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POLLUTION CONTROL: POLICIES PROPOSED BY ECONOMISTS

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ABSTRACT

This paper reviews in a general fashion measures suggested by economists for the control of pollution and considers ways in which these measures can be combined with the use of pollution standards. The efficiency of measures such as taxes to control pollution, bribes for reductions in pollution and the availability and sale of pollution rights are discussed. Market-type measures such as pollution rights and uniform rates of taxation are not as efficient as some economists claim and often need to be modified for practical application. In this respect the contribution of Tietenberg seems to be of particular importance. Ways in which non-convexities in production possibilities and consumption relationships limit or rule out orthodox economic approaches to pollution control are discussed and illustrated. Uncertainty and variability of ambient conditions are also seen as limiting the applicability of traditional economic policies for pollution controls. The point is illustrated that even when emissions cannot be varied (for economic or other reasons) with ambient conditions, variability of or uncertainty of ambient conditions influences the socially optimal level of emission as a rule.

INTRODUCTION

Although the discipline of economics or political economy developed several centuries earlier, the mainstream of economic thought ignored spillover effects or externalities from economic activity until the 1930's when Pigou published *The Economics of Welfare* [1]. Until then and conveniently for liberal philosophy, the need for government to regulate pollution by private individuals and companies was, with the exception of a few radical economists such as Engels, scarcely considered by economists [2]. Even then the subject of spillovers and pollution control did not achieve prominence in economics until after the mid-1960's.

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Economists are interested in the effects which pollution has on the level of satisfaction or welfare which citizens obtain from their resources, and with the effectiveness and value of various means for regulating pollution such as pollution taxes or subsidies and pollution rights and quotas. They themselves are not concerned with the discovery of engineering and natural scientific relationships involved in the control of pollution although these relationships are essential data in any pollution control problem.

Economic models which are used for discussing the social effects and control of pollution abstract considerably from variations which appear to occur in the world. Consequently, these models may only be able to capture the essence of a particular pollution problem if they are significantly modified. Nevertheless, economists use their abstract models to support various means of pollution control in principle.

Simple models are used in this paper to discuss pollution control by the taxation approach of Pigou [1], by the bargaining method of Coase [3], by the sale of pollution rights as suggested by Dales [4] and by the enforcement of environmental standards as discussed for instance by Baumol [5]. Particular attention is paid to the relative efficiency of taxation and legal sanctions as means for enforcing environmental standards.

TAXATION OF PRODUCTION: PIGOU'S APPROACH

Pigou observed that the marginal private cost to firms of producing products may diverge from the marginal costs to society of such production [1]. Producers of a particular product, for instance steel, may emit pollutants into the atmosphere which result in uncompensated damage to the health and property of others. Consequently, the marginal private costs of production (the costs borne by producers) of the commodity (steel) fail to reflect the marginal costs to society of its production and in a free enterprise competitive economy in which companies seek to maximize their profit, production of the commodity and associated pollution will be socially excessive. The marginal private costs of production by companies can be brought into line with social costs by imposing a suitable tax on the output of the product which is a source of pollution. In the absence of regulation of this type, firms treat the environment as a free resource for waste disposal and pollute excessively.

Pigou's argument is readily illustrated by means of Figure 1. Let X represent the quantity of production of an industry causing uncompensated pollution and let BT represent the combined marginal private production costs of all firms in the industry. Because of pollution spillovers, the marginal social costs of the combined production of firms, indicated by BS in Figure 1, exceed their marginal private costs of production. If AD represents the demand curve for product X (the price which purchasers are prepared to pay for the various

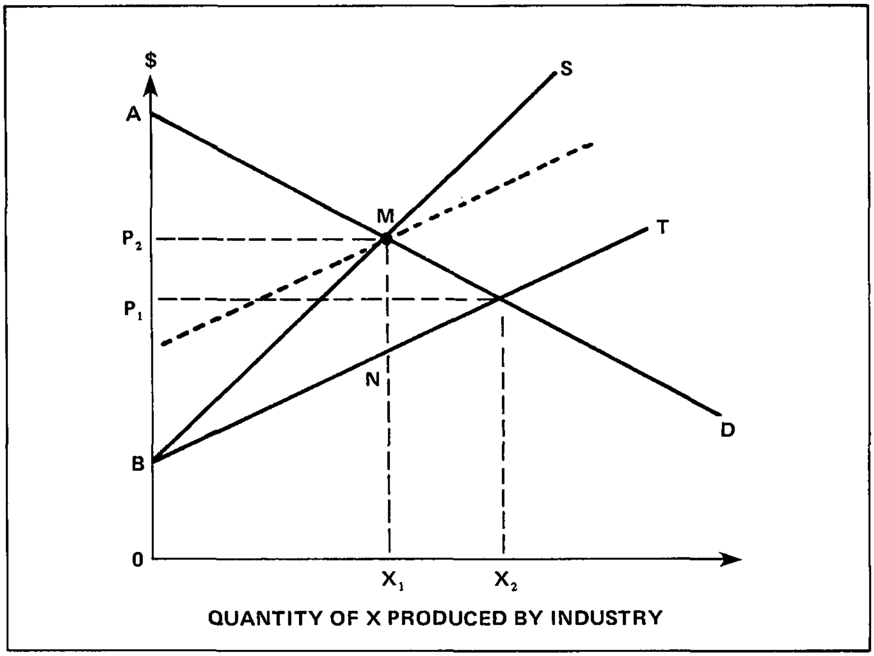

Figure 1. Pigovian pollution tax.

quantities of X stated on the X-axis) and if AD also indicates the marginal value to society of extra production of X, it is socially optimal to produce and consume X_1 of X. When X_1 of X is produced, the product's marginal value in consumption is just equal to its marginal social cost of production. But in the absence of charges for the use of the environment, firms will produce a larger and socially excessive quantity of output X_2, the level of output for which the demand price offered by purchasers just equals the marginal (private) costs of production incurred by firms.

Pigou suggests that this level of socially excessive production arising from pollution spillovers, might be remedied by imposing a suitable uniform tax on the production of the commodity. For instance, in the case illustrated, the imposition of a tax of $MN on each unit of X produced ensures that the socially optimal quantity of X is produced. After the imposition of the tax the firms' combined marginal costs of production are as indicated by the dotted line in Figure 1. Hence, the tax helps to "internalize" the pollution externality and the profit-maximizing behavior of firms leads them to produce X_1 of X.

However, Pigou's approach has some shortcomings. The main shortcoming is that it can be inefficient to attempt to control the level of pollution by regulating only the quantity of production. It can be more efficient to tax the offending emission directly. For instance, pollution in a particular instance may arise from the use of a particular input in the production process and this input may have a perfect but slightly more expensive substitute. For example, the use of coal with a high sulphur content may be the main source of the pollutant and it may be possible at little extra cost to switch to coal with a low sulphur content. The Pigovian approach will not encourage such a switch but will merely result in a much reduced level of production based on the use of coal with a high sulphur content. On the other hand, a suitable tax on the offending emissions will encourage substituion of inputs. The taxation or regulation of output rather than the taxation of offending emissions is relatively inefficient if the costs of policing, monitoring and enforcing the regulations are similar in both cases. Nevertheless the crude Pigovian approach continues to have supporters. For instance Victor argues [6, pp. 42, 43]:

> Although this form of pollution control is more crude than direct effluent charges it is appealing for several reasons. It could be implemented relatively quickly since only rough measures of effluents are required given that in this system of control, effluent discharge is not the tax base and therefore does not need to be measured precisely. This does not mean that precise measures of effluents are not better than imprecise measures. . .

Another limitation of Pigou's model is its assumption that competition in markets is pure or perfect. While it may be socially justifiable to restrict polluting production in a perfectly competitive environment, this need not be so under monopolistic conditions. A monopolist has an opportunity to create an artificial scarcity of his product, to restrict its supply, in order to raise his profit and may pursue this anti-social action. Even taking account of the fact that his production gives rise to spillovers of pollutants, restrictions on output by the monopolist may mean that the production level determined by him is below a socially optimal one. Any further restriction of his output would only worsen the social position, even though a tax on his emission of pollutants might improve it.

CONTROLS ON EMISSIONS OF POLLUTANTS THEMSELVES

The simplest model used by economists for discussing the control of emission of pollutants is the one illustrated by Figure 2 [7]. The model takes account of the costs of abating the emission of pollutants as well as the external benefits from reducing such emissions. It is recognized that while the costs of pollution abatement and the benefits of such abatement may be difficult to specify in practice, in principle these factors need to be taken into account in determining the optimal level of pollution abatement. Given an existing level of emission of pollutants, it is socially optimal to reduce this level of emission until the marginal external benefits from doing so are equal to the marginal cost of achieving this reduction.

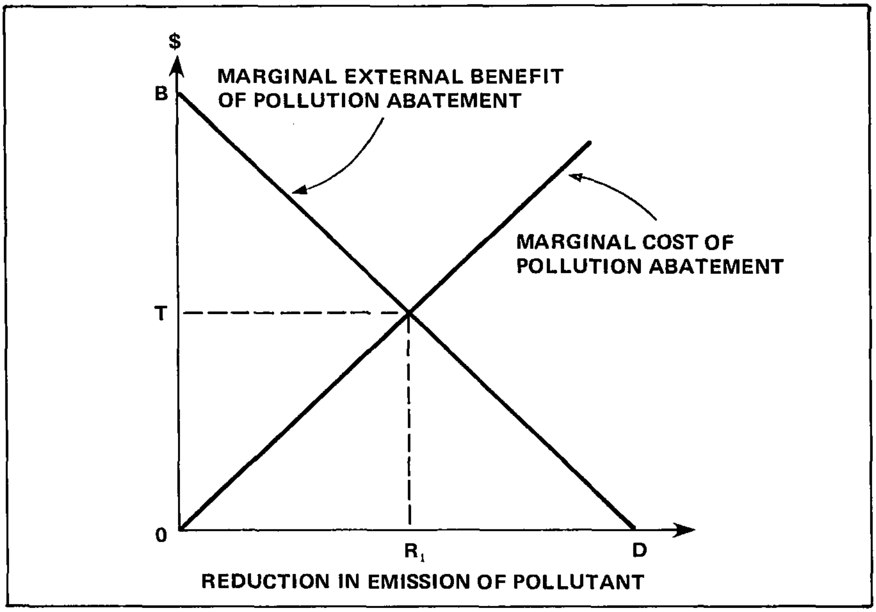

Figure 2. Reduction in emission of pollutant.

The socially optimal amount of emission of pollutants could be achieved by imposing a tax of $T on each unit of the pollutant emitted. As long as the marginal cost of abating pollution is less than the marginal tax on the emission of pollutants it pays polluters to reduce their emissions. When the pollution tax per unit of emissions is set at T it pays polluters to reduce their level of pollution by OR_1.

Coase argues that the same reduction in pollution can be achieved if parties damaged by pollution pay (bribe) polluters to reduce their level of pollution [3]. Curve BD in Figure 2 represents the marginal amounts which damaged parties would be prepared to pay polluters to reduce their emission of a pollutant and OC represents the marginal amounts which polluters would require to compensate them for their cost of abating pollution. In the absence of significant barriers to negotiations, damaged parties could conceivably pay acceptable bribes to polluters which lead to a reduction in emissions by OR_1. The bribe which damaged parties would be willing to pay for any further reduction beyond OR_1 would not be sufficient to cover the cost of pollution abatement.

The difficulty with Coase's approach is that negotiations are not costless. When large numbers of people are damaged it may be costly for damaged parties to organize collective action and action to stem the damage may be on a smaller scale than warranted because of the presence of free-rider problems [8]. Some damaged parties may not participate in collective action to limit pollution because they expect that others will act and they will obtain benefits at no cost to themselves. Another problem is that this approach can encourage blackmail. Companies may deliberately increase their level of pollution emission in order to obtain extra compensation or larger bribes. As a result they would be rewarded for adding to social cost.

Dales argues strongly in favor of the sale of pollution rights as a means for controlling the level of emission of pollutants [4]. In certain circumstances, this method results in a socially optimal level of emission of pollutants. If, as in Figure 3, E represents the existing level of emission of pollutants and R_1 indicates the optimal level of reduction in emissions, $E - R_1$ is the optimal level of emissions. Certificates for the right to pollute, to emit $E - R_1$ of pollutants, could be auctioned or sold by the government. The market equilibrium price of these certificates ensures efficiency in the emission of pollutants. Firms which find it more costly to abate pollution will purchase certificates and those that find it least costly will abate pollution rather than buy pollution certificates or rights. Thus any level of pollution reduction is achieved at least cost to the community and in addition, firms have an incentive to invent and adopt pollution reducing technology.

Even when the level of emission of pollutants is set in accordance with "community" or other standards, and is not necessarily optimal in the sense discussed above, Dales' method can be used to obtain efficiency in reducing pollution to meet these standards.

Rights to emit pollutants equal to the quantity consistent with the environmental standard could be auctioned or sold at a price which just equates the demand for these rights with their supply. This should ensure that the environmental standard is achieved at minimum cost.

Dales' method of controlling pollution can be illustrated by means of Figure 3. Suppose that community standards require the emission of a pollutant to be limited to $E - R_1$. Rights to emit the pollutant can be sold or auctioned and the supply of rights can be limited to ensure rights to a total emission of $E - R_1$. The availability of pollution rights can be limited to the supply indicated by the vertical line at $E - R_1$ in Figure 3. In Figure 3, polluters' demand for pollution rights is represented by curve DE and corresponds to polluters' cost of reducing emissions from level E. Given the demand curve DE and the supply curve S, the market equilibrium for pollution rights is established when the price per unit of pollutant emitted is P_1. Under the same cost-benefit conditions, the price of emission rights P_1 equals the optimal pollution tax rate T discussed in connection with Figure 2.

The models in Figure 3 suggest that the efficiency of Dales' method of pollution control and the optimal taxation approach are clearcut. But these models rely on abstractions which are sometimes not warranted. Circumstances, discussed in the next Section can arise which make these control measures inefficient.

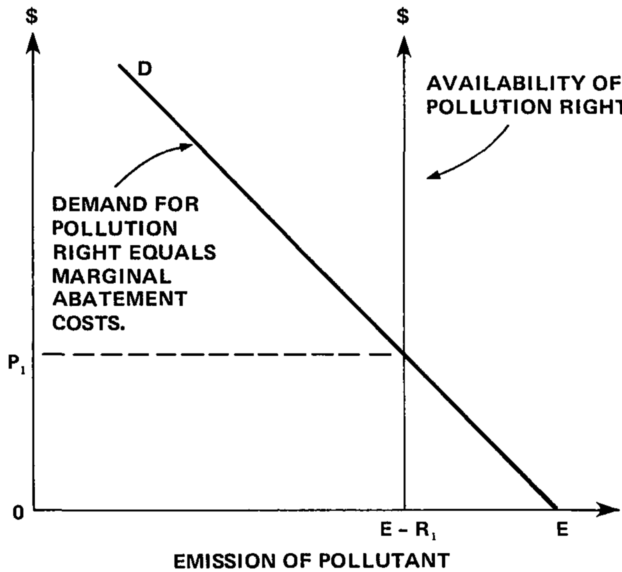

Figure 3. Dales' sale of pollution rights.

STANDARDS AND CONTROL OF POLLUTION BY FIAT VERSUS CONTROL BY TAXATION

Baumol and Oates argue that a suitable tax on pollution emissions is a more efficient means to reach an environmental standard than the imposition of quantitative pollution restrictions or pollution quotas on polluters, for instance, the use of laws which specify the maximum permissible amount of pollutant which can be emitted by a polluter [5, 9]. The fiat approach, if it is to be efficient requires the regulating authorities to have a great deal of information about the pollution control costs experienced by individual polluters whereas the taxation approach does not and the optimal tax rate, the one which ensures that the standard is just met, can be found by trial-and-error. Their basic argument can be seen from the example illustrated in Figure 4. Assume that there are two polluters, firm 1 and firm 2, and measure the emission of the pollutant by firm 1, to the right of 0 and that by firm 2 to the left of 0. Let $\hat{e}_1$ and $\hat{e}_2$ represent the existing levels of emission by the two firms and $m\hat{e}_1$ the marginal cost to firm 1 of reducing its emission from $\hat{e}_1$ and $n\hat{e}_2$ the marginal cost to firm 2 of reducing its emission from $\hat{e}_2$. Firm 1 experiences greater costs in abating pollution than firm 2. Imagine that the attainment of an environmental standard requires that the total level of emissions be reduced from $E = \hat{e}_1 + \hat{e}_2$ to $\overline{E} = \overline{e}_1 + \overline{e}_2$.

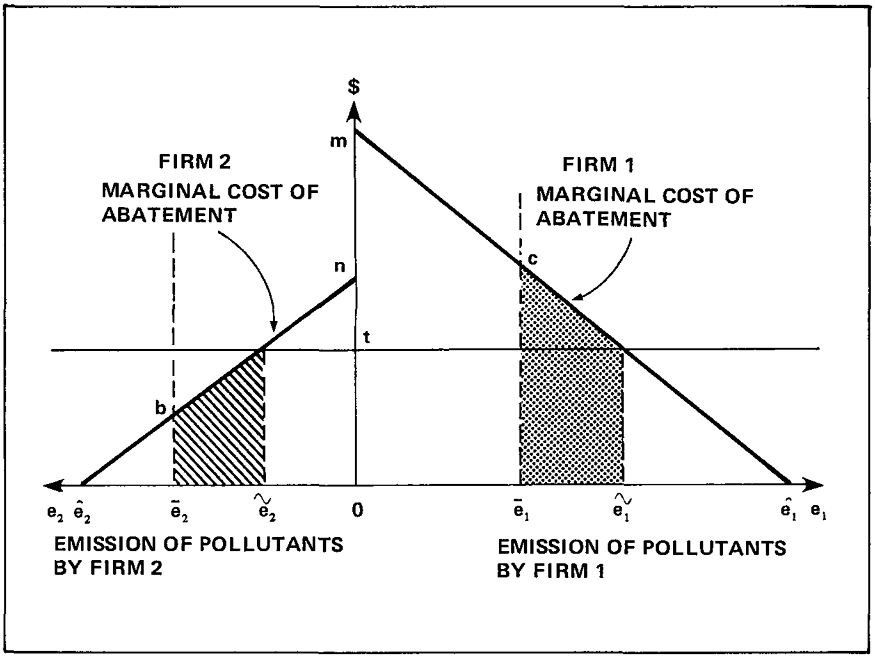

Figure 4.

One fiat or legal solution is to divide the permissible global level of emissions equally between polluters. In the case illustrated this results in each polluter being allowed a maximum level of emission of $\bar{e}_1 = \bar{e}_2$. The total cost of this method of achieving reduction in emissions to $\bar{E}$ is equivalent to the area of triangle $\bar{e}_1 \hat{e}_2 c$ plus the area of triangle $\hat{e}_2 \bar{e}_2 b$. Hence the global reduction in emissions is not achieved at minimum cost. The differential calculus indicates that the cost of abating emissions for any level of abatement is not a minimum unless the marginal cost of abatement (rate of change of abatement cost) is equal for all polluters. In the case illustrated and assuming that global emissions are restricted to $\bar{E}$, this condition is satisfied when emissions by firm 1 and firm 2 are $\tilde{e}_1$ and $\tilde{e}_2$ respectively. Costs to the community of abatement in the optimal case are less than those in above fiat case by the equivalent of the difference between the area of the dotted quadrilateral in Figure 4 and the cross hatched quadrilateral.

The optimal allocation of emissions to achieve the standard can be achieved by imposing a uniform tax of t on each unit of pollutant emitted. The common rate of tax ensures, if firms are profit maximizers, that the marginal costs of abatement are equalized for all polluters. This method ensures that the necessary condition for minimizing the overall costs of abatement is satisfied. The uniform tax rate can be varied until the proposed environmental standard is observed to be satisfied. The uniform tax solution ensures that the cost minimization is satisfied whereas the fiat solution does not.

But the demonstration by Baumol and Oates [5, 9] of the superiority of uniform pollution tax compared to fiat regulation and the similar one by Dales [4] of a uniform market price for the sale of pollution rights assumes that collectively damages from emission depend *only* on the *total global* level of emissions. The place at which the emission occurs makes no difference to the damage which it causes. In many instances this is an inappropriate assumption and when it is violated the optimal abatement of pollution cannot be achieved by the imposition of a *uniform* emission tax [10]. The optimal taxation level or price for emission rights may need to vary from place to place. This is easily demonstrated when the parties damaged by and the spread of pollution from two sources of pollution are disjoint.

Consider the case shown in Figure 5 as an illustration. This figure has the same interpretation as Figure 4 except that it is now assumed that firm 1 produces in area 1 and its emissions have no effect outside this area and that likewise frim 2's emissions have no effect outside area 2. The marginal external benefits from reducing firm 1's emissions from $\hat{e}_1$ (or the marginal damages from e_1) are shown by the broken line CD. Similarly, the marginal external benefits from firm 2's reducing its emissions below $\hat{e}_2$ is shown by AB. Hence the socially optimal level of emissions for firm 1 is e_1^* and for firm 2 is e_2^*. These levels of emission could be achieved by imposing a per-unit pollution

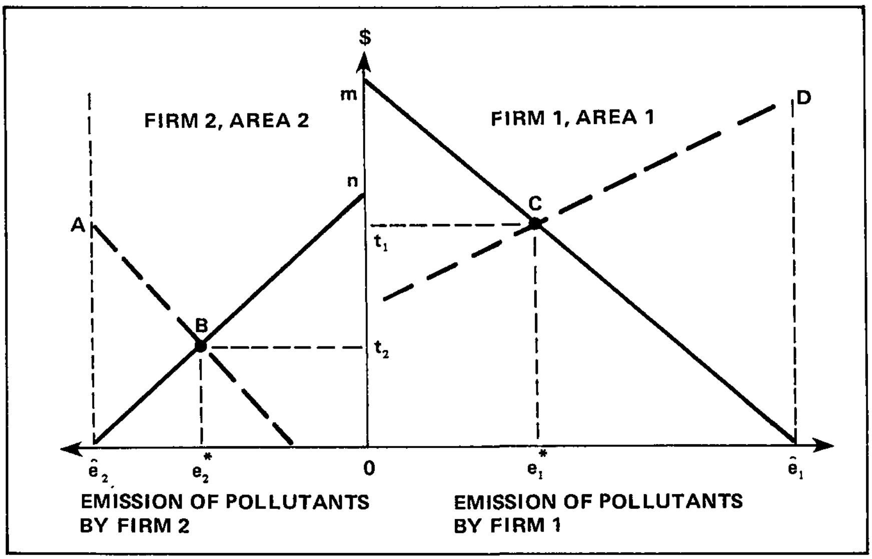

Figure 5. Differential pollution taxes.

tax of t_1 on firm 1's emissions and a pollution tax of t_2 on firm 2's. Note that the rate of these taxes differ. Because of disjointness the imposition of a uniform tax to achieve a global rate of emission of $e_1^* + e_2^*$ would not be socially optimal. Such a measure would result in socially excessive emission in area 1 and socially excessive abatement in area 2.

While the case of disjointness may not be common, it is not uncommon for the damages stemming from each unit of emission of a pollutant to vary from place to place. Whenever such variation occurs a uniform emission tax is likely to be a socially inefficient means for regulating pollution. While zoning of the taxation structure can be used to overcome the Tientenberg objection, tax rates have to be tailored for each zone. If the required number of zones is large, a large number of tax rates have to be tailored and the simplicity and low cost of the taxation approach may be lost.

NON-CONVEXITIES

Convexity of relevant production functions has been assumed so far. It should be observed that non-convexity of production possibility sets or preference relations can rule out the possibility of using a simple tax-subsidy method to achieve a socially optimal configuration of production or consumption when externalities occur. Non-convexities can occur for example when increasing returns are important.

This can be illustrated by the simple case in which *perfectly competitive* firms produce one product using one variable input. If the production possibility set of the firms is like that shown in Figure 6 (strictly convex in the boundary formed by production function) any desired level of output or any desired level of use of the variable resource (along the production function) can be achieved by taxes or subsidies on output or on the use of the input. The iso-profit line tangential to the production possibility set can be altered by taxation and subsidies so as to be tangential to it at any desired point. Thus suppose that market prices are such that BC is the iso-profit line tangential to the production function. This results in an output of x^* and employment of Z^*. Assume that (taking account of pollution) an output of $\bar{x}$ is socially optimal. Then a tax can be imposed on the production of x which swings the tangential iso-profit line around to DF and results in the production of $\bar{x}$ by profit-maximizing firms. A possible supporting hyperplane corresponds to each point on the production function [11, p. 163]. But if the production possibility set of the firm is re-entrant as shown in Figure 7 and therefore non-convex, the production function boundary of the set cannot have a supporting hyperplane corresponding to each point [11, p. 163]. It is impossible for the production possibility set to have a supporting hyperplane in its re-entrant portion.

Thus suppose that taking account of pollution externalities, an output of $\bar{x}$ is socially optimal and that the firm's production function is as in Figure 7.

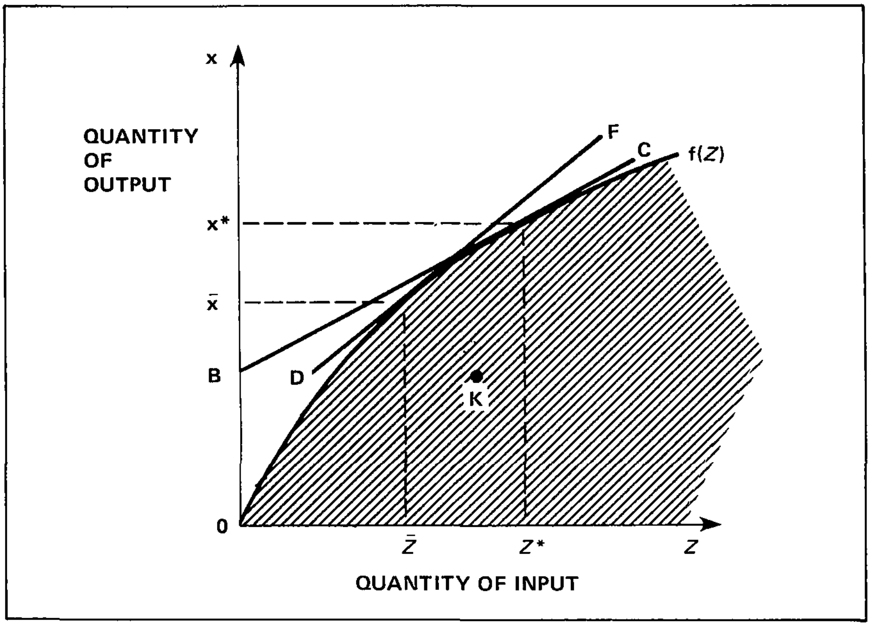

Figure 6. Convex case—strictly convex in production function boundary.

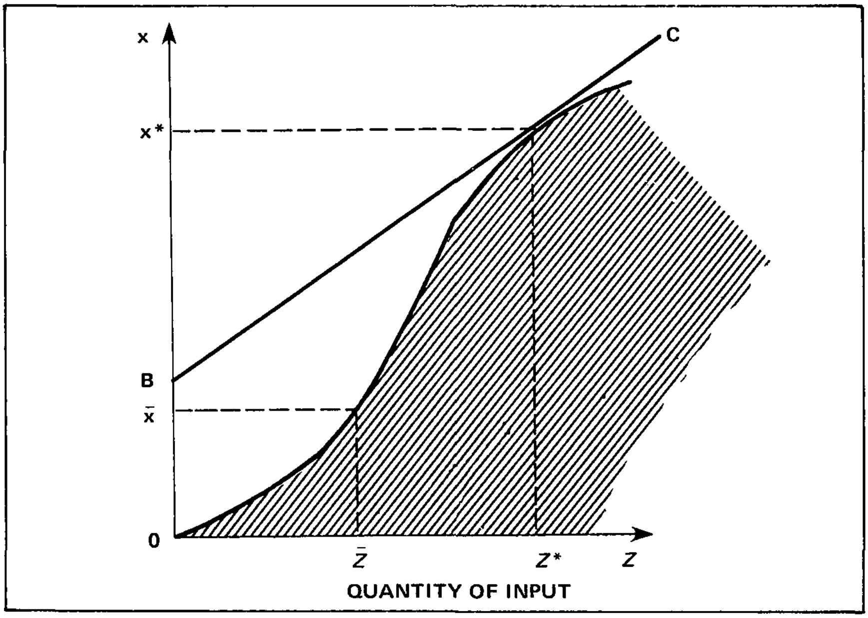

Figure 7. Non-convex case.

Constant per unit taxes on the output of x are incapable of enticing a firm to produce $\overline{x}$. Thus if market prices are such that the iso-profit line tangential to the production function is BC, it is impossible by imposing a constant per unit tax on the production[1] of x to reduce production to $\overline{x}$. In a circumstance such as this it may be necessary to impose a *quota* on the production of x or $\overline{x}$ or to vary the rate of tax with output (so that the iso-profit lines become curve-linear) in order to achieve the socially desired level of output. But the variable tax rate approach means that the simplicity and the main advantages claimed for the tax-subsidy solution are lost.

It should also be observed that a constant tax-subsidy rate approach is ineffective in achieving a social optimum when the social optimum occurs for a production combination in the interior of the production possibility set. A firm cannot maximize profit by producing at an interior production combination if prices after tax or subsidy are constant. However, a quota may be used to achieve a desired interior configuration of production.

Again if the production possibility set is convex *but not strictly so* in its production function boundary, constant tax or subsidy rates may be incapable of steering production to a social optimum different from the private productive optimum for firms. The production function contains linear segments in this case and changes in relative prices cannot be used to direct production with certainty to a point within a linear segment of the production function. For instance the production function shown in Figure 8 contains a linear segment between D and F. Suppose that the firm's profit-maximizing level of production is F but that E corresponds to its socially optimal level. Constant rates of taxes cannot be used to swing production to E with certainty. They can only be used to make the after-tax iso-profit lines parallel to DF but in this case any level of production in the range $D \leqslant x \leqslant F$ may minimize profit. Perfect control is impossible by constant tax rates in this case.

Non-convexities may rule out the use of constant tax-subsidy rates to achieve a social optimum after pollution is taken into account in a range of production and consumption situations. The circumstances mentioned above generalize to n-commodities. Figures 9 and 10 indicate two additional examples in which taxes and subsidies at a constant rate are not effective in achieving a desired social optimum. Figure 9 indicates the production possibility relationship between two products. Due to a non-convexity in the production possibility set, it is impossible to steer the economy to a point such as A by taxes or subsidies at a constant rate. In Figure 10, combinations of products equally sought after or preferred to any combination form a non-convex set. The indifference curve $I_1 I_1$ bounds one such set. Given this relationship,

[1] That is a rate of taxation independent of the level of production. In contrast, a variable tax rate alters with the level of production.

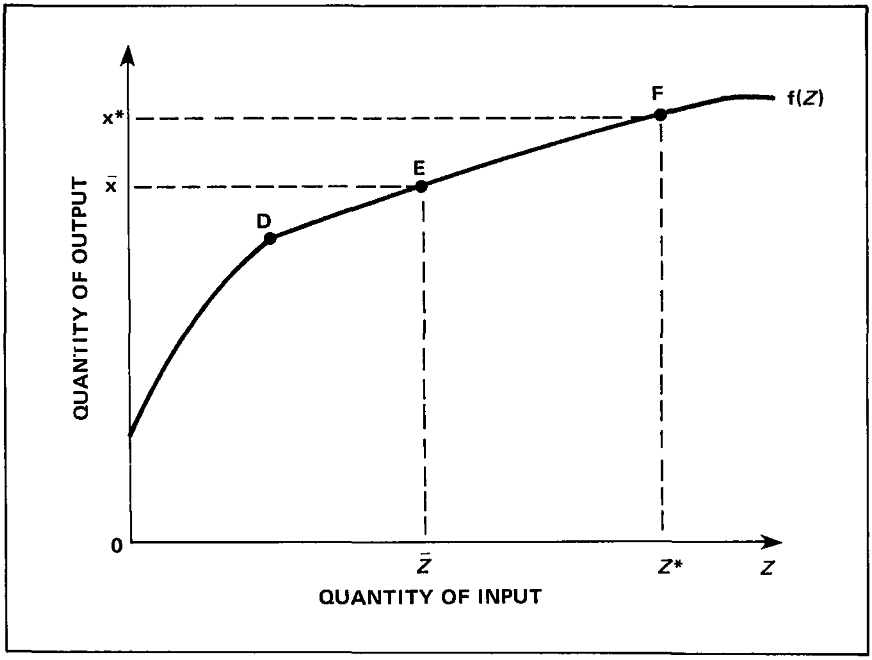

Figure 8. Convex but not strictly convex case

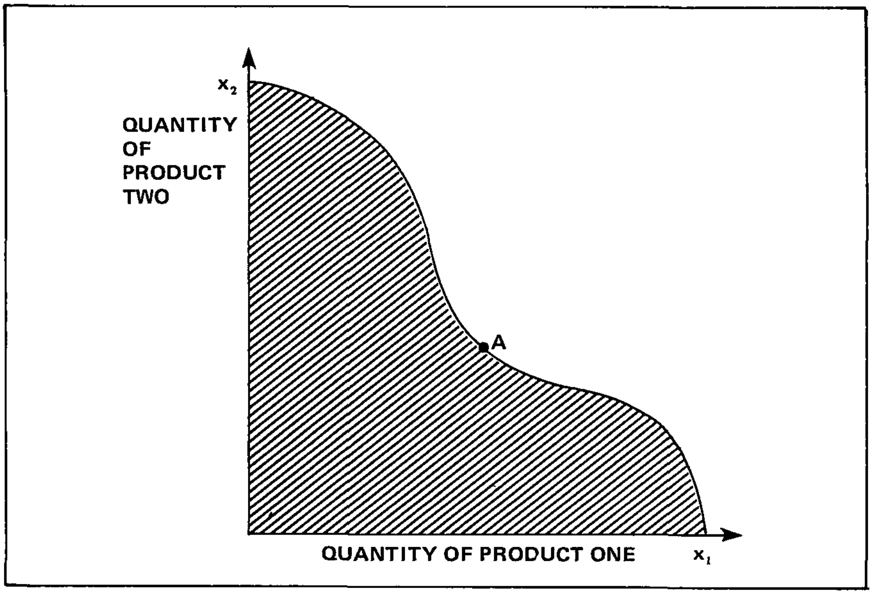

Figure 9. Non-convex production possibility set.

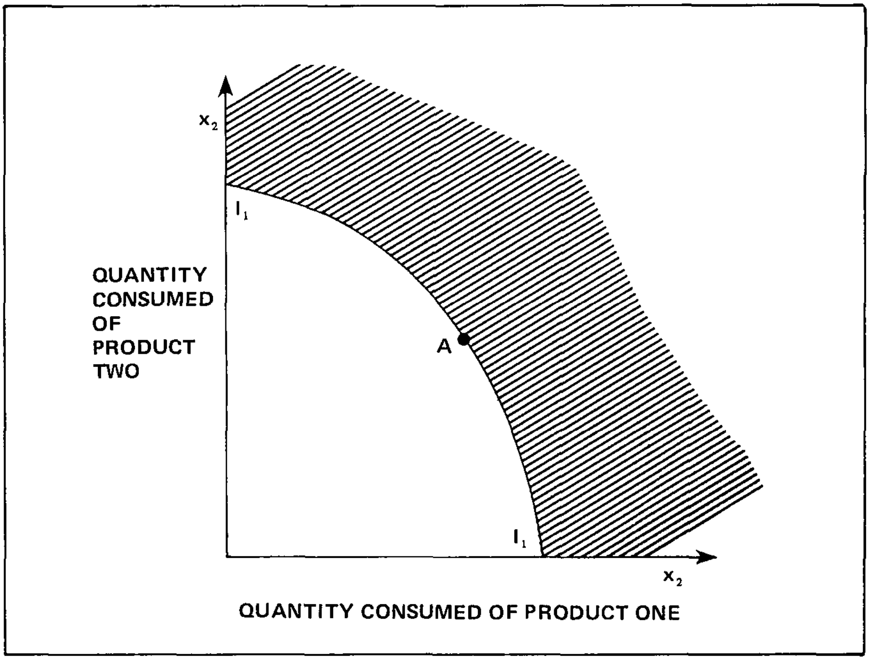

Figure 10. Non-convex preference relation.

consumption consists either of all of one product or the other, and not of some of each. Because of the non-convexity shown it is impossible by changing relative prices by (uniform) taxes or subsidies to steer consumption to a position such as A in which some of both products is being consumed. A movement to a position such as A may be desired to reduce unfavorable externalities.

MISCELLANEOUS ASPECTS OF POLLUTION CONTROL

The above discussion has concentrated on the abatement costs proper of reductions in the level of pollution and has paid little attention to the agency costs of regulating pollution, that is the costs incurred by a government agency itself in administering pollution control measures. These costs include the cost of collecting information and enforcing regulation. In assessing the social desirability of any social control measure on pollution, account must be taken of abatement costs as well as agency costs. Control measures which are socially desirable when abatement costs alone are considered need not be so when agency costs are taken into account.

Taking account of agency costs Victor says [6, p. 42]:

> Perhaps the main point in favour of effluent standards and against effluent charges is that standards are easier and therefore cheaper to

> administer. It is a simpler task to check that the outflow of a particular effluent does not exceed a specified limit than to measure continually the amount of effluent discharge. For effluent charges to be effective as a method of pollution control, a broadly developed and highly sophisticated system of effluent monitoring would be required and this would take many years to develop, at considerable cost.

Although Victor's statement is a rather sweeping one, the possibility which he mentions cannot be ignored.

Difficulties too arise if the ambient environmental conditions for the release of pollutants vary, possibly in uncertain ways. Emission charges or standards may need to be altered as ambient conditions vary but it may not pay to "fine-tune" these measures. The question then needs to be considered of determining the optimal rigidity or inflexibility of pollution controls in view of uncertainty, the costs of change and the costs of obtaining accurate information about prevailing conditions and behavior.

However, even when controls are not adjusted to such changing ambient conditions, the variability of ambient conditions can have implications for optimal policy. If variability of ambient conditions is ignored in setting emission controls, the optimal level of emission sought may differ from the truly optimal value. Certainty bias may arise [12]. For example suppose that the external damages resulting from the emission of a pollutant are simply specified by

$$D = qm^2 \tag{1}$$

where D represents the damages in dollars, q is the quantity emitted of the pollutant and m measures the ambient conditions (e.g., reduced flow of water, air, temperature, and so on). For any given q, damages rise at an increasing rate with increases in the ambient condition.

If the ambient condition varies, then for any given q, emission, damages on average are

$$E[D] = q(E[m]^2 + \text{var } m) \tag{2}$$

and changes in the average damages per period with respect to q are

$$\frac{dE[D]}{dq} = E[m]^2 + \text{var } m. \tag{3}$$

Assume that the total cost of keeping emissions at level q (rather than $\hat{q}$ in the absence of control) are

$$C = C(q) \text{ where } C'' < 0. \tag{4}$$

Then *net* social damages on average per period or damages for an interval of time are minimized when

$$C'(q) = E[m]^2 + \text{var } m. \tag{5}$$

In the case shown in Figure 11 this social optimum occurs when $q = \overline{q}$.

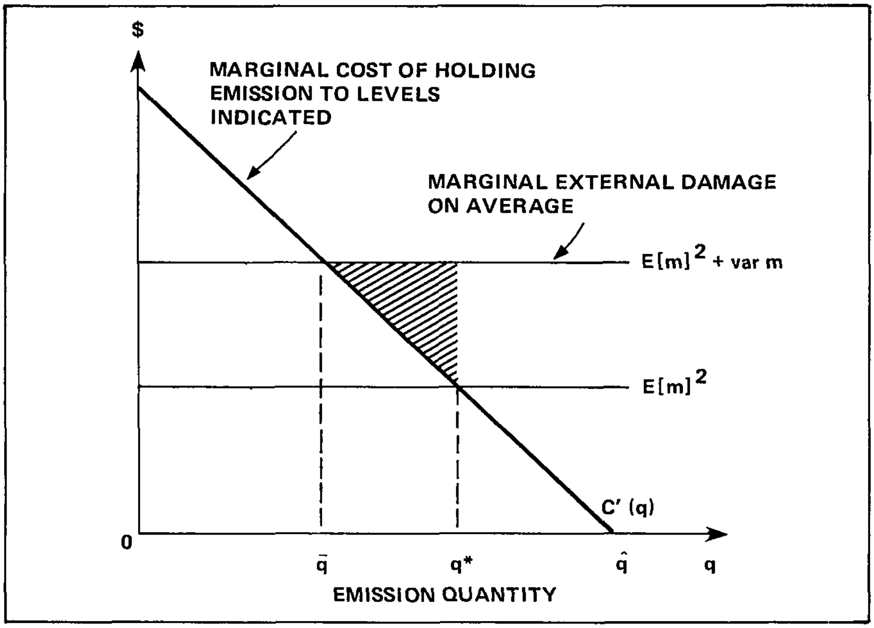

Figure 11. Even when emissions cannot be varied with ambient conditions, variability of or uncertainty of ambient conditions influences the socially optimal level of emission as a rule.

If in contrast the value of q, emission, is selected so as to be optimal when average ambient conditions prevail, a socially excessive amount of pollution is permitted. In this case

$$D - C = qE[m]^2 - C(q) \qquad (6)$$

is maximized and the maximum occurs when

$$C'(q) = E[m]^2 \qquad (7)$$

In the example shown in Figure 11, this approach results in q* of emission of the pollutant being allowed per period, a socially excessive amount even *taking account of the fact that it is not feasible to alter the amount of emission according to prevailing ambient conditions*. The loss in attainable "social welfare" on average is equivalent to that indicated by the hatched triangle.

While in the above case altering emissions to average conditions results in excessive emissions being allowed, in other cases the functional relationships may be such that this approach leads to excessive limitation on emissions. This would occur for instance if in the above example

$$D = f(q) - qm^2. \qquad (8)$$

The examples illustrate the point that even when emissions of pollutants cannot be varied with ambient conditions, variability or uncertainty of ambient conditions influence the socially optimal level of emissions as a rule. (For a consideration of general mathematical factors affecting certainty bias, see [12].)

However, pollution charges or adjustments at the margin of pollution activity, like those discussed above, may fail to control pollution in a globally optimal way. For instance, the infra-marginal damages caused by pollution from the use of an existing technique may be much greater than for an alternative technique and the socially optimal action may be for producers to switch to the latter technique. A pollution tax or charge designed to promote optimality at the margin may not induce this switch [13] but merely ensure that pollution with the existing technique is abated in an optimal manner. Problems of this nature and non-convexities in pollution control relationship [13-15] may make "easy" economic methods for optimally rectifying pollution emissions impossible to apply.

CONCLUSIONS

As a result of the recent upsurge in interest by economists in the socially optimal control of pollution, we have become aware that there is no simple method of pollution control which is socially optimal under all circumstances. Economists have had to modify some of their earlier inflated claims for the efficiency of particular social means of control. We are now all more aware of the pitfalls inherent in the alternative approaches to pollution control even though there are still many pitfalls to discover.

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