, at a willingness to pay of 1629 dollars per ton, the optimal gasoline tax rate would have been 20 cents per liter, rather than 6.1, if it were the only available instrument. At this level, gasoline taxes alone would have reduced emissions by 34 percent, generating revenues of almost 800 million dollars[28].

A higher gasoline tax could be justified by a number of alternative assumptions, but not (as shown in Section 3) by a higher (or lower) demand elasticity. Firstly, since the technical control cost curve is steep for reductions exceeding 1.2 million tons, a further rise in the gasoline tax is one among very few effective instruments if further reductions are needed. Secondly, attaching a separate value to the transfer of funds from the private sector to the public sector, quite rational for a country that has suffered severely under inadequate public finances, would justify a higher tax rate (in the present analysis, no value to this transfer is assumed). Thirdly, reduction in usage also has benefits in terms of reduced congestion, noise and accidents, neither of which are accounted for in this analysis.

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[28] Given the assumed time perspective of 2-4 years, the assumption that all the technical measures have reached their full effect is probably optimistic, indicating that the base of the presumptive gasoline tax (and consequently its rate), is conservatively assessed.

5 Concluding . .marks

The task set was to study whether imperfect demand management instruments such as gasoline taxes can play a role in a cost effective pollution control program. We started by presenting an analytical framework which allows the comparison of demand management instruments with mandated abatement requirements. On theoretical grounds, the framework provided the following results: i) adding mandated abatement requirements to a program consisting of indirect taxes will improve the program; ii) adding indirect taxes to a program consisting of mandated abatement requirements will improve the program; iii) the set of programs in which abatement and demand management is combined in a cost-effective fashion is characterized without knowledge of the demand elasticity for gasoline; iv) the cost associated with not including gasoline taxes in the tool-kit for the control program is, however, larger the higher the demand elasticity.

To investigate the practical significance of these findings, the framework was applied to a recently analyzed program of technical interventions to reduce air pollution from urban transport in Mexico City. It was found that a tax of 6.2 cents per liter would be suitable for a program aimed at reducing emissions from the 1995 vehicle fleet by about 70 per cent. Using a demand elasticity of -.4, the gasoline tax would make the targeted emission reductions attainable at 11 per cent lower social costs, including the welfare costs of demand manipulation. The low level of the tax is partly explained by the fact that the technical interventions will have reduced average emission coefficients by 60 to 70 per cent, so that marginal emissions per liter, the base of a Pigouvian gasoline tax, are also diminished. The recommended tax would have been higher if: i) a value were associated with the transfer of funds to the public sector (the tax will collect 350 million dollars in Mexico City alone); ii) higher emission reductions were targeted, and/or; iii) reduced congestion, accidents and road damage were valued as well.

After recent increases in gasoline prices of 50 per cent, implicit tax rates in Mexico are higher than those suggested above. The higher tax rate may well be justified by the reasons mentioned, as well as by the fact that average emission coefficients are still much higher than those assumed above for 1995. For a city with a persistent problem of air pollution, it is possible that the tax decrease over time, if reductions in emissions coefficients are sufficient to so warrant, or that it increase over time, if the increase in demand is such that increasingly expensive measures must be undertaken.

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