STAATLICHE ALLOKATIONSPOLITIK IM MARKTWIRTSCHAFTLICHEN SYSTEM

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Preface

In the Musgravean tradition the concept of public goods has become a central element of the theory of public allocation policy. The basic argument for this prominent role of public goods is that jointness in consumption - and possibly also nonexcludability of consumers who are unwilling to pay - renders market provision inefficient ('*market failure*'). Hence public intervention was called for to enhance allocative efficiency. In recent years, however, quite a different research program, namely the economic theory of policy (or public choice), provided explanations for the working of *public* allocation procedures for public goods. The thrust of this theory is that it is not at all clear whether the public provision of public goods, per se, is apt to improve upon the market allocation. Public choice economists rather identified various inefficiencies in public allocation procedures which are sometimes paraphrased as '*policy failure*'.

Most contributions to the modern theory of public goods are somewhere located in the wide ranges of 'market failures' and/or 'policy failures'.[1] This wide spectrum is also characteristic for the eight contributions of the present volume: The first two papers, i.e. that of M.E. Burns and C. Walsh and that of B.-A. Wickström, study 'market' allocation procedures in the absence of public intervention - for either costlessly excludable or nonexcludable public goods. The next two investigations of R. Pethig and O. von dem Hagen focus attention not only on 'exit' but also on 'voice' (Hirschman), that is, on voluntary or market activities broadly conceived as well as on participation in political allocation procedures. Political allocation procedures (voice) are studied in the subsequent contributions by H. Hanusch and P. Biene and by F. Dudenhöffer who focus attention on elections. A. Endres assesses the impact and efficiency of alternative policy tools for environmental protection. Giving policy advice presupposes a normative, comparative analysis of policy instruments and allocation procedures. Scope and limits of such an analysis are discussed by W. Blümel in the last paper of this volume.

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1) Blümel, W., Pethig, R., and von dem Hagen, O. (1985), The Theory of Public Goods: A Survey of Recent Issues, Discussion Paper 80-84, Economics Department, University of Oldenburg.

Environmental Policy with Pollutant Interactions

by
Alfred Endres

1. Introduction

Alternative means of environmental policy are usually analyzed in economics within the framework of a set of pollution standards serving as targets for environmental quality:
"On the basis of evidence concerning the effects of unclean air on health or of polluted water on fish life, one may, for example, decide that the sulfur-dioxide content of the atmosphere in the city should not exceed x percent, that the oxygen demand of the foreign matter contained in a waterway should not exceed y, or that the decibel (noise) level in residential neighborhoods should not exceed z, at least 99 percent of the time. These acceptability standards, x, y, and z, then amount to a set of constraints that society places on its activities. They represent the decision maker's subjective evaluation of the minimum standards that must be met in order to achieve what may be described as "a reasonable quality of life."[1)]

Environmental policy instruments as charges, direct controls and tradeable pollution permits are discussed as the means to attain these standards.
The standards are "admittedly somewhat arbitrary"[2)], reflecting the difficulty to calculate a socially optimal level of pollution, environmental policy could aim at.

The problem to be dealt with in this paper is generated by the fact that acceptability standards for several pollutants should not be defined independently from each other. Generally, the environment does not provide special sub-capacities for the assimilation of each pollutant. Several pollutants rather draw upon the same capacity of the environment simultaneously. Moreover, they often react chemically. In these cases their mixtures generate an environmental impact

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1) W.J. Baumol, W.E. Oates (1975), p. 137.

2) W.J. Baumol, W.E. Oates (1975), p. 134.

different from the sum of the impacts that each individual pollutant would have in the absence of the others. Synergisms among pollutants are an example for this type of an interaction.

Below, any pair of pollutants X_i, X_j is called "interactive" if the acceptable level of X_i depends upon how much of X_j is discharged[3].

Even though the main body of the environmental economics literature (often implicitely) assumes that different pollutants can be regulated independently from each other, some authors allow for environmental quality to be determined by interactive pollutants[4]. However, there has not been much effort to answer the question of how the properties of alternative means for environmental policy are affected by the existence of pollutant interaction[5].
In this paper effluent charges and marketable pollution permits are compared regarding their efficiency and accuracy in the presence of interactive pollutants. Direct controls are mentioned in passing.
For all policies it is assumed that the environmental policy makers know the nature of pollutant interaction but can only estimate the polluters' marginal abatement cost functions. There is some focus in the analysis below, to the question of how the policy makers' knowledge of the marginal abatement costs changes in the process of applying alternative environmental policy instruments.

It is assumed below, that a single indicator "I" exists which relates the quantities of n pollutants ($X_1,\ldots,X_n$) to "load units" of this medium. (The higher the index value the lower the quality of the environmental medium). This indicator is assumed to take care of the problems of simultaneous environmental capacity use and chemical reactions.

3) This is a wide definition of the term "interaction", adopted from the literature of fn. 5). A narrower definition might use this term only if the marginal environmental impact of one pollutant depends upon the emission level of another one.

4) See e.g. K.G. Mäler (1974), R. Pethig (1979).

5) Notable exceptions are B. Beavis, M. Walker (1979), H. Bonus (1970).

Here, the target of environmental policy can be defined in terms of a predetermined level $\bar{I}$ of this index. It should be noted that this type of a target definition is compatible with indefinitely many combinations of n pollutant quantities.

Of course, it cannot be said in general terms what properties the environmental constraint, defined for the economic process by setting the target $\bar{I}$, might have. If the indicator would take the linear additive form of $I = a_1X_1 + \ldots + a_nX_n$ where the a_i are constant "load-parameters", the pollutants could be substituted against each other at a constant rate for each given level $\bar{I}$. This very simple type is called "linear interaction", below.

Of course, the marginal rate of substitution among pollutants $-(dX_j / dX_i)_{dI=0}$ may decrease (convex interaction) or increase (concave interaction) or take non-monotone forms (non-convex/non-concave interaction)[6]. It is even possible that pollutants are complements rather than substitutes. Here, the detrimental effects of different pollutants compensate each other. This case, however, will not be discussed below.
Following Sprague (1970) these types of interactions are illustrated in figure 1 for the case of two pollutants denoted X and Y.
Henceforth, the existence of a regulatory agency is supposed, aiming at a decrease of the environmental load in its control region from the unregulated level I* to a predetermined target level $\bar{I}$. There are n pollutants supposed to be generated by n regional industries, one pollutant by each. The unregulated equilibrium pollution levels are denoted $X^*_1,\ldots,X^*_n$. The emissions reduced from their unregulated levels $X^*_1,\ldots,X^*_n$ to any level $\hat{X}_1,\ldots,\hat{X}_n$ are denoted $\hat{x}_1,\ldots,\hat{x}_n$. Since $\bar{I}$ can be met with many combinations of pollutant quantities it is to be decided which combination the agency is to aim at.

6) Taking the toxicity to fish as an indicator of the environmental load caused by a combination of pollutant concentrations, J.B. Sprague (1970) found high evidence for linear pollutant interaction.
From the four air quality indices surveyed by A.E.S. Green et al. (1980), three take the linear interactive form. In the Soviet Union, interactive ambient air quality standards are used. They all take the form of linear interaction. See F.J. Dreyhaupt (1971), p. 66.
Of course, the use of linear indicators in biology and other sciences is no proof of the underlying environmental structure being a linear one. Indicators are only proxies, after all Their quality cannot be assessed by the author, a simple economist only.

It is supposed that the agency is trying to find the pollutant allocation $(X^{*}_{1}{}^{*},...,X^{*}_{n}{}^{*})$ which meets the environmental constraint $\bar{I}$ at minimum cost.

Simultaneously with the problem of finding $(X^{*}_{1}{}^{*},...,X^{*}_{n}{}^{*})$ the agency of course has to solve the problem of assigning each industry pollutant quantity $X^{*}_{i}{}^{*}$ to the individual generators of pollutant i. Since the latter problem is extensively treated in the literature using independent targets for the pollutants[7], it is ignored henceforth.

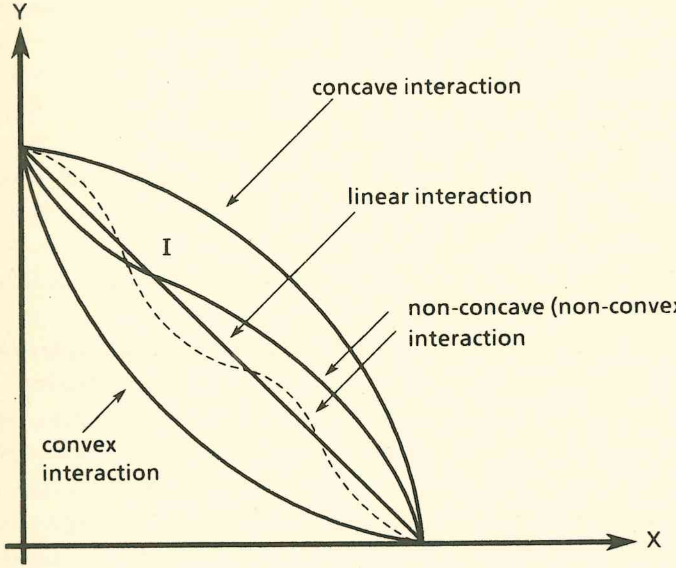

Figure 1: Types of interaction among pollutants

7) See e.g. W.J. Baumol, W.E. Oates (1975), P. Burrows (1979), A. Endres (1985), H. Siebert (1981).

2. Properties of the Optimum

Before analyzing the ability of alternative policies to meet $\bar{I}$ at minimum cost the nature of the optimum allocation is to be elaborated. The problem of the environmental agency is one of constrained cost minimization. The objective function is

(1) $$C = \sum_{i=1}^{n} C^{(i)}(x_i),$$

where C is the aggregated abatement cost of all polluters, $C^{(i)}$ is the abatement cost of the industry generating pollutant i and x_i is the abatement quantity of this pollutant[8].

$\partial C^{(i)}/\partial x_i > 0$, $\partial^2 C^{(i)}/\partial x_i^2 > 0$ is supposed to hold for any pollutant i. The first constraint for the cost minimization is the environmental standard to be met, i.e.,

$\bar{I} - I(x_1,...,x_n) \geq 0$, where $\partial I/\partial x_i < 0 \quad \forall i \varepsilon \{1,...,n\}$.

Moreover, you cannot clean up more mess than generated. Thus, for each abatement activity an "upper boundary condition"

$X^{*}_{i} - x_i \geq 0 \quad \forall i \varepsilon \{1,...,n\}$

holds, where X^{*}_{i} is the unregulated "status quo ante" euqilibrium quantity of pollutant i.

Finally, the levels of pollution abatement are non-negative, i.e., $x_i \geq 0 \quad \forall i \varepsilon \{1,...,n\}$ holds[9].

The Lagrangean function for this constraint minimization problem is

(2) $$Z = C(x_1, ..., x_n) + \mu(I(x_1, ..., x_n) - \bar{I}) + \sum_{i=1}^{n} \lambda_i (x_i - X^{*})$$

8) The index (i) in $C^{(i)}$ is dropped , below, where no confusion seems to be possible.
As mentioned above, the problem of assigning the maximum allowable emission level for each industry to the members of this industry is not analyzed in this paper. It is therefore assumed that within each industry, the pollution allowances are distributed in a manner minimizing intra-industry abatement cost.
The reader familiar with the traditional environmental economics literature will notice that this assumption is warranted in the case of the effluent charges and transferable permits policy, but excessively favourable in the case of a command and control policy.

9) A more general model might allow for activities simultaneously generating $x_i < 0$, $x_j > 0$ if the effect of the latter one upon the environmental quality index overcompensates the effect of the former

The Kuhn-Tucker Conditions are

(3) $\partial C/\partial x_i + \mu\partial I/\partial x_i + \lambda_i \geq 0$ $\quad x_i \geq 0$ $\quad x_i(\partial C/\partial x_i + \mu\partial I/\partial x_i + \lambda_i) = 0$ $\quad \forall i \varepsilon \{1,...,n\}$

(4) $I(x_1,...,x_n) - \bar{I} \leq 0$ $\quad \mu \geq 0$ $\quad \mu(I(x_1,...,x_n) - \bar{I}) = 0$

(5) $(x_i - X^*_i) \leq 0$ $\quad \lambda_i \geq 0$ $\quad \lambda_i(x_i - X^*_i) = 0 \quad \forall i \varepsilon \{1,...,n\}$

According to the Arrow-Enthoven Theorem, these conditions are necessary and sufficient for a global solution of our cost minimum problem, given the constraint qualification is met, the objective function $C(x_1,...,x_n)$ is differentiable and quasiconvex and the constraint function $I(x_1,...,x_n)$ is differentiable and quasiconcave. (The condition that $\exists i \varepsilon \{1,...,n\}$ such that $\partial C/\partial x_i > 0$ at the solution, is met anyway, in the problem analyzed here). The Kuhn-Tucker Conditions allow for interior and corner solutions. In the case of an interior solution $(0 < x_i < X^*_i, \forall i)$, for the reduction of any pair of pollutants i, $j \epsilon \{1,...,n\}$ it follows that

$$\partial C/\partial x_i = -\mu\partial I/\partial x_i$$
$$\partial C/\partial x_j = -\mu\partial I/\partial x_j$$

(6) $$\rightarrow -(dx_j/dx_i)_{dC=0} = -(dx_j/dx_i)_{dI=0}$$

Condition (6) indicates that in the solution the marginal rate at which the two pollutants can be substituted against each other at the predetermined index level $\bar{I}$ (their marginal rate of substitution) equals the marginal rate at which the two pollutants can be substituted against each other at a given level of aggregate abatement cost (their marginal rate of transformation). Thus, given the above requirements are met, an interior solution can be illustrated as follows, for the case of two pollutants X and Y.

In Fig. 2, $\hat{C} < \bar{C} < \bar{\bar{C}}$ show alternative levels of aggregate abatement cost and $\bar{I}$ shows the predetermined environmental constraint. The size of the "box" in Fig. 2 represents the non-negativity and upper boundary conditions. The solution is given by P**(x**,y**) where an iso-abatement-cost curve is tangent to the constraint curve.

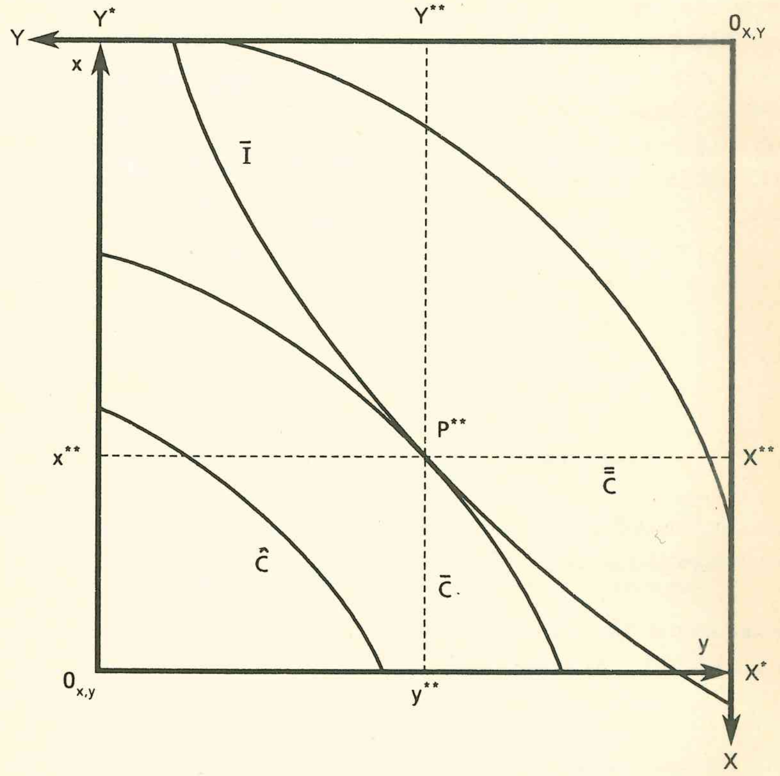

Figure 2: Meeting the target at minimum cost - the interior solution

It should be noted that since x = X* - X and y = Y* - Y, the solution in terms of abatement levels (x**, y**) corresponds to a solution in terms of emission levels (X**, Y**) still generated after abatement is done. Moreover, a curve which is

concave (convex) towards the x, y-origin is convex (concave) towards the X,Y-origin.
Corner solutions can turn up in two kinds of forms.
First, in the nonnegativity condition(s) of one (several) variable(s) the strict equality sign may hold, second in the upper boundary condition(s) of one (several) variable(s) the strict equality sign may hold (or both).
To give an example for the first type, suppose that in the solution, $0 < x_i < X^*_i$ $\forall i \varepsilon \{1,\ldots,j-1, j+1,\ldots,n\}$ and $0 = x_j < X^*_j$ hold.
Then,

$$\frac{\partial C/\partial x_i}{\partial C/\partial x_j} \leq \frac{\partial I/\partial x_i}{\partial I/\partial x_j},$$

i.e.,

(7) $$-(dx_j/dx_i)_{dC=0} \leq -(dx_j/dx_i)_{dI=0} \text{ holds.}$$

This is shown in Fig. 3 for two abatement activities x (for x_i) and y (for x_j) (and the strict unequality holding in (7)):

For the second type of a corner solution, the case of $0 < x_i = X^*_i$ and $0 < x_j < X^*_j$, $\forall j \varepsilon \{1,\ldots,i-1, i+1,\ldots,n\}$ is illustrative. Here,

$$\frac{\partial C/\partial x_i}{\partial C/\partial x_j} = \frac{-\mu \partial I/\partial x_i - \lambda_i}{-\mu \partial I/\partial x_j},$$

i.e.,

(8) $$-(dx_j/dx_i)_{dC=0} \leq -(dx_j/dx_i)_{dI=0} \text{ holds.}$$

This is shown in Fig. 4 for two abatement activities x (for x_i) and y (for x_j) (and the strict unequality holding in equation (8)).

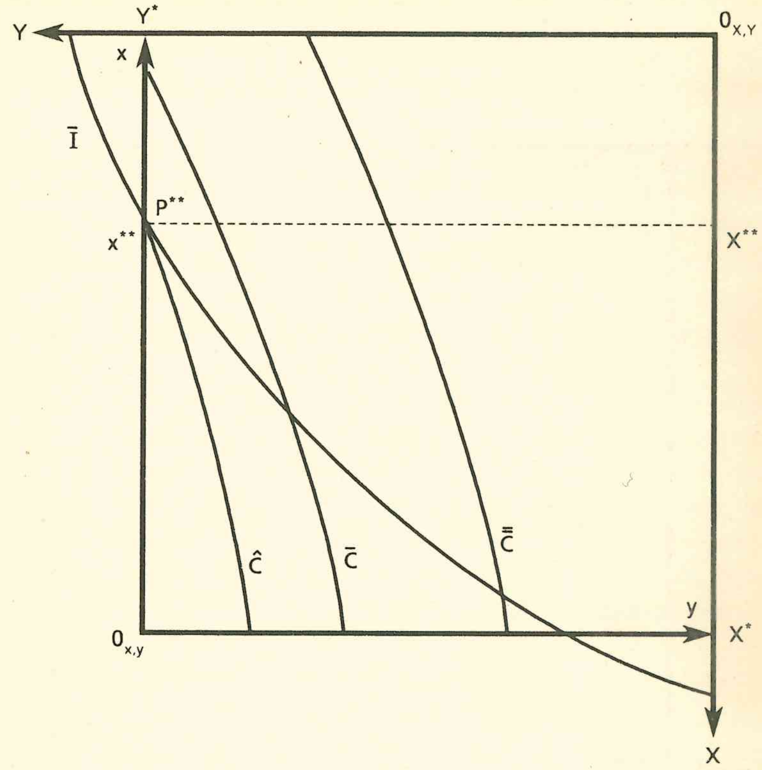

Figure 3: Meeting the target at minimum cost - corner solution I

The properties of the solution of the cost minimization problem under environmental restrictions have been established. How about the chances to arrive at this optimum by applying alternative environmental policies? Discussing this question, the cases of linear, concave and nonconcave interaction in the environmental target constraint are separately dealt with, below.

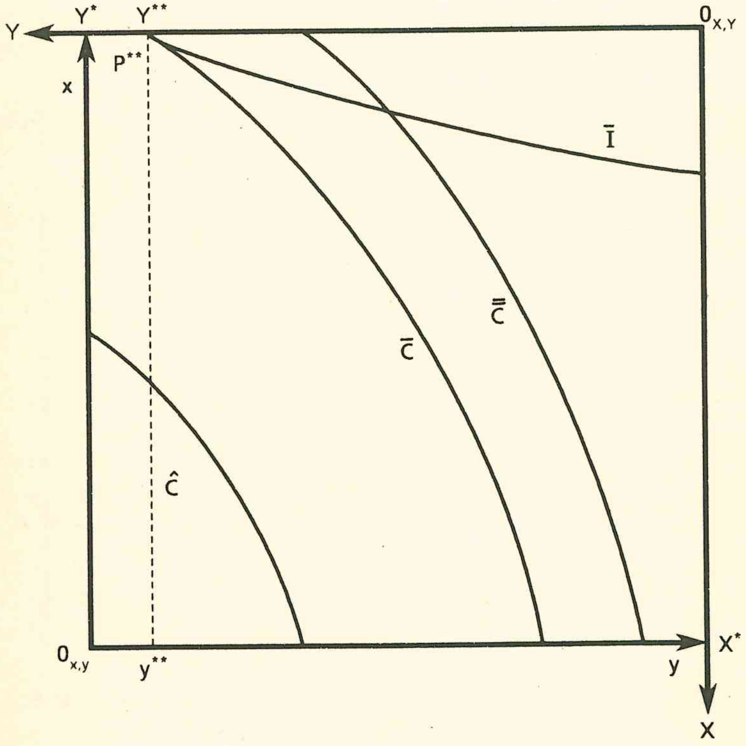

Figure 4: Meeting the target at minimum cost - corner solution II

3. Linear Interaction

3.1 Effluent charges

Suppose, the regulatory agency is to use effluent charges as a means to achieve the predetermined interactive quality standard $\bar{I}$ [10].

To decide which of the indefinitely many combinations of the n pollutants compatible with $\bar{I}$ it is to aim at, the regulatory agency has to make a guess on the marginal abatement costs of the n polluting industries. On the basis of this estimate and the agency's knowledge of $I(X_1,...,X_n)$, the n pollutant target levels $(\bar{X}_1,...,\bar{X}_n)$, are defined. These levels are the ones the agency takes to meet the environmental restriction $\bar{I}$ at minimum cost.

The estimate of the abatement cost functions is also needed for another purpose: It provides the basis for a guess on how the n polluting industries will adjust their discharges to alternative levels of tax rates $t_{X_1},...t_{X_n}$, just as in the case of no pollutant interactions: Consider any polluter A in any i-polluting industry wanting to minimize his burden of environmental policy $B_A = t_{X_i} \cdot X^{(A)}_i + C^{(i)}_A\ (x^{(A)}_i)$. The first term indicates the firm's emission tax bill and the second term its abatement cost. Under the above mentioned condition of increasing marginal abatement cost, the burden is minimized for

(9) $$t_{X_i} = \partial C^{(i)}_A / \partial x^{(A)}_i .$$

Thus , under an effluent charge law each polluter will reduce emissions until the marginal abatement cost equals the tax rate, as is well known in the literature. Using this information and having assessed the marginal abatement cost, the regulatory agency tries to set tax rates $t_{X_1},...,t_{X_n}$ equal to (its guess of) the marginal abatement cost of the polluting industries in the target situation $(\bar{X}_1,...,\bar{X}_n)$.

If the target situation is not attained after the industries' adjustment to the taxes, the tax rates have to be revised. It is hoped that a solution will be attained after

10) Henceforth, it is assumed that discharges of any pollutant X_i decrease (increase) when the respective tax rate t_{X_i} increases (decreases).
Of course, there are exceptions from this rule. See e.g. R. Pethig (1979), pp. 135 f.

an iterative process of trial and error [11]

Fig. 5 illustrates this "pricing and standards" technique for the case of linear interaction, the existence of an interior solution and two pollutants X, Y.

The first quadrant of fig. 5[12] depicts the situation of the X-industry. The unregulated equilibrium emission quantity of that industry is X*. C(x) is the total, $\partial C/\partial x(x)$ the marginal abatement cost curve.

Of course, it is highly unlikely that the regulatory agency's estimate of the abatement cost of the X-industry (and any other industry) would be correct. Therefore, in the first quadrant of fig. 5, the agency's estimates $C^e(x)$ and $\partial C^e/\partial x(x)$ are distinguished from the true curves C(x), $\partial C/\partial x(x)$. The second quadrant depicts the situation of the Y-industry, analogously.
The solution of the constraint cost minimization is graphically derived in the third quadrant[13]. P**(X**,Y**), where an iso-cost curve C** derived from the true abatement cost curves is tangent to the target line $\bar{I}$ represents the genuine optimum. $\bar{P}(\bar{X},\bar{Y})$, where an iso-cost curve $\bar{C}^e$ derived from the agency's estimate of the abatement costs is tangent to the target line represents the optimum as assessed by the agency.

Under these circumstances the regulator will set tax rates $t_X^{(1)} = \partial C^e/\partial x(\bar{x})$, $t_Y^{(1)} = \partial C^e/\partial y(\bar{y})$, which he expects to induce abatement activities $\bar{x}$, $\bar{y}$ to bring emissions down from X*,Y* to the targent levels $\bar{X}$,$\bar{Y}$.

The firms adjust to these taxes by reducing emissions up to the point where their marginal abatement costs equal the tax rates. However, the costs calculated by the firms in their adjustment are the genuine abatement costs [14], rather than the

11) See W.J. Baumol, W.E. Oates (1975), Ch.10.

12) The quadrants are counted counterclockwise, beginning with the upper right hand quadrant.

13) The third quadrant of fig. 5 shows what the box in fig. 2 has shown. For simplicity, in fig. 5 and the following figures, the bottom and the left hand side of the box have not been drawn. It should be kept in mind, however, that each level of X(Y) in the third quadrant corresponds to a level of x(y) on the left hand side (bottom) of the box.

14) It is assumed that each firm is aware of its own marginal abatement cost function.

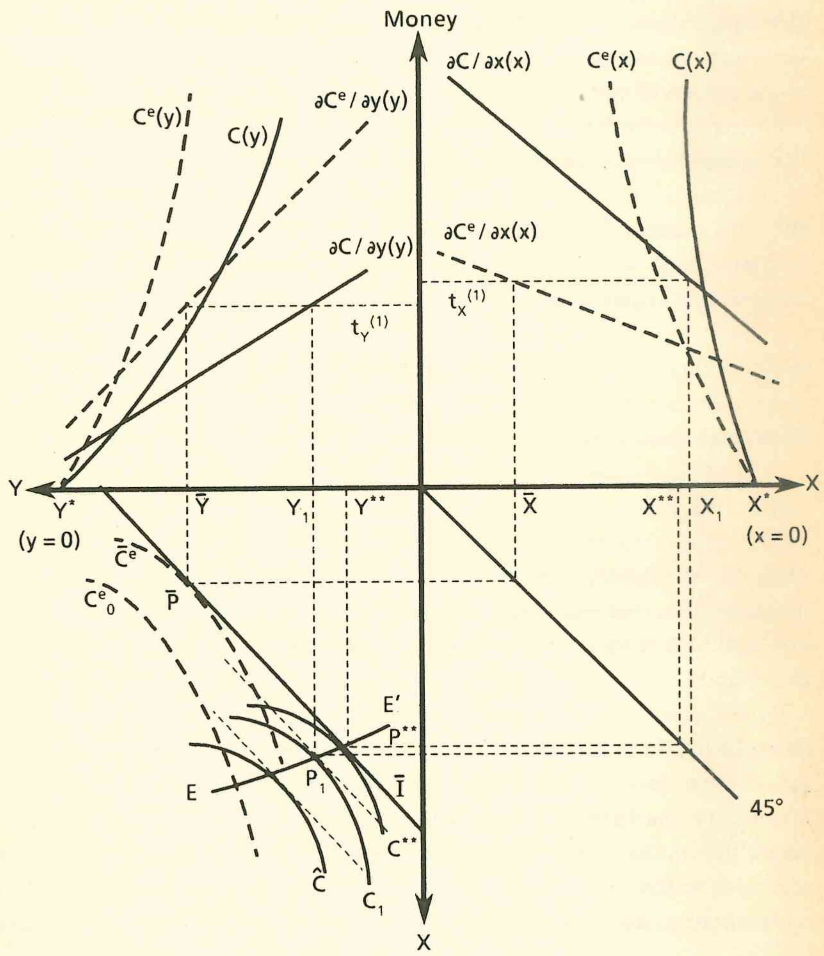

Figure 5: Effluent charges with linear interaction

marginal abatement costs, as estimated by the agency.

Thus, the post tax emission equilibrium is X_1, Y_1 with $t^{(1)}_X = \partial C/\partial x(x_1)$, $t^{(1)}_Y = \partial C/\partial y(y_1)$.

This equilibrium is illustrated as P_1 in fig. 5, missing the target $\bar{P}(\bar{X},\bar{Y})$.

Therefore, the tax rates have to be revised.

In the process of restructering tax rates the regulatory agency can rely upon the following informations, given interaction is linear:

The agency knows from (6) that in the cost minimum situation (X^{**},Y^{**})

$$\text{(6a)} \qquad -(dy/dx)_{dC=0}(X^{**},Y^{**}) = -(dy/dx)_{dI=0}(X^{**},Y^{**}) \text{ holds.}$$

From (9) it is known that

$$\text{(9a)} \qquad (t_X/t_Y) = -(dy/dx)_{dC=0}(X^{**},Y^{**}) \text{ holds.}$$

The agency concludes that

$$\text{(10)} \qquad (t_X/t_y) = -(dy/dx)_{dI=0}(X^{**},Y^{**}) \text{ holds}^{15)}.$$

Thus, the regulatory agency can take it for granted that in the optimum it is struggling for, realized as emission tax equilibrium, the relative tax rate for the two pollutants equals the marginal rate of pollutant substitution, evaluated in the solution.

Since $I = I(X,Y)$ is known to the agency and the marginal rate of pollutant substitution does not depend on the levels of pollutants in the case of linear interaction, the agency knows the term $-(dy/dx)_{dI=0}$ in (10) without knowing where the solution lies. Therefore, the agency is aware of the relative optimum tax rates without having complete information on the polluting industries marginal abatement costs.

15) For the case of n variables the equations are

$$\text{(6)} \; -(dx_j/dx_i)_{dC=0}(X^*{}_1{}^*, \; ,X^*{}_n{}^*) = \; (dx_j/dx_i)_{dI=0}(X^*{}_1{}^*,\ldots,X^*{}_n{}^*), \; \forall i,j \varepsilon \{1,\ldots,n\}$$

$$\text{(9b)} \; t_{X_i}/t_{X_j} = -(dx_j/dx_i)_{dC=0}(X^*{}_1{}^* \; ,X^*{}_n{}^*), \forall i,j \varepsilon \{1,\ldots,n\}$$

$$\text{(10a)} \; t_{X_i}/t_{X_j} = -(dx_j/dx_i)_{dI=0}(X^*{}_1{}^*, \; ,X^*{}_n{}^*), \forall i,j \varepsilon \{1,\ldots,n\}$$

In the abatement equilibrium attained after the agency's first tax rate estimation (P_1) the condition $t^{(1)}_X / t^{(1)}_Y = -(dy/dx)_{dI=0}$ holds. Thus, all the agency has to do after realizing that the environmental restriction is not met, in P_1, is to raise the absolute value of the tax rates leaving relative taxes as they are. In fig. 5, this would correspond to a move of the equilibrium allocation along the line EE' from P_1 towards P^{**}.

Even though it is well known that restructering tax rates may be difficult in practice[16] (with or without pollutant interaction) it is interesting to note that in the case of linear interaction the agency's strive for optimality is not more complicated than in the case of regulating a single pollutant. The simple decision rule is:

If the load on the environment after adjusting to the tax rates set in the first place is above the target level $\bar{I}$, all tax rates have to be raised in the same proportion, until $\bar{I}$ is met. If the load falls short of the level aimed at (contrary to what is shown in fig. 5) all tax rates may be reduced by the same percentage amount.

In the cases of corner solutions (not shown in fig. 5) the procedure of tax restructering would be basically the same. Consider the example of a corner solution at $X^{**}, Y=0$. Here, increasing tax rates in the same proportion starting from an initial situation P_1, violating the constraint $\bar{I}$, would result in a situation $X^0, Y=0$, with $X^0 \geq X^{**}$. If $X^0 > X^{**}$ (as shown in fig. 5a), still violating $\bar{I}$, both tax rates could be increased, as in the case of an interior solution, until $\bar{I}$ is met. Alternatively, having attained $X^0, Y=0$, t_Y could be left constant, increasing t_X only, until $\bar{I}$ is met.

3.2 Transferable discharge permits

Suppose the regulatory agency is using transferable discharge permits as a means of environmental policy. Then, a quantity of permits is issued by the agency guaranteeing that the environmental target level $\bar{I}$ is met. The agency has the option of auctioning the permits off, or giving them away free of charge to the polluters. In both schemes permits can be resold. Moreover, the permits may be

16) See W.J. Baumol, W.E. Oates (1975), Ch 10.

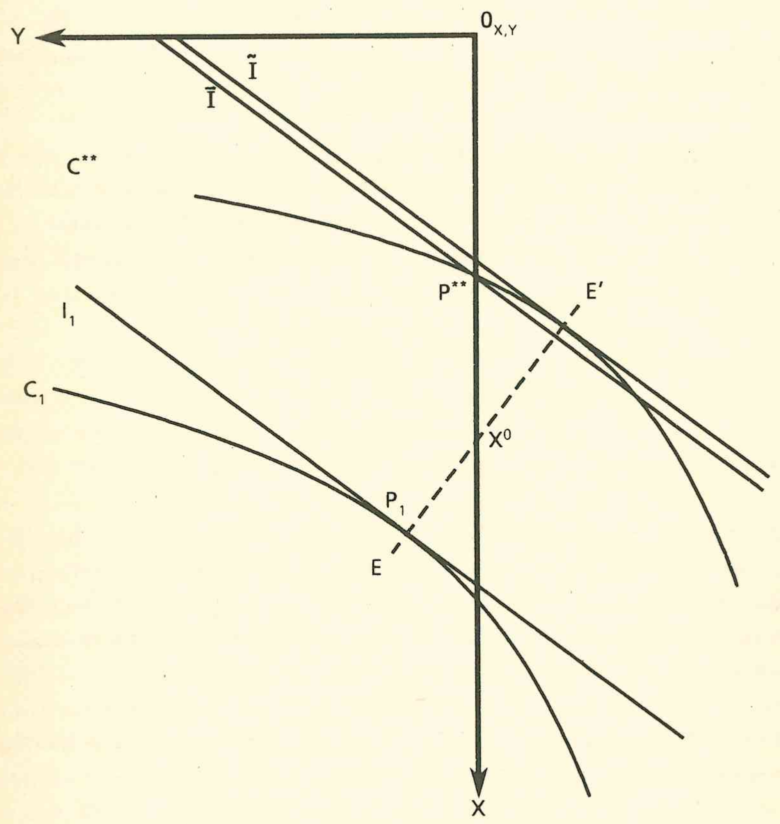

Figure 5a: Effluent charges with linear interaction - a corner solution

designed as separate emission rights, one type of a right for each type of a pollutant, or they may be written in the form of "load-permits" (L-permits), allowing the generation of load-units in terms of the indicator I. Shaping L-

permits, it would be convenient to use one of the pollutants (say, j) as a numeraire. Then, the permits would be written out in units of pollutant j. One L-permit would certify the right of discharging one unit of pollutant j or, alternatively, the quantity of pollutant i, equivalent to a unit j in terms of the index I. In the case of linear interaction, it follows from the definition of I that the quantity of pollutant i equivalent to one unit of j is $1/(a_i/a_j)$ units. The coefficient a_i/a_j shows the adverse effect of pollutant i relative to the adverse effect of the numeraire pollutant, i.e., the marginal rate of pollutant substitution.

Consider the properties of a L-permit policy with free initial distribution:

If the regulatory agency is aiming at a set of emissions $(\bar{X}_1,...,\bar{X}_n)$, as outlined above, it may assign the permits as follows: A number of $\bar{X}_j$ L-permits are given to the j-industry (discharging the numeraire pollutant). Each firm k in the j-industry may be assigned a quantity of $X^{(k)}{}_j{}^* \; \bar{X}_j/X^*_j$ permits (where $X^{(k)}{}_j{}^*(X^*_j)$ is firm k's (industry j's) unregulated emission level), leaving the emission share of each firm within the industry at its pre-regulatory level[17].

Each i-industry $(i \in \{1,...,j-1,j+1,...,n\})$ may be assigned a quantity of L-permits certifying the right to discharge $\bar{X}_i$ pollutant units, i.e., $a_i/a_j \; \bar{X}_i$ permits. Analogously to what has been said for the members of the j-industry, each firm k in the i-industry may receive $a_i/a_j \cdot X^{(k)}{}_i{}^* \cdot \bar{X}_i/X^*_i$ permits. If this initial distribution of permits put into effect by the agency would not be modified by trade among firms of different industries, the agency's environmental target $(\bar{X}_1,...,\bar{X}_n)$ would be realized and maintained.

Of course, the procedure outlined above is just an example of determining the initial allocation of rights. If the agency is not afraid of the permit market process getting caught in a local optimum between the initial distribution of rights and the global optimum it might just assign a quantity of permits to each industry i proportional to its pre-regulatory emission level X^*_i.

If in the pre-regulatory equilibrium $I^* = a_1X^*_1 + ... + a_nX^*_n$ holds, each industry might be granted the right to pollute $X^*_i \cdot \bar{I}/I^*$ pollutant units leaving the interindustry distribution of emission quantities at its pre-regulated form and

17) The problem of firms producing higher unregulated emission levels to secure a higher endowment of permits is ignored here

confining the index to the target level $\bar{I}$. In this case, each industry i would be assigned $a_i/a_j X^*_i$ $\bar{I}/I^*$ L-permits.The latter procedure would be very attractive because the agency would not have to worry about estimating the marginal abatement costs of the polluting industries at all. Thereby, the permit policy would achieve an important advantage compared to the effluent charge policy. Nevertheless, $(\bar{X}_1,...,\bar{X}_n)$ will be used as a starting emission allocation below, for better analytical comparability of the charges and the permits policies.

How about the incentives to modify the initial distribution of pollution rights? Suppose the cost to abate an additional amount of pollutant i equivalent to a unit of the numeraire pollutant j differs from the cost to abate an additional amount of pollutant k equivalent to a numeraire unit, in the starting situation. Then, there are potential gains from permit trade between the i-and k-industry. If the marginal abatement cost for a j-equivalent in industry i are higher (lower) than the marginal abatement costs for a j-equivalent in industry k, then, a L-permit can be traded from the k-(i-)industry to the i-(k-)industry to their mutual advantage. Of course, given the above assumption on the slope of the marginal abatement cost curves, these costs of the industry supplying (demanding) permits rise (fall) in the process of trading since more (less) pollutants are abated. The competitive equilibrium occurs where the marginal abatement costs in terms of numeraire equivalents of the two industries have adjusted to each other in the transaction process. With equal marginal abatement costs across the industries in terms of j-equivalents, all gains from trade are exhausted[18].

Figure 6 illustrates the market for discharge permits for two pollutants X and Y in the case of perfect competition. Y serves as the numeraire pollutant.
The initial permit assignments of the two industries are indicated as $\bar{Y}$ and $a \cdot \bar{X}$ in the second and first quadrant, respectively. a stands for a_X/a_Y, the marginal rate of pollutant substitution. Since permits are written in numeraire units, the abscissa in the first quadrant depicting the situation of the X-industry has been rescaled into Y-units. Thus, the marginal abatement cost curve of the X-industry,

18) The analogy to the traditional analysis without pollutant interaction should be noted. Here, an optimal intra-industry distribution is defined by equal marginal abatement costs for all the member firms of the industry. Of course, this condition is still valid in the case of interactive pollutants, in addition to the one explained above.

shown in the first quadrant, indicates the marginal cost of the X-industry to abate pollutant X in terms of Y-equivalent units.
From the definition of I, it follows that $Y = a \cdot X$ units of X in terms of Y-equivalents. Therefore, the marginal abatement cost of X defined for Y-equivalents is $dC(x)/dy = 1/a\ \partial C/\partial x(x)$, shown in the first quadrant[19].

Since in the initial situation, the X-industry is allowed to emit a quantity $\bar{X}$ of its pollutant (i.e., it is forced to abate $\bar{x}$ pollutants) its rescaled marginal abatement cost is $1/a \partial C/\partial x(\bar{X})$, in this situation. Thus, the marginal willingness to pay of the firms in that industry to receive a (small) additional quantity of L-permits would be just that amount of money. If the industry's firms were *offered* that amount they would supply a marginal L-permit. The marginal cost of the Y-industry is $\partial C/\partial y(\bar{y})$ in the initial situation. Thus, this amount of money is the marginal permit supply (demand) price of the firms in that industry. Since in the example given in fig. 6 $\partial C/\partial y(y)$ happens to be smaller than $1/a \partial C/\partial x(x)$, the firms in the Y-industry turn out to be the suppliers in the permit market, the X-firms being their customers. Thus, $\partial C/\partial y$ is the supply curve and $1/a\ \partial C/\partial x$ is the demand curve of the permit market.

To read quantities supplied along the same scale as quantities demanded the supply curve $\partial C/\partial y$ is shifted from the second to the first quadrant in fig. 6 to an extent of $a \cdot \bar{X} + \bar{Y}$. The transformed curve is labeled $\partial C/\partial y^T$. It should be noted that units of Y removed by the Y-industry are read from the left to the right in that quadrant and units of Y-equivalents removed by the X-industry are read from the right to the left.
It is obvious that the initial situation $1/a \partial C/\partial x(x) > \partial C/\partial y(y)$ is no equilibrium in the permit market. The equilibrium will be reached if the X-industry buys Y^*-Y^{**} permits from the Y-industry.
Then, $1/a\ \partial C/\partial x = \partial C/\partial y$ holds, i.e. supply and demand curves intersect.
Since $a = -(dy/dx)_{dI=0}$, in the case of linear interaction, this equilibrium condition is identical to equation (6a), the condition for the minimum cost situation keeping the target $\bar{I}$.

19) For total abatement cost, $C = C(x)$ holds. With $X = 1/a\ Y$, $X = X^*\text{-}x$ and $Y = Y^*\text{-}y$, $dC(x)/dy = 1/a\ \partial C/\partial x$ follows.

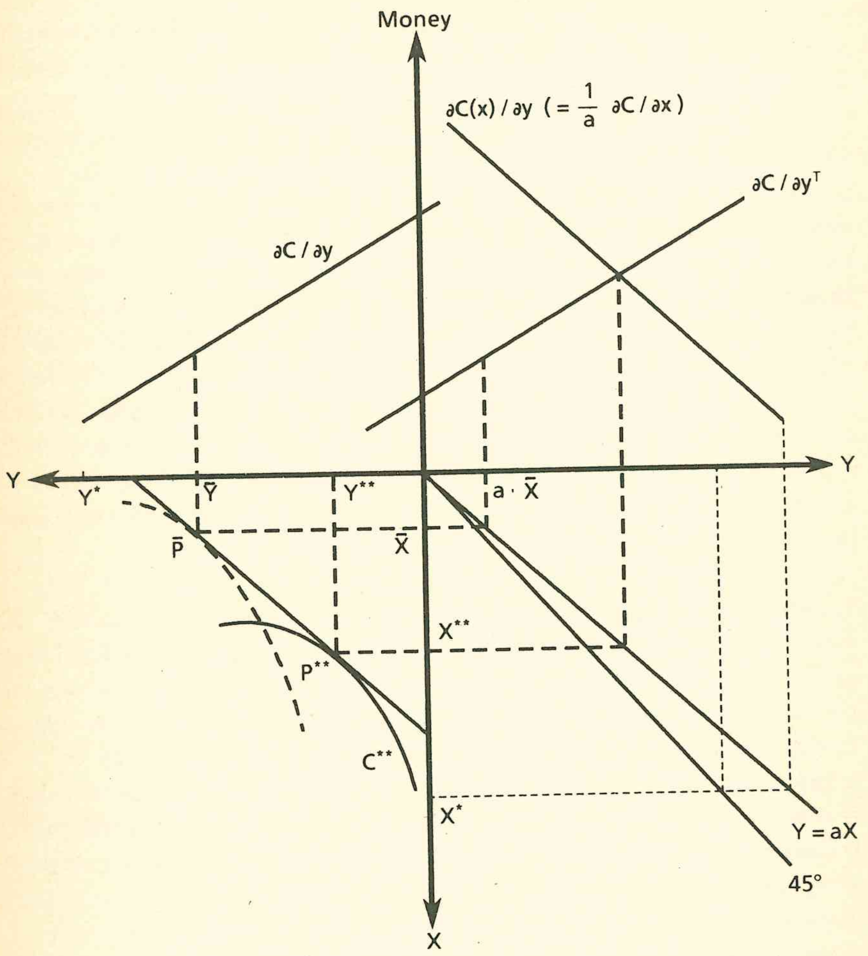

Figure 6: Transferable discharge permits with linear interaction

Since this optimum is unique we can be sure about the permit market equilibrium being identical to the solution of the regulatory agency's problem, (X**,Y**).

It is worth noting that with the permit policy this efficient allocation is achieved without the detour of preliminary allocations which violate the environmental target, as necessary in the effluent charge approach[20].

4. Concave Interaction

4.1 Effluent charges

Analogously to what has been said above, the regulatory agency is aiming at an emission allocation $\bar{X}_1,...,\bar{X}_n$, with the tax rates $t^{(1)}{}_{x_1},...,t^{(1)}{}_{x_n}$. The rates are set according to the shape of the policy restriction $\bar{I}$ and according to what the agency takes to be the marginal abatement costs in the n polluting industries. The polluters, however, adjust their emission levels to $X^{(1)}{}_1,...,X^{(1)}{}_n$ according to their true marginal abatement costs. If the agency's estimate fails to be accurate, as assumed in this paper, $(\bar{X}_1,...,\bar{X}_n) \neq (X^{(1)}{}_1,...,X^{(1)}{}_n)$ follows, in general[21]. Also, the environmental target is missed ($I(X^{(1)}{}_1,...,X^{(1)}{}_n) \neq \bar{I}$), in general[22].

As in the case of linear interaction, the result of $\bar{X}_i > X^{(1)}{}_i$ ($\bar{X}_i < \bar{X}^{(1)}{}_i$) is signalling to the agency that it overestimated (underestimated) the marginal abatement cost of the i-industry, in the first place. This will certainly be helpful for a reassessment of the cost functions.

It is important to note, however, that contrary to the case of linear interaction, there is no simple decision rule for the correction of the tax rates misspecified in the first step. Even though conditions (6), (9b), (10a), still hold when interaction is

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20) It is obvious that in the case of linear interaction a corner solution, say X**,Y = 0, (not shown in fig. 6) would also be a permit market equilibrium.

21) In the (practically irrelevant) special case, in which the agency's estimate of the marginal abatement cost functions is the same monotonic transformation of the true functions for all industries, $(\bar{X}_1,...,\bar{X}_n) = (X^{(1)}{}_1,...,X^{(1)}{}_n)$ would hold

22) If, accidentally, $I(X^{(1)}{}_1,...,X^{(1)}{}_n) = \bar{I}$ holds in spite of the agency misjudging the marginal abatement costs, the agency would have to check whether the relative tax rates for all pollutants equal the (inverse) marginal rates of pollutant substitution (see equ. (10)) in this situation. Only then, $(X^{(1)}{}_1,...,X^{(1)}{}_n)$ would meet $\bar{I}$ at minimum cost.

concave (given the solution is an interior one), they are not much of a help in this case. The reason is that the marginal rate of pollutant substitution is no longer constant. Thus, in (10a) the marginal rate of pollutant substitution calculated in the cost minimum situation $(X^*_1{}^*,...X^*_n{}^*)$ is not known to the agency even though the shape of the policy restriction $I = I(X_1,...,X_n)$ is known because the agency does not know the values $X^*_1{}^*,...,X^*_n{}^*$. Thus, equation (10a) does not provide a compass for the revision of the tax rates.

All the agency can do when the industries do not react as expected to the effluent charges is to reassess the marginal abatement costs of the polluting industries and to try out a new set of tax rates.

Thus , the simple process of trial and error in the linear interactive case turns into a complex one when interaction is concave. In this process, not only the absolute levels of the tax rates but also the relative rates are questionable to the agency.

The problem is illustrated in fig. 7 for two pollutants X and Y, and the case of an interior solution.

Industries' adjustment to the initial set of tax rates $t^{(1)}{}_X$, $t^{(1)}{}_Y$, leads to the situation $P_1(X_1,Y_1) \neq \bar{P}(\bar{X},\bar{Y})$, where the constraint $\bar{I}$ is violated. $P^{**}(X^{**},Y^{**})$ again shows the optimum, unknown to the agency.

In P_1 the agency does not know how to change the tax rates. Rising both taxes proportionally until $\bar{I}$ is met, which was all it had to do in the case of linear interaction, would result in a situation on $\bar{I}$ "north east" to P_1 in fig. 7, missing the optimal situation[23].

It can be concluded that the possibility of attaining a predetermined environmental target at minimum cost by the use of effluent charges is hampered by the existence of concave pollutant interaction.

23) The following procedure would be helpful to the agency: Having achieved $\bar{I}$ by proportionally increasing both tax rates, realizing a situation of, say, $\bar{\bar{P}}(\bar{\bar{X}},\bar{\bar{Y}})$, the agency might check whether $t_x/t_Y \gtrless -(dy/dx)_{dI=0}(\bar{\bar{X}},\bar{\bar{Y}})$ holds. It would then conclude whether the solution lies to the right or to the left of $\bar{\bar{P}}$ (i.e , whether $(X^{**} < \bar{\bar{X}}, \bar{\bar{Y}}^{**} > Y)$ or $(X^{**} > \bar{\bar{X}}. Y^{**} < \bar{\bar{Y}})$, hold. Then, taxes would have to be adjusted, accordingly.

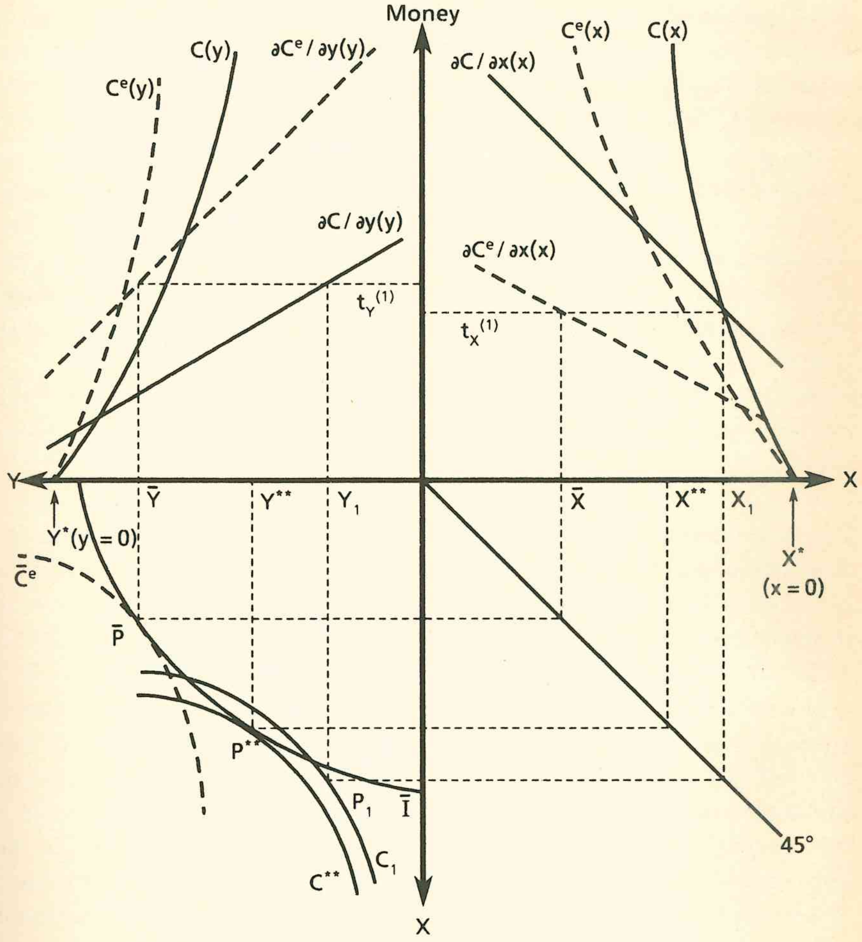

Figure 7: Effluent charges with concave interaction

4.2 Transferable discharge permits

In the case of linear interaction the quantity of i-emissions equivalent to a unit of numeraire emissions j is constant at $1/(a_i/a_j)$, the reciprocal of the marginal rate of pollutant substitution. Thus, one L-permit can be used to discharge $1/(a_i/a_j)$ units of pollutant i, irrespective to the prevailing pollutant combination.
This is no longer true in the case of concave interaction. Since the marginal rate of substitution between the numeraire pollutant j and any other pollutant i depends upon the quantity of pollutants X_i and X_j (and of all other pollutant quantities) discharged, no constant "exchange rate" among the pollutants exists. Thus, for each alternative pollutant distribution, the agency has to set a different exchange rate, corresponding to the marginal rate of pollutant substitution prevailing in this very situation[24].
Apart from this divergency, the permit market equilibrium is defined analogously to the case of linear interaction. It is illustrated in fig. 8 for the case of two pollutants X and Y and an interior solution.

The environmental damage index I is a function monotonely increasing in the quantities of pollutants X and Y. Therefore, the index function $I = I(X,Y)$ can be rewritten as $Y = Y(X,I)$. For any given level of I, say, $\bar{I}$, this function indicates the (maximal) quantity of Y compatible with $\bar{I}$, for any given level of X. With $Y(X=0,\bar{I})$ denoting the quantity of Y meeting the standard $\bar{I}$ when no X is discharged, $Y = Y(X=0,\bar{I}) - Y(X,\bar{I})$ gives the quantity of Y equivalent to X for each given level of the latter pollutant. For the index level $\bar{I}$, considered in this analysis, this function is abbreviated to $Y = I^T(X)$. Graphically it is obtained by shifting the constraint function $\bar{I}$ from the third to the fourth quadrant of fig. 8 transforming $Y(\bar{I}, X=0)$ to the origin of that quadrant. At any situation $\hat{X}, \hat{Y}$, the additional pollution of a unit of X has to be offset by the reduction of $\partial I^T/\partial X$ units of Y, keeping the standard $\bar{I}$. $\partial I^T/\partial X$ is identical to the marginal rate of pollutant substitution $-(dY/dX)_{\bar{I}}$.

Accordingly, an additional L-permit in the X-industry is the right to a firm A of

24) With perfect competition in the market for permits, no individual polluter's activities do have any effect on this rate. So relative prices of polluting X_i or X_j are given for each firm.

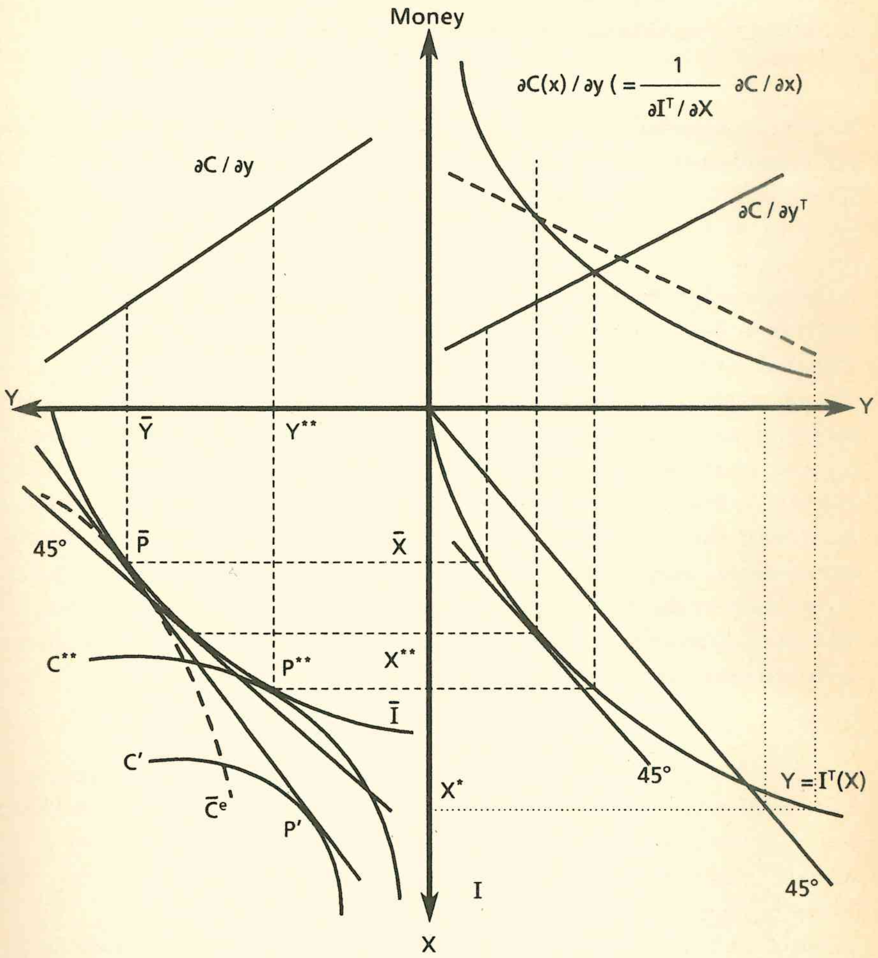

Figure 8: Transferable discharge permits with concave interaction

that industry to pollute $1/(\partial I^T/\partial X)$ additional units. Buying an L-permit in a situation where the pollution distribution is $\hat{X},\hat{Y}$ and the firm already abated $\hat{x}_A$ units, thereby saves abatement costs of

$$\frac{1}{\partial I^T/\partial X}(\hat{X})\partial C/\partial x(\hat{x}_A).$$

So that is the maximum amount the firm would be willing to pay to get hold of an additional permit.

Thus,

$$\frac{1}{\partial I^T/\partial X}(X)\partial C/\partial x(x).$$

is the permit demand function of the firms in the X-industry[25]. The demand curve is shown in the first quadrant of fig. 8 where the abscissa is rescaled to Y units [26]. (The dashed curve ($\partial C/\partial x$) is just serving as a construction line).

The aggregate permit supply function of the Y-industry's firms is not affected by changing from linear to concave interaction since the discharges of this industry serve as the numeraire pollutant. Selling a permit induces additional abatement cost of $\partial C/\partial y$ to a firm in this industry. Thus, $\partial C/\partial y$ is the permit supply function of the firms in the Y-industry. To read quantities demanded and supplied along the same scale the supply curve $\partial C/\partial y$ is shifted from the second quadrant of fig. 8, to $\partial C/\partial y^T$ into the first one, as it was in the case of linear interaction.

Market equilibrium is illustrated by the two curves intersecting with equilibrium pollution quantities X**,Y**. The equilibrium condition is

$$\frac{\partial C}{\partial y} = \frac{1}{\partial I^T/\partial x}\frac{\partial C}{\partial x}.$$

Since $\partial I^T/\partial X = -(dy/dx)_{\bar{I}}$, the permit market equilibrium condition is identical to the condition for constraint cost minimization, (equation (6a)). Thus, as in the case of linear interaction, the market equilibrium allocation is identical to the solution aimed at by the regulatory agency. This result is plausible by the following reasoning:

Firms of the Y-industry supply permits until their marginal abatement costs are equal to the equilibrium price of a permit. Firms of the X-industry demand permits until their marginal abatement costs in terms of Y-equivalents are equal to that very equilibrium price. The marginal abatement costs (in terms of the numeraire pollutant) of the firms in the two industries to be equal is a requirement for a cost minimum allocation.

25) It should be kept in mind that it was assumed above that the problem of cost minimal allocation of abatement activities *within* each industry is solved. Therefore, the marginal abatement costs of all the firms in the X-industry are equal at $\partial C/\partial x$ in the equilibrium.

26) For total abatement cost, $C = C(x)$ holds. With $Y = I^T(X)$, $X = X^*\text{-}x$ and $Y = Y^*\text{-}y$, $dC(x)/dy = 1/(\partial I^T/\partial X)\ \partial C/\partial x$ follows.

The consequence of all that is that tradeable emission permits as a means of environmental policy appear to be less sensitive to a change from linear to concave interaction than emission taxes. The trial and error process of the latter becomes much more complicated whereas the nature of the competitive equilibrium in the former case is virtually uneffected[27].

5. Non-Concave Interaction

The case of non-concave interaction comprises a monotonely decreasing marginal rate of pollutant substitution $d(-(dY/dX)_{dI=0})$, $dX<0$ (convex interaction) and all forms of non-monotone changes in this rate.

It should be noted that the Kuhn-Tucker conditions, given in section 2., may not represent the solution of the cost minimum situation in these cases since the condition of quasi-convexity of the constraint function (with respect to the variables X,Y, i.e., quasi-concavity with respect to the variables x,y) is not met. Apart from that, a convex section in the constraint $\bar{I}$ may intersect the axis in a "cusp", possibly violating the constraint qualification.

Below, the example of a target constraint, exhibiting a concave and a convex section, is considered. (See $\bar{I}$ in fig. 9-11).

27) The permit policy would run into trial and error problems, also, if the regulatory agency would persue the following policy, perhaps seeming to be plausible, at first glance: The agency might issue a specific type of a permit for each type of a pollutant assigning a quantity of $\bar{X}$ and $\bar{Y}$ to the polluting industries, according to its guess of the cost minimum. Then, it might allow permit trade at fixed permit prices Z_X,Z_Y with Z_X/Z_Y chosen according to the marginal rate of pollutant substitution in the starting situation (P). Trade among firms of the two polluting industries would result in a situation with
$Z_X/Z_Y = -(dY/dX)_{dC=0}$, as shown at P' in fig. 8.
Here, the target $\bar{I}$ would be missed. Therefore, the relative permit prices would have to be modified. In this procedure, the agency would have to go through an iterative process with uncertain ends, as in the case of the effluent charge policy.

Here, the problem of multiple optima arises: A local optimum occurs at $\hat{P}(\hat{X},\hat{Y})$ where an iso-abatement cost curve is tangent to the target curve $\bar{I}$. The global optimum, however, is in the corner P** with $X = X^{**}, Y = 0$.

To avoid lenghthy considerations, below, the discussion is confined to the points different from the cases of linear and concave interaction.

5.1 Effluent charges

For the effluent charge policy the problems of the regulatory agency are not much different from the case of concave interaction, in the first place.

Starting in $P_1(X_1,Y_1)$, again, the agency will have to go through a process of "complicated trial and error" restructering the tax rates, as in the previous case. However, the process may end up in a situation $\hat{P}$, satisfying $t_X/t_Y = -(dY/dX)_{dI=0} = -(dY/dX)_{dC=0}$. As mentioned above, this situation may only qualify for a local optimum (and does so in the example of fig. 9). In this situation, there would be no reliable signal inherent to the tax policy indicating to the agency that it could do better than that.

There is, however, a "weak test" the agency may apply to check whether $\hat{P}$ is a global optimum or a local one, only:

If in $\hat{P}$, the tangency to $\bar{I}$ and to the iso-cost curve $\hat{C}$ (tangent to $\bar{I}$ in $\hat{P}$), is a separating line for $\hat{C}$ and $\bar{I}$, then the agency can be sure that $\hat{P}$ is the global optimum, since the iso-cost curves are known to be convex towards the X,Y-origin.

If this tangency does intersect $\bar{I}$, however, $\hat{P}$ may be a local or the global optimum. So meeting the separating line criterion is a sufficient but not a necessary condition for $\hat{P}$ to represent the global optimum.

This is illustrated in fig. 10:

If the constraint takes the form of $\bar{I}_a$, the tangency to $\hat{C}$ and $\bar{I}$ through $\hat{P}$ is a separating line. Therefore, $\hat{C}$ is identical to C**, the minimum cost compatible with the constraint.

If the constraint takes the form of $\bar{I}_b$ or $\bar{I}_c$ the tangency ceases to be a separating line. In the case of $\bar{I}_b$, $\hat{C}$ nevertheless represents the minimum cost compatible with the constraint. In the case of $\bar{I}_c$, however, the corner solution X_c^{**}, $Y = 0$ meets the constraint at a cost less than $\hat{C}$, making $\hat{P}$ an inferior local optimum.

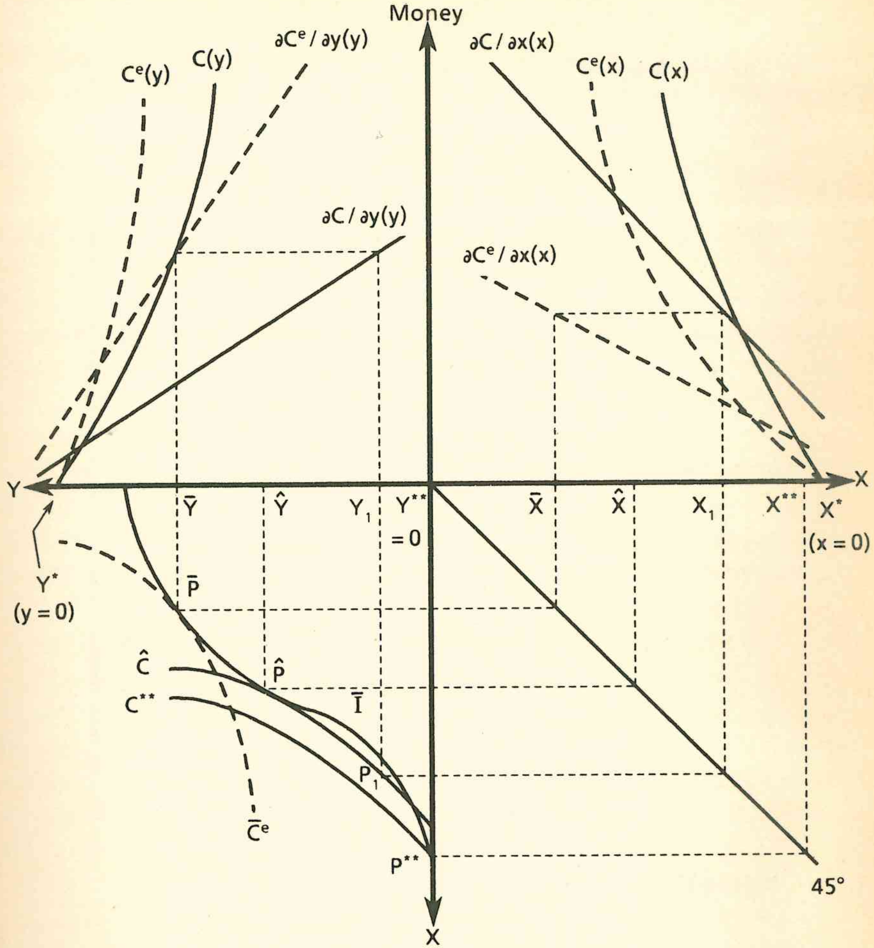

Figure 9: Effluent charges with non-concave interaction

It is interesting to note that it is not impossible to end up in the globally optimal corner solution P** after an iterative process of tax setting: Even though the

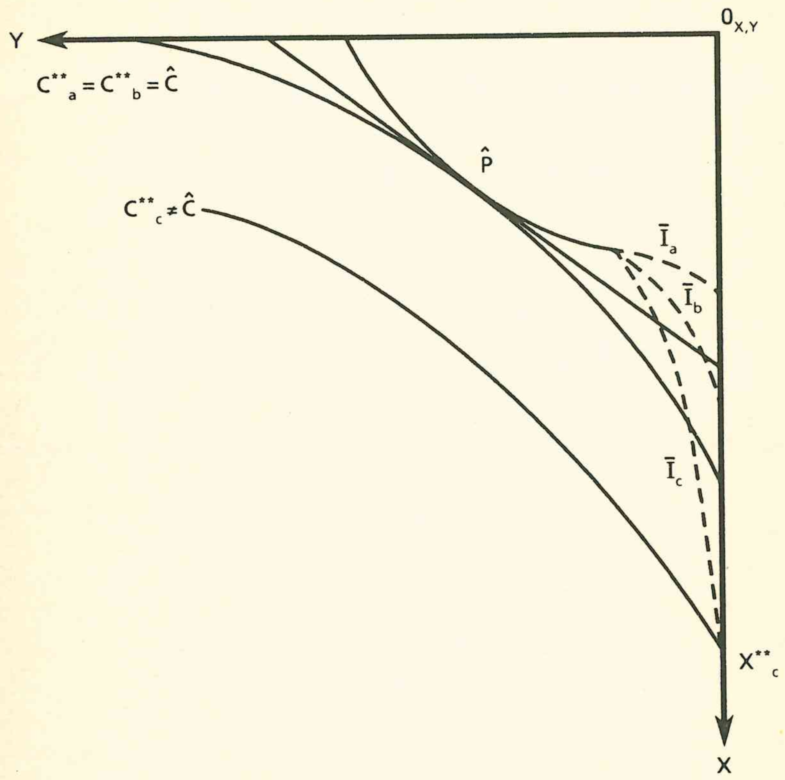

Figure 10: "Weak test" for global optimality

constraint is convex close to $P^{**}(X^{**}, Y=0)$, the situation qualifies for an effluent charge equilibriuim. The appropriate tax rates are $t_Y \geq \partial C/\partial y(y=Y^*)$ and $t_X = \partial C/\partial x(x^{**})$. The reason for that result (perhaps surprising to some) is that marginal abatement costs are monotonely increasing for both industries (i.e., their attainable "emission reduction sets" are convex). In this case, any emission

combination can be attained as an effluent charge equilibrium, if only the tax rates are set correctly.

On the other hand,it should be clear that there is no guarantee for the agency to find the global optimum in the process of restructering tax rates. It may well end up at the "wrong" optimum (if at any optimum at all). Finding the right one is the less likely the more local optima there are.

5.2 Transferable discharge permits

Fig. 11 illustrates the permit policy with non-concave interaction for the case of two pollutants X and Y. In the first quadrant of fig. 11, $\partial C/\partial y^T$ is the Y-industry's permit supply curve, as in the cases of linear and concave interactions. The curve

$$\frac{1}{\partial I^T/\partial X} \cdot \frac{\partial C}{\partial x}$$

indicating the permit demand curve in the previous cases, exhibits a downward sloping and an upward sloping part in the case of non-concave interaction as underlying here. The upward sloping part corresponds to the convex part of the constraint curve $\bar{I}$. Here, the amount of X-emissions equivalent to one unit of Y increases (as X increases), i.e. for the first factor of

$$\frac{1}{\partial I^T/\partial X} \cdot \frac{\partial C}{\partial x}, \frac{\partial(1/\partial I^T/\partial X)}{\partial X} > 0$$

holds.

This tends to make the X-industry's marginal willingness to pay for a L-permit increase (as Y decreases (and X increases)). Of course, there is a countervailing effect in the sense of the marginal abatement cost increasing with x (decreasing with X) providing for $\partial^2 C/\partial x \partial X < 0$ for the second factor of

$$\frac{1}{\partial I^T/\partial X} \cdot \frac{\partial C}{\partial x}.$$

In the case considered here, however, the first tendency is supposed to overcompensate the second one. This makes the X-industry's marginal willingness to pay for permits increase with X, i.e

$$\frac{1}{(\partial I^T/\partial X)^2} \cdot \frac{\partial^2 I^T}{\partial X^2} = \frac{\partial C}{\partial x} + \frac{\partial^2 C}{\partial x \partial X} \cdot \frac{1}{\partial I^T/\partial X} > 0,$$

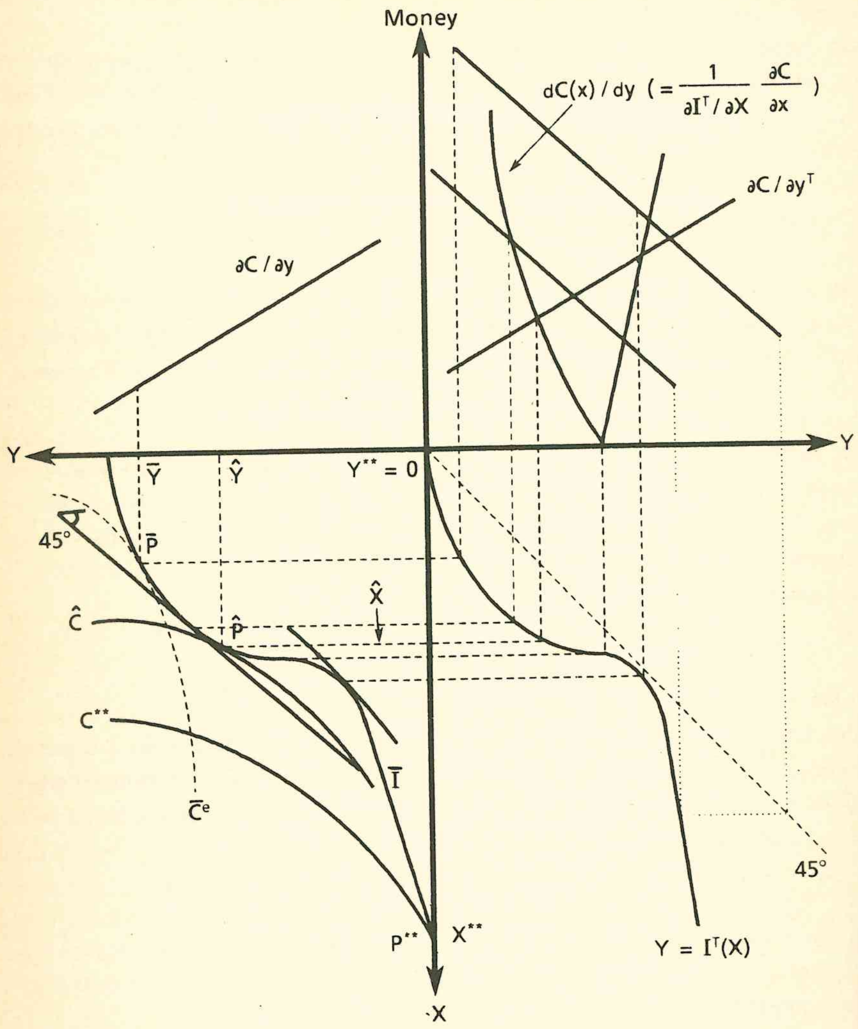

Figure 11: Transferable discharge permits with non-concave interaction

in the relevant section. Of course, the curve

$$\frac{1}{\partial I^T / \partial X} \cdot \frac{\partial C}{\partial x}.$$

represents the permit demand curve of the X-industry only in its downward sloping part. Moreover, to qualify for the demand curve, the points $(z^0 x^0)$ on this curve have to meet the total condition

$$\int_{x=0}^{x^0} \frac{1}{\partial I^T / \partial X} \frac{\partial C}{\partial x} dx \leq z^0 x^0,$$

where z^0 denotes the permit price.
The point, where

$$\frac{\partial C}{\partial y^T} = \frac{1}{\partial I^T / \partial X} \frac{\partial C}{\partial x}$$

holds, is identical to the local constraint cost minimum $\hat{P}(\hat{X},\hat{Y})$ meeting condition (6a). This point may violate the aforementioned total condition. Moreover, the global optimum $(X^{**}, Y = 0)$ may not be an equilibrium in the permit market at all.
Therefore, the tradable permit policy possibly fails to attain the solution of the constrained cost minimization problem.

5.3 Command and control policy

So far, the command and control approach to environmental protection has not been mentioned in this paper. Using this policy, the regulatory agency specifies the maximum amount of emissions for each polluting industry. Each firm within each industry is assigned an individual share of the respective amount. There is no trading of emission rights and no charge for the emission units below the firm's limit. With this policy, all the agency can do is to assign the emission quantities $\bar{X}_1, \ldots, \bar{X}_n$, thought to minimize the cost of meeting $\bar{I}$ to the n industries. Each quantity $\bar{X}_i$ would be distributed among the members of the i-industry according to what the agency thinks to be their marginal abatement costs.
By this procedure the agency could be sure that the environmental target $\bar{I}$ would be met. It would be unclear to the agency, however, what the efficiency sacrifices of that policy might be. If the agency would misjudge the marginal abatement costs of the n industries (as assumed for all policy alternatives, above), the environmental target would be attained at excessive cost.

Irrespective of interaction being linear, concave or non-concave, the command and control approach would not provide for any signal to the agency that it does the wrong thing, let alone what kind of a corrective should be taken.
The lack of any incentive for correction is a regretable property of the command and control policy whatever the type of pollutant interaction may be.
Thus, in addition to the general inability to assign efficient pollution limits to the firms within one polluting industry, well known in the literature, the command and control approach will generally be unable to assign efficient pollution limits among different polluting industries drawing upon the same capacity of the environment.

6. Summary

The possibilities to meet an interactive pollutant constraint at minimum cost have been considered. Effluent charges, transferable discharge permits and the (briefly mentioned) command and control strategy have been used to represent the environmental policy options.

It turned out that effluent charges are efficient in the case of linear pollutant interaction. The environmental policy constraint is met in an iterative process not more complicated than in the case of no pollutant interaction, as analyzed traditionally in the literature. Given concave interaction, charges are still efficient but the trial and error process towards meeting the environmental policy target is more complicated than in the linear case. In the case of non-concave interaction providing for the possibility of multiple optima the complicated trial and error process may even end up missing the global optimum. Then, effluent charges would stop being an efficient means of environmental policy.
Tradeable emission permits will always guarantee that the environmental target is met. In addition, they are an efficient means of environmental policy in the cases of linear and concave interaction. With non-concave interaction, however, they may loose the efficiency property.

The environmental target can savely be attained by a command and control strategy. In general, however, this strategy will be inefficient, regardless of the form of pollutant interaction.

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