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ENVIRONMENTAL POLICY

Anastasios Xepapadeas

University of Crete
Dept. of Economics
Crete, Greece

LECTURE NOTES IN

ENVIRONMENTAL POLICY

by

Anastasios Xepapadeas

Professor of Economics

University of Crete, Department of Economics

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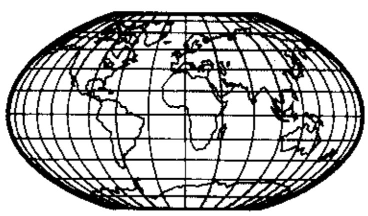

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1. Introduction

The purpose of these notes is to provide some formal presentation of recent topics in environmental policy. The notes cover issues related to standard environmental policy design, environmental policy in a dynamic framework, environmental policy under asymmetric information and under market imperfections, and environmental policy design for international environmental problems.

2. Basic Environmental Policy Framework

1 INTRODUCTION

The presence of detrimental environmental externalities, which take the form of environmental pollution generated by the industrial sector of the economy, calls for specific policy measures that could induce individual polluters (firms) to behave in a way that would result in the socially-desirable level of environmental pollution.

In this section we develop a basic framework for environmental policy design which is used for the derivation of alternative environmental policy instruments. The two major approaches to environmental policy – economic incentives, and command and control – are presented, and the alternative instruments corresponding to these approaches are analysed and evaluated. Environmental pollution in this framework is assumed to be of the flow or fund type. For this type of pollution the assimilating capacity of the environment is such that it does not allow the accumulation of pollutants. Thus pollution generates damages only in the period emitted and not in subsequent periods. Examples of fund or flow pollution include smoke; noise; organic pollutants that can be transformed by bacteria, in an oxygen-rich environment, into substances that are not harmful. Considering flow type pollution allows for the use of a static analytical framework that greatly simplifies exposition.

Another feature of this chapter is that the only distortion considered is the environmental externality. This implies that only one instrument is required to correct the distortion. When more distortions, such as informational asymmetries or market imperfections, are included along with the environmental externality, then more complex instruments become necessary.

2 INDUSTRIAL POLLUTION AND THE SOCIAL OPTIMUM

The development of policy instruments capable of securing the socially- desirable level of pollution implies that an environmental regulator, or more generally a social planner, chooses pollution levels by maximizing a criterion function. This is given by a social welfare function, defined on environmental variables along with the other relevant choice variables. The social optimum determines optimal pollution and provides the benchmark for comparisons with unregulated market equilibrium. These comparisons in turn determine the appropriate environmental policy instruments.

Three alternative approaches are used in this section to characterize the social optimum. All three are equivalent; each of them, however, highlights different aspects of the problem and allows an alternative interpretation of the optimality conditions. The alternative models developed in this section will also prove useful in the subsequent extensions, since these extensions can be presented more clearly by using alternative ways to model the problem of the social planner and the firms. The three models are: first, the social planner chooses emissions using derived damage and profit functions; second, the choice is over output production and pollution abatement; and third, the choice is strictly over inputs that can be used for either production or for pollution abatement.

2.1 Descriptive Models of Industrial Pollution and Social Damages

We start the exposition by considering a market of $i=1,\dots,n$ firms that behave competitively. The firms produce a homogeneous output q_i and during production generate emissions e_i. Let $x_i=(x_{i1},\dots,x_{iM})$ be a vector of M inputs. Some of these inputs can be used for pollution abatement. Then the production possibility set is a set of all (q_i, e_i, x_i)

combinations that are technically feasible given the structure of the technology.

A derived profit or derived benefit function can be defined as:

$$B_i(e_i) = \max_{q_i \geq 0} \pi_i = \max_{q_i > 0} \left[pq_i - c_i(q_i, e_i)\right], \; B_i^{\prime\prime}(e_i) < 0 \tag{B}$$

where p is the exogenously determined output price, and $c_i(q_i,e_i)$ is a convex cost function decreasing in e_i. A reduction in emissions will increase costs since this involves the use of resources for pollution abatement. The cost function is defined as:

$$c_i(q_i, e_i) = \min_{x_i \geq 0} \; w \cdot x_i$$

$$\text{s.t.} \quad G_i(q_i, e_i, x_i) \leq 0$$

where w is the vector of competitive input prices and $G_i(\cdot\,,\cdot\,,\cdot)$ is a product transformation function of outputs and inputs.

It will prove convenient in many cases to consider a specification of the production-emission technology in terms of an emission function, and abatement. Let $e_i = s_i(q_i, \alpha_i)$ be an emission function, where α_i denotes the level of abatement activity. This function is assumed to be increasing in output and convex for any given abatement activity level, and decreasing in abatement activity and convex for any given output level. Convexity with respect to abatement means that successive increases in this activity reduce emissions at a decreasing rate, reflecting diminishing returns in the pollution treatment process.

Let $c_i(q_i, \alpha_i)$ be a convex cost function defined as:

$$c_i(q_i, \alpha_i) = \min_{x_i \geq 0} \; w \cdot x_i$$

$$\text{s.t.} \quad f(x_i) \geq q_i$$

$$h_i(x_i) \geq \alpha_i$$

where $f_i(x_i)$ is a twice-differentiable and strictly concave production function, while $h_i(x_i)$ is a twice-differentiable and strictly concave function indicating the efficient abatement level associated with any given input vector. Given the emission and cost functions the firm's profit is defined in terms of output and abatement as:

$$\pi_i(q_i, \alpha_i) = pq_i - c_i(q_i, \alpha_i) - \tau(e_i) \tag{QA}$$

where $\tau(e_i)$ reflects private emission-related costs, which can be attributed to the existence of environmental policy.

A further specification of the technology can be made in terms of production, emission and abatement functions. Let there be a partition of the inputs into a vector of m productive and emission-generating inputs $x_i^p = (x_{1i}^p, \ldots, x_{mi}^p)$, and a vector of M-m abatement inputs $x_i^a = (x_{m+1}^a, \ldots, x_{Mi}^a)$. Define the production and abatement functions as the twice-differentiable and strictly concave functions $q_i = f_i(x_i^p)$, $a_i = h_i(x_i^a)$ respectively and the twice- differentiable and strictly convex emission function $e_i^G = s_i(x_i^p)$. Then net emissions released in the ambient environment are defined as $e_i^G - \alpha_i$. The firm's profit is defined in terms of inputs as:[1]

$$\pi_i(x_i^p, x_i^\alpha) = p f_i(x_i^p) - w^p \cdot x_i^p - w^\alpha \cdot x_i^\alpha - \tau\left(s_i(x_i^p) - h_i(x_i^\alpha)\right) \tag{I}$$

where w^p and w^α are the competitive input prices, and as before $\tau(e_i^G - \alpha_i)$ reflects private emission-related costs.

Having described the production-emission structure of the technology the next step is to define social damages due to pollution. Since a nondepletable externality is considered, the consumers are affected by the total amount of emissions generated by the firms. Let $E = \sum_{i=1}^n e_i$ be total emissions generated. Assume that the utility function of the jth individual, $j=1,\ldots,J$, is defined with respect to a vector of N traded goods $c_j = (c_{1j}, \ldots, c_{Nj})$, and total emissions E. The derived utility function over total emissions, when a consumer with wealth W_j maximizes his/her utility by purchasing the traded goods at a price $\varrho = (\varrho_1, \ldots, \varrho_N)$, is defined as:

[1] There are formulations where emissions are treated as an input in the production process. In this case the production function takes the form $q_i = f_i(x_i, e_i)$.

$$v_j(\varrho, W_j, E) = \max_{c_j \geq 0} \; u_j(c_j, E)$$

$$\text{s.t.} \;\; \varrho \cdot c_j \leq W_j$$

Assuming a quasi-linear utility function in a numeraire commodity the derived utility function can be written, following Mas-Colell et al. (1995), as:

$$v_j(\varrho, W_j, E) = \varphi_j(E)$$

where we assume that φ_j is twice-differentiable with $\varphi_j^{/} < 0$, and $\varphi_j^{//} < 0$. Define the individual damage function for the jth consumer as $d_j(E) = -\varphi_j(E)$. Social damages can then be defined as the sum of individual damages:

$$D(E) = \sum_{j=1}^{J} d_j(E), \;\; E = \sum_{i=1}^{n} e_i \tag{D}$$

The social damage function is a strictly increasing and strictly convex function.

2.2 Social Optimum and Suboptimality of Competitive Markets

The above framework, describing production-emission technology and social damages, can be used to analyse the problem of the social planner or environmental regulator. The social planner seeks to determine the levels of a set of choice variables such that social welfare, which includes environmental damages, is maximized. The problem of the social planner is solved for the three alternative models describing technology.

2.2.1 Emission choice model (ECM)

Social welfare is defined as total benefits from production less social damages from emissions. Using the derived profit function (B) and the social damage function (D) the social planner solves the problem:

$$\max_{(e_1, \ldots, e_n) \geq 0} \; \sum_{i=1}^{n} B_i(e_i) - D(E), \;\; E = \sum_{i=1}^{n} e_i \tag{ECM}$$

which has necessary and sufficient first-order conditions for the socially-optimal emissions e_i^* generated by the ith firm:

$$B_i^{/}(e_i^*) - D^{/}(E^*) \leq 0, \text{ with equality if } e_i^* > 0 \tag{2.1}$$

Thus when positive emissions are generated marginal benefits equal marginal social damages. Since $D^{/}(E^*) = \sum_{j=1} d_j^{/}(E^*)$, which is the sum of the consumers' marginal damages from emissions, condition (2.1) is Samuelson's optimality condition for a public bad.

3 STANDARD ENVIRONMENTAL POLICY INSTRUMENTS

Given the suboptimality of the unregulated competitive markets, the social planner can correct this distortion in the full information competitive context using a number of environmental policy instruments which internalize external social damages.

Environmental policy instruments can be divided into two broad categories: economic incentives or market-based instruments, and direct regulation or command and control approaches. Following the OECD classification, economic instruments include environmental or emission charges or taxes, marketable or tradeable emission permits, output taxes, deposit–refund systems, performance bonds and voluntary agreements. Along with taxes, the case of subsidies can also be included. On the other hand, command and control approaches include the use of limits on output, inputs, emissions or technology at the firm level. The polluting firms are required to set outputs, inputs or emissions at some prespecified level, or they are required not to exceed (or fall short of) certain predefined levels. This form of direct regulation is popular among decision-makers; however, since the early 1980s, economic instruments – which have been advocated by economists for a number of decades – have started gaining popularity in the management of environmental pollution.

3.1 Emission Taxes

The polluting firms fully internalize external social damages if they are confronted with an emission tax per unit of waste released in the ambient environment, equal to marginal social damages. This price incentive for emission control is the well-known 'Pigouvian tax' or 'effluent fee'.

Let the emission tax τ be defined as $\tau = D'(\sum_{i=1}^{n} e_i^*)$ and consider the ECM model. The firm solves the problem:

$$\max_{e_i \geq 0} B_i(e_i) - \tau e_i$$

with necessary and sufficient first-order conditions

$$B_i'(e_i^o) \leq \tau, \text{ with equality if } e_i^o > 0 \qquad (2.5)$$

Since $\tau = D'(\sum_i e_i^*)$, it can be seen by comparing (2.5) to (2.1) that the emission tax leads to the socially-optimal emissions for firm i, that is $e_i^o = e_i^*$.

The same result can be obtained by using the OACM or the ICM. In both of these models the firm solves:

$$\max_{(q_i, \alpha_i) \geq 0} pq_i - c(q_i, \alpha_i) - \tau e_i, \; e_i = s_i(q_i, \alpha_i) \qquad (2.6.1)$$

$$\max_{(x_i^p, x_i^\alpha) \geq 0} pf(x_i^p) - w^p \cdot x_i^p - w^\alpha \cdot x_i^\alpha - \tau\left[s_i(x_i^p) - h_i(x_i^\alpha)\right] \qquad (2.6.2)$$

By taking the first-order conditions it can be shown that for $\tau = D'$:

$$\text{from (2.6.1) } \{q_i^o = q_i^*, \; \alpha_i^o = \alpha_i^*\} \Rightarrow e_i^o = e_i^*$$

$$\text{from (2.6.2) } \{x_i^{op} = x_i^{*p}, \; x_i^{o\alpha} = x_i^{*\alpha}\} \Rightarrow e_i^o = e_i^*$$

Furthermore in the long run, the Pigouvian tax provides the correct incentives for entry assuming symmetric firms. The zero profit condition for long-run equilibrium using the OACM under the Pigouvian tax is:

$$P(nq)q - c(q, \alpha) - F - \tau s(q, \alpha) = 0$$

It is clear that by adding this constraint to the optimality conditions of problem (2.6.1) and setting $\tau = D'(n^* e^*)$, the optimal allocation under the regulated market equilibrium will reproduce the socially-optimal allocation, or $(q^o, \alpha^o, n^o) = (q^*, \alpha^*, n^*)$.

3.1.1 General equilibrium considerations

In the previous section the optimal emission tax was determined in the context of a partial equilibrium framework. However, environmental taxes when imposed will have to coexist with other taxes in the economy. When environmental taxes are considered in the broader framework of the economy as a whole, two interrelated issues arise. The first relates to determining the optimal emission tax in the presence of other distortionary taxes in the economy, including commodity and labour taxes. The second relates to whether the gross efficiency cost of emission taxes is reduced when tax revenues are used to lower existing distortionary taxes.

The choice of an optimal emission tax either equal to or less than environmental damages can be regarded as an efficient instrument for environmental protection. It has been argued, however, that in the presence of other distortionary taxes in the economy environmental taxes may result in benefits over and above benefits associated with environmental protection. These benefits are associated with the way in which tax revenues are recycled in the economy and in particular with the possibility of reducing distortionary taxation in the economy. As noted by David Pearce the use of environmental taxes to reduce distortionary taxes in a revenue neutral way could result in two benefits. The first benefit relates to environmental protection while the second relates to the distortionary cost of the tax system. Several meanings have been attached to the double dividend claim:

(i) Benefits exist when tax revenues from environmental taxes are used to reduce distortionary taxation as compared to the case where tax revenues are returned to tax payers in a lump-sum fashion.

(ii) There are zero costs or even benefits if tax revenues are used to reduce typical or representative distortionary taxes.

(iii) The revenue neutral swaps raise the welfare gains from environmental taxes.

(iv) The revenue neutral swap produces a second dividend in the form of higher employment or profits.

The idea of a double dividend, especially in the strong form or in the form of an employment double dividend, is especially appealing to policy makers since it implies that environmental taxes could be introduced without any cost and therefore there is no need to justify them in terms of uncertain environmental benefits. Theoretical and empirical research does not seem however to support the idea of a double dividend in its strong form or in its employment form. In particular the double dividend hypothesis holds only in the weak form but not in general for the other forms. Two effects are present when a revenue neutral tax swap takes place. The first is the revenue effect which reflects welfare gains from reducing distortionary taxes, and the second is the interdependence effect which reflects the likely increase of preexisting tax distortions due to the introduction of environmental taxes that also create extra costs. The extra costs are mainly due to losses of revenue and efficiency in labour and capital markets if environmental taxes discourage employment and investment. These two effects work in different directions with the interdependence effect exceeding the revenue effect under plausible parameters values..

Based on these results it seems that although the concept of a second dividend and the consequent 'no cost' introduction of environmental taxes is appealing to policy-makers, the difficulty in establishing the strong double dividend hypothesis – especially when the existing tax system is suboptimal – suggests that the environmental benefits of emission taxes is a crucial factor in justifying their introduction.

3.2 Subsidies

A subsidy scheme involves payments to the firm for reducing emissions below a given benchmark. Denoting this benchmark by $\bar{e}_i$, a linear subsidy scheme is defined as $v(\bar{e}_i - e_i)$, where v is the subsidy per unit reduction of emissions below the benchmark level. Under the subsidy scheme the firm solves the problem:

$$\max_{(q_i,\alpha_i)\geq 0} \; pq_i - c_i(q_i,\alpha_i) + v(\bar{e}_i - e_i), \quad e_i = s_i(q_i,\alpha_i)$$

Since the firm's objective function under the subsidy scheme differs from the corresponding objective function under taxes only by the constant $v\bar{e}_i$, a subsidy equal to marginal social damages evaluated at the optimal emission level will induce firms to emit at the social optimum, e_i^*.

Although taxes and subsidies offer the same marginal incentives for emission reductions, they differ with respect to their effects on long-run pollution. This is because they affect the long-run entry–exit decisions of firms differently.

The long-run market equilibrium condition under the subsidy scheme, assuming again symmetric firms, is:

$$P(nq)q - c(q,\alpha) - F + v\bar{e} - ve = 0$$

If we set $v = D'(n^* e^*)$, it is clear that under the subsidy scheme a larger number of firms will enter the market than under the Pigouvian tax. Thus the Pigouvian tax leads to a reduction in the industry size relative to the unregulated equilibrium, while a subsidy leads to an increase in the industry size. It is possible that the increase in the industry size under the subsidy scheme could lead to an increase in total emissions in the long run.

3.3 Tradeable Emission Permits

Tradeable or marketable emission permits represent a system of tradeable property rights for the management of environmental pollution. Tradeable permits involve the determination of a total level of allowable emissions and then distribution of these permits to the firms. After their initial distribution, permits can be traded subject to a set of prescribed rules.

Permits can be allocated by means of an auction or by initiating a 'grandfathering' system which allocates permits on the basis of the past emission records of firms. Let $e^* = \sum_i e_i^*$ be the total number of permits issued by the environmental regulator and let $\tilde{e}_i$ with $\sum_i \tilde{e}_i = e^*$ be the initial permits holding of firm i. After the initial distribution, firm i's net demand for permits is $(e_i - \tilde{e}_i)$, $e_i = s_i(q_i,\alpha_i)$. Assuming competitive markets for permits, the firm is a price taker in the permits market and solves the problem:

$$\max_{(q_i,\alpha_i)\geq 0} \; pq_i - c_i(q_i,\alpha_i) - P^T\left[s_i(q_i,\alpha_i) - \tilde{e}_i\right] \tag{2.7}$$

where P^T is the equilibrium price for permits. The necessary and sufficient first-order conditions for the profit-maximizing choices q_i^o, a_i^o imply:

$$p-\frac{\partial c_i}{\partial q_i}-P^T\frac{\partial s_i}{\partial q_i}\leq 0, \text{ with equality if } q_i^o>0 \tag{2.8.1}$$

$$-\frac{\partial c_i}{\partial \alpha_i}-P^T\frac{\partial s_i}{\partial \alpha_i}\leq 0, \text{ with equality if } \alpha_i^o>0 \tag{2.8.2}$$

The above conditions determine the profit-maximizing output, abatement and emissions as functions of the output and the permit prices, or $q_i^o=q_i^o(p,P^T)$ and $\alpha_i^o=\alpha_i^o(p,P^T)$, $e_i^o=s_i(q_i^o,a_i^o)$. The aggregate demand for permits is defined as $e^o(P^T)=\Sigma_i e_i^o(P^T)$, suppressing p.

The impact of changes in the price of permits on output, abatement and demand for permits can be obtained by comparative static analysis of system (2.8) for interior solutions.
Thus

$$\frac{\partial q_i^o}{\partial P^T}=\frac{P^T(-s_{q_i}s_{\alpha_i\alpha_i}+s_{\alpha_i}s_{\alpha_i q_i})}{D}<0$$

$$\frac{\partial \alpha_i^o}{\partial P^T}=\frac{-s_{\alpha_i}c_{q_i q_i}+s_{q_i}c_{\alpha_i q_i}}{D}>0$$

where $D=P^T(c_{q_iq_i}s_{\alpha_i\alpha_i}-s_{\alpha_iq_i}c_{\alpha_iq_i})>0,\ c_{q_iq_i},\ s_{\alpha_i\alpha_i}>0,\ s_{\alpha_iq_i}>0,\ c_{\alpha_iq_i}>0$

Therefore an increase in the price of permits will reduce output and increase abatement. Furthermore both the individual demand for permits and the aggregate demand for permits are downward sloping, since the slope of the aggregate demand for permits is determined as:

$$\frac{\partial e^o}{\partial P^T}=\sum_{i=1}^{n}\left[\frac{\partial s_i^o}{\partial q_i}\frac{\partial q_i^o}{\partial P^T}+\frac{\partial s_i^o}{\partial \alpha_i}\frac{\partial \alpha_i^o}{\partial P^T}\right]<0$$

In equilibrium the price P^T clears the permits market, that is:

$$\Sigma_i(e_i^o-\tilde{e}_i)=0 \text{ or } \Sigma_i s_i^o\left(q_i^o(p,P^T),\alpha_i^o(p,P^T)\right)=\Sigma_i e_i^o=\Sigma_i\tilde{e}_i=e^*$$

It follows then by comparing (2.8.1) and (2.8.2) with the first-order conditions of problem (2.6.1) that the competitive equilibrium permit price is $P^T=D'(e^*)$. The market creates the correct incentive for firms which emit at the socially-optimum level e_i^*.

The equilibrium in the permit market is shown in Figure 2.1, where BB is the aggregate demand for permits. If the total issued number of permits is e^* and the individual demands for permits are B_1B_1 and B_2B_2, for two firms, then permits are finally allocated to each firm according to e_1^*, e_2^*. If the total quantity of permits is chosen optimally, at the point where the marginal damage function $D'(e)$ intersects the demand for permits, then the social optimum is achieved. This solution is equivalent to the Pigouvian tax solution, since problem (2.7) is equivalent to problem (2.6.1) because the objective functions differ only by a constant. Thus firms' emissions in the tax problem is a function of the tax rate in the same way as demand for permits is a function of the permit price, with both reflecting marginal benefits from emissions. So the Pigouvian tax determined at the intersection of the marginal damage function with the market demand for emissions equals the equilibrium permit price.

Assuming as before symmetric firms and positive fixed costs for the new entrants, the zero profit condition under permits can be written as:

$$P(nq)q-c(q,\alpha)-F-P^Ts(q,\alpha)$$

for $P^T=D'(e^*)=\tau$, the socially-optimal long-run allocation is obtained.

3.4 Deposit–Refund Systems

In a deposit–refund system the main target is the avoidance of pollution by returning potentially-polluting products or their residuals. Under this system a deposit is paid on the potentially-polluting product and the refund follows upon the return of the product. There is considerable experience in market-generated deposit–refund systems mainly because of factors such as reuse value (beverage containers), recycle value (lead batteries), or more generally the avoidance of some charges imposed on the potential polluter's production.

The choices involved in a deposit–refund system can be described with the help of a simplified model. Let $B_i(e_i)$ be the derived benefit function for the ith firm with e_i interpreted as pollution, or as the production of the polluting output that contains a fixed proportion of pollution. It is assumed that the firm pays a tax τ per unit of produced e_i less the returned units. It is assumed that the return rate is a function of the refund offer R, defined as $r(R)$ with $r \in [0,1]$, $r(0)=0$, $r'(R) \geq 0$, $r''(R) \leq 0$. Assume to simplify things that individuals who can return the polluting product have zero disposal and return costs, and finally assume that the returned product has a reuse value v. The firm chooses output e_i and the refund offer R to maximize profits, or:

$$\max_{(e_i, R) \geq 0} \; B_i(e_i) - \tau e_i\left[1 - r(R_i)\right] + r(R_i)(v - R_i)e_i$$

with necessary and sufficient first-order conditions:

$$B_i'(e_i^o) - \tau\left[1 - r(R_i^o)\right] + r(R_i^o)(v - R_i^o) \leq 0, \text{ with equality if } e_i^o > 0 \qquad (2.9.1)$$

$$r'(R_i^o)(\tau + v - R^o) - r(R_i^o) \leq 0, \text{ with equality if } R_i^o > 0 \qquad (2.9.2)$$

From (2.9.2) the firm will make a positive refund offer if tax savings plus the reuse value are sufficiently large. The optimal offer is determined at the point where marginal refund gains net of refund expenses equal the refund rate. Using the implicit function theorem in (2.9.1) and (2.9.2), comparative statics indicate that an increase in the tax rate will induce higher return rates, through the increase of the refund offer, or:

$$\frac{dR}{d\tau} = \frac{-r'}{r''(\tau + v - R) - 2r'} > 0$$

Consider now the case of a regulator who introduces a deposit–refund system. The regulator's problem is:

$$\max_{(e_i, R) \geq 0} \; \sum_{i=1}^{n} B_i(e_i) - D\left(\left(1 - r(R_i)\right)E\right) + r(R_i)(v - R_i)E, \quad E = \sum_i e_i$$

with necessary and sufficient first-order conditions

$$B_i'(e_i^*) - D'\left[(1 - r(R))\right] + r(R^*)(v - R^*) \leq 0, \text{ with equality if } e_i^* > 0$$

$$r'(R^*)(D' + v - R^*) - r(R^*) \leq 0, \text{ with equality if } R^* > 0$$

which have a similar interpretation as conditions (2.9). By comparing the optimality conditions for the regulator with the corresponding conditions for profit maximization, the optimal tax is defined as $\tau = D'$.

3.5 Output Taxes

Output or product taxes (or charges) are taxes levied on products that are environmentally harmful when used in production or consumption processes or when consumed. Output taxes are sometimes confused with Pigouvian taxes, although they are levied on the output in contrast to the Pigouvian taxes which are levied on emissions. As can be shown, the equivalence of the output and the Pigouvian taxes holds only in the special case of a single input production function.

Assume a single input production process, $q = f(x^p)$ where $e = s(x^p) = s(f^{-1}(q)) = z(q)$. The regulator, assuming identical firms, solves the problem:

$$\max_{x^p > 0} \; \int_0^{nf(x^p)} P(Q)dQ - nw^p x^p - D(ne)$$

with necessary and sufficient first-order conditions for interior solutions:

$$p\frac{\partial f(x^{*p})}{\partial x^p} - w^p - D'\frac{s'(x^{*p})}{f'(x^{*p})}f'(x^{*p}) = 0 \qquad (2.4.1.a)$$

On the other hand the firm solves the problem:

$$\max_{x^p \geq 0} \; pf(x^p) - w^p x^p - \tau f(x^p) \tag{2.10}$$

with necessary and sufficient first-order condition for interior solution $(p-\tau)f'(x^{op}) = w^p$. If the output tax is set as $\tau = [D's'(x^{*p})]/[f'(x^{*p})]$, then the first-order condition for the firm implies $pf'(x^{op}) = w^p + D's'(x^{op})$, or that the marginal value product of the input equals the marginal social cost, which is the same as condition (2.4.1) or (2.4.1.a) for the social optimum. Thus the output tax is optimal.

However this optimality condition does not hold when the input space is increased.

3.6 Performance Bonds and Noncompliance Fees

Performance bonds are payments by potential polluters to authorities before an operation that could be harmful to the environment begins, in anticipation of compliance by the polluter to the environmental regulation associated with the activity. If compliance takes place, payments are refunded. Otherwise the initial payment (bond) is forfeited. The limited use of performance bonds in environmental policy design can be attributed to imperfect monitoring of polluting activities, liquidity constraints, and legal restriction in contracting.

Noncompliance fees, on the other hand, are applied when polluters do not comply with the environmental regulation. The key issue here is that the rate of the fees is proportional to the benefits that the polluter achieves by not complying with the environmental regulation. The administering of noncompliance fees might be impeded by measurement problems and legal restrictions regarding profits from noncompliance.

3.7 Voluntary Agreements

Voluntary agreements are a relatively new instrument of environmental policy. A voluntary agreement is a result of negotiations between the government or an environmental regulator on the one hand, and potential polluters on the other. Reductions of emissions are obtained through an agreement that can take the form of a contract. In the contract, the firm agrees to achieve an environmental target such as emissions reduction through changes in investment patterns, technological change or waste treatment. In exchange the firm could receive subsidies in order to change its technology.

The use of voluntary agreements can mainly be justified in cases in which the target is to obtain environmental protection through technological innovation, especially in cases where market imperfection exists, or when environmental innovation has positive spillovers.

3.8 Command and Control Regulation: Performance and Design Standards

Under command and control the regulator specifies an emission limit for the firm. The firm then adjusts output or abatement so that the standard is achieved. Let $\bar{e}_i$ be the maximum allowable emission for firm i. The firm chooses output and abatement to solve the problem:

$$\max_{(q_i,\alpha_i) > 0} \; pq_i - c_i(q_i,\alpha_i) \quad \text{s. t. } e_i \leq \bar{e}_i, \; e_i = s_i(q_i,\alpha_i) \tag{2.13}$$

The Lagrangean function for this problem is defined as:

$$\mathfrak{L} = pq_i - c_i(q_i,\alpha_i) + \lambda_i\left[\bar{e}_i - s_i(q_i,\alpha_i)\right]$$

The Kuhn-Tucker conditions imply that if (q_i^o, a_i^o) solve the maximization problem (2.13), then a Lagrangean multiplier $\lambda_i \geq 0$ exists such that:

$$p-\frac{\partial c_i(q_i^o,\alpha_i^o)}{\partial q_i}-\lambda_i\frac{\partial s_i(q_i^o,\alpha_i^o)}{\partial q_i}\le 0,\ \text{with equality if } q_i^o>0 \tag{2.14.1}$$

$$-\frac{\partial c_i(q_i^o,\alpha_i^o)}{\partial \alpha_i}-\lambda_i\frac{\partial s_i(q_i^o,\alpha_i^o)}{\partial \alpha_i}\le 0,\ \text{with equality if } \alpha_i^o>0 \tag{2.14.2}$$

$$\bar{e}_i-s_i(q_i^o,\alpha_i^o)\ge 0,\ \lambda_i\left[\bar{e}_i-s_i(q_i^o,\alpha_i^o)\right]=0,\ \lambda_i\ge 0 \tag{2.14.3}$$

For strictly increasing cost function with respect to abatement and strictly decreasing emission function with respect to abatement, $\lambda_i>0$ from (2.14.2). Thus the emission constraint is always satisfied as equality and it will be optimal for the firm to discharge up to the allowed emission limit. Using the envelope theorem, λ can be interpreted as the shadow cost of the emission limit indicating the marginal change in profits from increasing the stringency of the emission standard. If the limit $\bar{e}_i$ is set at the welfare maximizing level e_i^*, the command and control approach is equivalent to emission charges.

This type of regulation where the actual emissions are the objective of direct regulation is called performance standard. A performance standard leaves the firm maximum freedom to comply with the standard by either reducing output or by increasing abatement, but requires individual monitoring and knowledge of compliance costs. If emission monitoring is expensive or technically infeasible then the regulator could require the use of a specific technology. This type of regulation is called a design standard.

Design standards can be specific or general. A specific design standard for a firm manufacturing tyres and creating hazardous creosote in the process, could be the requirement that the firm use a specific procedure for disposing of or storing hazardous wastes. On the other hand a performance standard would require that the firm generate creosote below a prespecified level. More general design standards may require potential polluters to apply 'best practice' or 'best available' technology.

Let $\bar{\alpha}_i>0$ be the minimum required abatement to use the specific design. The problem for the firm is:

$$\max_{q_i\ge 0,\alpha_i} pq_i-c_i(q_i,\alpha_i)$$

$$\text{s t. } \alpha_i\ge\bar{\alpha}_i$$

The necessary and sufficient conditions imply that $(q_i^o,\alpha_i^o,\mu_i)\ge 0$ exists such that:

$$p-\frac{\partial c_i(q_i^o,\alpha_i^o)}{\partial q_i}\le 0,\ \text{with equality if } q_i^o>0 \tag{2.15.1}$$

$$-\frac{\partial c_i(q_i^o,\alpha_i^o)}{\partial \alpha_i}+\mu_i\le 0,\ \text{with equality if } \alpha_i^o>0 \tag{2.15.2}$$

$$(\alpha_i^o-\bar{\alpha}_i)\ge 0,\ \mu_i(\alpha_i^o-\bar{\alpha}_i)=0,\ \mu_i\ge 0$$

From (2.15.2), $\mu_i>0$ for interior solutions and thus the constraint is always binding, that is $\alpha_i^o=\bar{\alpha}_i$. From (2.15.1) output is determined as $q_i^o=q_i(\bar{\alpha}_i)$ and emissions under the standard are determined as $e_i=s_i(q_i(\bar{\alpha}_i),\bar{\alpha}_i)=s_i(\bar{\alpha}_i)$. Therefore there is a direct relationship between the design standard and emissions. If the regulator sets an emission target, e_i^+, then the optimal design standard for this target is defined as $\alpha_i^+=s_i^{-1}(e_i^+)$.

Although by choosing the emission target and the abatement level a performance standard and a design standard both lead to the same emission level, the output abatement combinations are different in the two cases. By comparing (2.14.1) to (2.15.1) it can be seen that output under the performance standard is lower than output under the design standard since in the former case there is an extra implicit marginal output cost, $\lambda(\partial s/\partial q_i)$, that reduces output as compared to the design standard case. This discrepancy reveals the qualitative difference between the two regulatory approaches. The performance standard provides more flexibility for the firm since it can reduce output instead of increasing abatement to achieve the emission standard. This substitution is not however possible under the design standard.

4 ENVIRONMENTAL POLICY UNDER PRODUCTION EXTERNALITIES

The analysis in the previous sections focused mainly on cases in which emissions generated by firms during the output production process caused damages to individual consumers who have preferences defined over commodities and environmental quality.

There are, however, cases in which pollution generated by a firm negatively affects the production process of other firms, thereby creating a detrimental externality in production. This can be associated with the standard textbook case of an upstream pollution-generating firm and a downstream pollution-receiving firm, or a more general set-up where emissions generated by each producer adversely effect the production functions of all the producers in a given sector. This latter case can be associated for example with agricultural production, in which the use of polluting inputs such as fertilizers or pesticides creates agricultural run-off that pollutes surface or groundwater used for irrigation. This reduction in the quality of irrigation water adversely affects the production of each farmer.

In the upstream–downstream case, let firm 1 be an upstream firm that uses input x_1 to produce output according to the production function $f_1(x_1)$. The firm sells its output and buys an input at competitive prices, p_1 and w_1, respectively. The use of the input creates pollution according to the strictly increasing and convex emission function, $e_1=s(x_1)$. Consider for example the case where the upstream firm is a factory that contaminates a river, while the downstream firm is a cattle breeder who uses the river to provide water to his animals. The downstream firm which suffers from the detrimental externality has a production function defined as $g(x_2,Q)$, where Q is an index of water quality. Let $Q=Q(e_1)$ with $Q'<0$. Then firm 2's production function can be written as $f_2(x_2,e_1)$ with $\partial f_2/\partial e_1<0$.

In the unregulated equilibrium, firm 1 solves the problem:

$$\max_{x_1} \; p_1 f_1(x_1)-w_1 x_1$$

and chooses the optimal input x_1^o such that $p_1 f_1'(x_1^o)=w_1$ and thus $e_1^o=s(x_1^o)$. In maximizing its profits firm 2 treats the emissions of firm 1 as given, thus solving the problem $\max_{x_2} \; p_2 f_2(x_2,e_1^o)-w_2 x_2$. Optimal input is chosen according to the first-order condition such that $p_2 f_2'(x_2^o,e_1^o)=w_2$, or $x_2^o=x_2^o(e_1^o)$.

When the regulator's problem is examined, the objective is to maximize social profits, that is, total profits less any other environmental damages from emissions, defined as $D(e_1)$.[2] Thus the regulator solves the problem:

$$\max_{x_1,x_2} \left[p_1 f_1(x_1)-w_1 x_1\right]+\left[p_2 f_2(x_2,e_1)-w_2 x_2\right]-D(e_1), \; e_1=s(x_1)$$

The first-order conditions for an interior maximum are:

$$p_1 f_1'(x_1^*)-p_2\frac{\partial f_2}{\partial e_1}e_1'(x_1^*)-D'e_1'(x_1^*)=w_1 \qquad (2.16.1)$$

$$p_2\frac{\partial f_2(x_2^*)}{\partial x_2}=w_2 \qquad (2.16.2)$$

By comparing the unregulated solution with the regulator's solution it is clear that in the latter case firm 1 uses less of the polluting input, since in choosing the optimal level for x_1 the regulator equates the input's marginal value product with the marginal social cost that includes private costs plus the cost imposed on firm 2 plus the other marginal environmental damages. The regulator's optimum can be achieved by introducing a Pigouvian tax equal to aggregate marginal external damages, or $\tau=p_2(\partial f_2/\partial e_1)e_1'(x_1^*)+D'e_1'(x_1^*)$. The same outcome can be achieved in a command and control framework using a performance standard such as firm 1's emissions that will not exceed $e_1(x_1^*)$.

5. BARGAINING SOLUTIONS FOR ENVIRONMENTAL EXTERNALITIES

In the previous sections a number of policy instruments were examined which, when applied, could lead to the socially-optimal pollution level. This approach can be regarded as the traditional one, stemming directly from Pigou's (1938) *The Economics of Welfare*. According to this approach the divergence between private and social costs can be breached by imposing a tax on the party that creates the environmental damage, or by imposing other

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[2]Environmental damages in addition to those suffered by firm 2 can be associated with the pollution of the river which is used by individuals for recreational purposes. However the presence of these costs is not essential to the rest of the argument.

equivalent measures. In the classical example of a factory generating smoke that has harmful effects on individuals living nearby, the Pigouvian tradition would support the decision to make the owner of the factory liable for the damages created by the smoke and impose a tax that varies with smoke or equivalent damages, or restrict the creation of smoke, or even exclude the factory from residential areas. This type of reasoning led to the development of the different policy instruments that were described in the previous sections.

This approach was challenged by Coase who argued that 'the suggested [by the Pigouvian tradition] courses of action are inappropriate, in that they lead to results which are not necessarily, or even usually, desirable.' Coase's criticism lies in the fact that if, given two parties – say 1 and 2 – party 1 inflicts harm on party 2 by generating a detrimental externality, the Pigouvian tradition focuses on deciding how much party 1 should be restrained. According to Coase, by restraining party 1 in order to avoid harming party 2, party 1 is also harmed. Thus the problem is to decide on a policy, by weighing both harms involved: the harm to 2 from 1's activities and the harm to 1 from the restriction of its activities in order to reduce the harm to 2.[3] As Coase suggests, the decision should be guided by comparing the value of what is obtained by restricting a certain activity with the value of what is sacrificed by the restriction of the activity. This approach leads to bargaining processes among the parties in order to reach an optimal agreement on the level of the environmental externality. This optimal agreement can secure, under certain circumstances, a Pareto optimal solution without any need for regulation.

In order for this private bargaining process – which has come to be known as the Coase theorem – to take place, a basic requirement is the existence of well-defined and enforceable property rights or, as is more suitable in our analysis, well-defined and enforceable environmental rights. Well-defined property rights means that party 1 has to obtain party 2's permission in order to generate the externality that affects party 2, or that party 2 has the right not to accept the imposition of the externality by party 1.[4] Enforceable rights mean that the level of the externality, that is emission of pollutants, can be measured; otherwise there is no incentive to bargain for the right to emit a certain level of pollutants. Coase's theorem ascertains that in the presence of well-defined and enforceable property rights, the optimal solution can be achieved through private negotiations, irrespective of who owns the property rights (Figure 2.2).

6 UNCERTAINTY AND THE CHOICE OF POLICY INSTRUMENTS

The previous section indicated that the presence of uncertainty impedes the achievement of the optimal outcome through a bargaining solution. In this section the impact of uncertainty is examined with respect to the traditional environmental policy instruments. As has already been shown, under certainty environmental policy instruments are equivalent irrespective of whether they take the form of price instruments such as emission taxes or quantity instruments such as emission limits or quotas related to tradeable permits. Weitzman showed however that the equivalence does not hold under conditions of uncertainty.

In our framework uncertainty takes in general two forms. The first refers to uncertainty at the level of the firm that manifests itself through the firm's reduced profit or benefit function, emission function or abatement function. This is mainly technological uncertainty associated with uncertain pollutant content of inputs used in production (such as sulphur content of fuels), effects on abatement technology, learning effects in cleaning up procedures, price of abatement inputs and so on. The second refers to the social damage function and is associated with the inability to measure pollution damages with sufficient accuracy or with general uncertainties with respect to climatic conditions (for example, uncertainties regarding the increase in global temperature from the emissions of greenhouse gases) that affect social damages for any given level of emitted pollutants.

Considering these two types of uncertainty at the environmental regulator's level, the benefit function for the firm can be written as $B_i(e_i,\theta)$ where $\theta \in \Re$ has a distribution function $F(\theta)$ which is known to the regulator, while the damage function can be written as $D(e,\eta)$, $e=\sum_i e_i$ with $G(\eta)$, $\eta \in \Re$ being the distribution function for η. Thus θ denotes the first type of uncertainty while η denotes the second type. Total welfare in this case depends on the values of θ and η and can be written as $\sum_i B_i(e_i,\theta)+D(e,\eta)$. Thus the emission levels that maximize welfare can be defined as $e_i^* = e^*(\theta,\eta)$ where $B_i'(e^*(\theta,\eta),\theta) = D'(e^*(\theta,\eta),\eta)$. The optimal *ex ante* emission tax which is the price instrument will be contingent upon the realization of (θ,η) defined as

[3]In Coase's examples, the production of confectioneries creates noise and vibration that disturbs a nearby doctor, or cattle raising destroys crops on a neighbouring piece of land. The restriction, however, of the confectioner's activities or of cattle raising in the Pigouvian fashion will also harm the confectioner or the cattle raiser.

[4]The rights could also be the other way around.

$\tau(\theta,\eta) = D'(e^*(\theta,\eta),\eta)$. Using this tax, *ex ante* uncertainty is eliminated *ex post*. On the other hand the optimal *ex ante* quantity instrument, which could be either an emission limit or a quota related to marketable permits, is defined as $e^* = e^*(\theta,\eta)$, and again uncertainty is eliminated *ex post*.

However Weitzman shows that it is not feasible for the regulator to use contingent instruments since this may require the use of complicated and highly specialized contracts between the regulator and the firm which would be hard to understand and expensive to draw up. Second-best solutions are therefore considered in which the regulator does not use contingent instruments (Figure 2.3)

7. COST EFFECTIVENESS AND POLICY INSTRUMENTS

The analysis in the previous section indicated that in the presence of nonconvexities it might be difficult to determine the optimal policy, either because the regulator has to choose among many local optima, or the optimum is not well-defined either in the sense of unstable equilibria or no equilibrium at all. Apart from the possible nonconvexities a further problem in the pursuit of optimal policies relates to the informational requirements for the calculation of the optimal instruments, and especially with the correct estimation of the damage function. As an alternative to the pursuit of optimal policy, the approach of selecting a certain environmental standard[5] and then determining the instruments that could achieve this standard at a minimum cost has been proposed by Baumol and Oates. This approach, called the standards and charges approach by Baumol and Oates, demonstrates through a cost minimization theorem that the environmental quality standard can be achieved at a minimum cost.

The cost minimization theorem can be presented in the following way. Consider the input selection model (I) of Section 2.1. The regulator's problem can be set as:

$$\min_{(x_i^p, x_i^a)\geq 0} \sum_{i=1}^{n} w^p \cdot x_i^p + \sum_{i=1}^{n} w^a \cdot x_i^a$$

$$\text{s.t.} \sum_{i=1}^{n}\left[s_i(x_i^p) - h_i(x_i^a)\right] \leq \bar{e}$$

$$f_i(x_i^p) \geq q_i, \quad i=1,\ldots,n$$

The Lagrangean function for this problem is defined as:

$$\mathfrak{L} = \sum_{i=1}^{n} w^p \cdot x_i^p + \sum_{i=1}^{n} w^a \cdot x_i^a + \lambda\left[\sum_{i=1}^{n}\left(s_i(x_i^p) - h_i(x_i^a)\right) - \bar{e}\right] + \sum_{i=1}^{n} \mu_i\left[q_i - f_i(x_i^p)\right]$$

The Kuhn-Tucker conditions for this problem imply that if $(x_i^{*p}, x_i^{*a}) \geq 0$ solves the minimization problem then Lagrangean multipliers $(\lambda, \mu) \geq 0$ exist such that for all i=1,...,n:

$$w^p + \lambda\frac{\partial s_i(x_i^{*p})}{\partial x_i^p} - \mu_i\frac{\partial f_i(x_i^{*p})}{\partial x_i^p} \geq 0, \text{ with equality if } x_i^{*p}>0 \quad (2.23.1)$$

$$w^a - \lambda\frac{\partial h_i(x_i^{*a})}{\partial x_i^a} \geq 0, \text{ with equality if } x_i^{*a}>0 \quad (2.23.2)$$

$$\lambda\left[\sum_{i=1}^{n}\left(s_i(x_i^{*p}) - h_i(x_i^{*a})\right) - \bar{e}\right] = 0, \ \lambda \geq 0$$

$$\mu_i\left[q_i - f_i(x_i^{*p})\right] = 0, \ \mu_i \geq 0, \ i = 1,\ldots,n \quad (2.23.3)$$

In this problem λ can be interpreted as the shadow cost of emissions reflecting the increase in the firm's cost from

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[5]The environmental standard will reflect environmental quality at a given site. Standards for air can be set by using predetermined levels of concentration of certain pollutants in outdoor air, averaged over a certain period. Such pollutants, which have been called criteria pollutants, include sulphur dioxide (SO_2), total suspended particles (TSP), carbon monoxide (CO), nitrous oxides (NOX) and ozone . Standards for water can be set using predetermined levels of dissolved oxygen (DO) in the water body as a measure of ambient water quality or predetermined levels of biological oxygen demand (BOD) as a measure of emissions in the water body.

making the emission standard more stringent.[6] Solving (2.23.1), (2.23.2) and (2.23.4) for interior solutions, the demand for input functions is obtained as $x_i^{*j} = x_i^{*j}(w^p, w^a, \lambda, q_i, \bar{e}),\ j=p,a.$

Consider now the problem of firm i that is subject to an emission tax t_i per unit of emissions and seeks to choose input levels that minimize total production costs plus tax payments. The firm's problem is:

$$\min_{(x_i^p, x_i^a) \geq 0} \quad w^p \cdot x_i^p + w^a \cdot x_i^a + t_i\left[s_i(x_i^p) - h_i(x_i^a)\right]$$

$$\text{s.t. } f_i(x_i^p) \geq q_i$$

The Lagrangean for the problem is:

$$\mathcal{L} = w^p \cdot x_i^p + w^a \cdot x_i^a + t_i\left[s_i(x_i^p) - h_i(x_i^a)\right] + \mu_i\left[q_i - f_i(x_i^p)\right]$$

For the triplet $(x_i^{op}, x_i^{oa}, \mu_i) \geq 0$ that solves the above problem the Kuhn-Tucker conditions imply:

$$w^p + t_i \frac{\partial s_i(x_i^{op})}{\partial x_i^p} - \mu_i \frac{\partial f_i(x_i^{op})}{\partial x_i^p} \geq 0, \text{ with equality if } x_i^{op} > 0 \qquad (2.24.1)$$

$$w^a - t_i \frac{\partial h_i(x_i^{oa})}{\partial x_i^a} \geq 0, \text{ with equality if } x_i^{oa} > 0 \qquad (2.24.2)$$

$$\mu_i\left[q_i - f_i(x_i^{op})\right] = 0,\ \mu_i \geq 0,\ i = 1,\ldots,n \qquad (2.24.3)$$

Solving (2.24.1) to (2.24.3) for interior solutions the demand functions for inputs are obtained as $x_i^{oj} = x_i^{oj}(w^p, w^a, t_i, q_i),\ j=p,a$. It is clear that if the tax is set equal to λ, the shadow cost of the emission constraint, then $(x_i^{op}, x_i^{oa}) = (x_i^{*p}, x_i^{*a})$ and under the uniform emission tax $t_i = \lambda$, aggregate emissions equal the emission standard. If the emission standard is set at the welfare maximizing level in the sense of setting emissions at the point where marginal benefits equal marginal damages, then the emission tax will be equal to marginal damages calculated at the optimal emission level as derived in Section 3.1. If, however, the social welfare maximizing level of emissions can not be determined, either because the damage function is not known or because nonconvexities prevent the determination of a well-defined optimum, this approach can be said to achieve the standard at a minimum cost. It can easily be shown that the cost minimization theorem holds for other usual price incentive schemes.[7]

Suppose that the predetermined standard should be achieved by tradeable permits. For any initial allocation equal to the environmental standard, or $\tilde{e}_i$ such that $\sum_i \tilde{e}_i = \bar{e}$, firm i solves the problem:

$$\min_{(x_i^p, x_i^a) \geq 0} \quad w^p \cdot x_i^p + w^a \cdot x_i^a + P^T\left[s_i(x_i^p) - h(x_i^a) - \tilde{e}\right]$$

$$\text{s.t. } f_i(x_i^p) \geq q_i$$

The Kuhn-Tucker conditions for this problem are identical to (2.24.1) – (2.24.3) with t_i replaced by P^T. Demand functions for inputs depend on the price of permits or, $x_i^{oj} = x_i^{oj}(w^p, w^a, P^T, q_i) = x_i^{oj}(P^T),\ j=p,a$. In equilibrium the price P^T should clear the market or $\sum_i(e_i^o - \tilde{e}_i) = 0$, which further implies $\sum_i[s_i(x_i^{op}(P^T)) - h_i(x_i^{oa}(P^T))] = \bar{e}$. Thus $P^T = \lambda$, that is, the equilibrium permit price equals the shadow cost of emissions.

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[6] Let $C^*(w^p, w^a, q_1, \ldots, q_n, \bar{e})$ be the minimum cost function. Then by the envelope theorem $\partial C^*/\partial \bar{e} = -\lambda$.

[7] The case of subsidies is symmetric to the taxation case. The firm solves:

$$\min_{(x_i^p, x_i^a) \geq 0} \quad w^p \cdot x_i^p + w^a \cdot x_i^a - v\left[\bar{e} - s_i(x_i^p) + h(x_i^a)\right]$$

$$\text{s.t. } f_i(x_i^p) \geq q_i$$

Of course, as was mentioned earlier, under free entry taxes or subsidies affect entry–exit decisions of the firm differently.

8 CRITERIA FOR CHOICE OF ENVIRONMENTAL POLICY INSTRUMENTS

The discussion in the previous sections, while not exhaustive, covered to some extent the majority of the instruments which can potentially be used to achieve specific environmental policy targets. Given, however, the division of instruments between economic-based and command and control, and the existence of different kinds of instruments among the two major categories, there is an important issue of specifying criteria for instrument choice. The need to specify criteria becomes more pressing since some fundamental equivalence conditions among the instruments hold only under simplifying assumptions. When these assumptions are removed, the instruments are no longer equivalent and the use of the 'wrong' instrument could result in undesirable effects.

The basic criteria for choosing among environmental policy instruments can be set out as follows:

1. Environmental effectiveness – An instrument is effective if it can achieve specific policy objectives such as an ambient standard, an emission reduction, or a limit to the ambient concentration of a pollutant. The effectiveness of an instrument is mainly determined by the extent to which potential polluters react to its introduction. In this sense an instrument is more effective, the greater the incentive for pollution abatement and technical innovation which introduces environmentally-friendly processes.
2. Static efficiency – This refers to the achievement of the given environmental goal at a minimum cost given the level of technology and the location of the polluters.
3. Dynamic incentives – This concept refers to the incentives provided by the instrument in the long run. It includes incentives for the adoption of environmentally-friendly or 'clean' technologies, incentives for polluters to change location, or distortions in the relative price ratios of inputs that can make certain production methods relatively cheaper.
4. Flexibility – This refers to the ability of the instrument to adjust in order to maintain the environmental target where exogenous changes in technology or other types of economic activity take place. The crucial characteristic here is whether the adjustment takes place through a decentralized system of potential polluters or whether there is a need for new calculation by the regulating agency once an exogenous change has taken place.
5. Monitoring and enforcement – This is associated with the relative difficulty of obtaining measurements of emissions necessary to apply the specific instrument. The purpose of monitoring could be preparation of the tax bill, verification that the standard is observed, or auditing of self-monitoring. In general the accuracy of monitoring is impeded by purely technical features such as malfunctions of equipment, inadequate operation of devices, or inability to obtain entry to premises, or by more fundamental problems such as diffusion of pollutants through the receiving body or changes in climatic conditions that affect concentration. These reasons make it very difficult, if not impossible, to identify and monitor individual emissions with sufficient accuracy. Enforcement refers to actions to bring violators back into line. It includes mainly fines, court proceedings, penalties or indirect actions such as blacklisting. The relationship between accurate monitoring that determines the probability of detecting a violator and the application of penalties to the violator determines to a large extent the degree of compliance with a given instrument.
6. Equity – This criterion refers to the distributional effect of an instrument. For example charges imply payments for net emissions after abatement, that is, payment on residual pollution. The revenues from these taxes can be used in different ways with different distributional implications. On the other hand, to the extent to which the initial allocation of permits is through grandfathering or through auction, there are different distributional consequences.
7. Acceptability – This refers to the degree to which the specific group of polluters affected by the instrument accepts the policy instrument. If the instrument is not acceptable on a long-run basis, then frequent changes of instruments could erode the objectives of environmental protection. Acceptability of the instrument could be increased by the provision of adequate information about the instrument, its consequences and its relationship with other policy instruments, by consulting with the target group before its introduction, by discussing the actual application of the instrument and by gradual implementation that will allow the target group to adjust to the change in environment.

3. Dynamics and the Design of Environmental Policy

1 INTRODUCTION

The analysis of the environmental policy developed in the previous section was based on the assumption that the pollutants emitted during the production activities were of the flow or fund type, and it was the flow of emissions released in the ambient environment at any point in time that created the damages.

A very important class of pollutants, however, are those for which the stock is built into the ambient environment as emissions accumulate at a rate exceeding the rate at which natural processes can absorb them. For a stock pollutant the damages are not caused by the flow of emissions per unit time but by the stock of the accumulated pollutants. In fact stock pollutants are associated with a number of very important environmental problems.

The anthropogenic emissions of the so-called greenhouse gases (GHGs) – carbon dioxide, chlorofluorocarbons (CFCs), methane, nitrous oxides, and ozone – resulting from the burning of fossil fuels increase the stock of carbon, as well as of the other gases, in the atmosphere. The increase of the atmospheric concentration of the GHGs is expected to increase the earth's average temperature through the trapping of the earth's outbound radiation. This is the so-called greenhouse effect. The climate change due to global warming is expected to cause serious damages in the long run.[8] The greenhouse problem is a very good example of a stock externality since it is not the emissions of the GHGs that cause the environmental damages but the accumulated stock of these gases in the atmosphere.

Other examples of stock externalities include the accumulation of heavy metals such as lead in the soil, the acid depositions in soil, or the uncontrollable accumulation of nondegradeable waste in landfills. In all these cases it is the accumulation of the pollutant that creates the environmental damages.

Once, however, the notion of the stock externality is introduced, time is also explicitly introduced into the analysis. Environmental pollution becomes a dynamic process of accumulated emissions generated by production or consumption activities, and depletion of the pollutants either by natural processes, reflecting the environment's self-cleaning or assimilating capacity,[9] or by anthropogenic abatement processes.

Denoting by $S(t)$ the stock of pollution at time t and by $e(t)$ the flow of emissions per unit time, the dynamic process of pollution accumulation can be described in a continuous time context by a first-order differential equation of the form:

$$\frac{dS(t)}{dt} \equiv \dot{S}(t) = e(t) - \beta(S(t)), \; S(0) = S_o \geq 0$$

The function $\beta(S(t))$ reflects the removal or the decay of the pollution by natural sources and S_o is some initial accumulation of the pollutant. In most studies the rate at which pollution decays is considered constant so that $\beta(S(t)) = bS(t)$, where b is a constant exponential decay rate. Under this assumption the accumulation equation can be written as:

$$\dot{S}(t) = e(t) - bS(t), \; S(0) = S_o \geq 0 \tag{3.1}$$

Since damages relate to stock the damage function is an increasing and convex function of the pollution stock:

$$D(S(t)), \; D' > 0, \; D'' \geq 0 \tag{3.2}$$

[8]There is a large amount of literature on the "greenhouse effect". An idea about the damages associated with global warming can be obtained by considering the damage estimates from an increase in the mean temperature by 3°C. These estimates range from 0.25 per cent of the world product to 2.5 per cent.

[9]For example a large part of carbon dioxide emissions is removed from the atmosphere and is absorbed into the oceans.

The introduction of dynamics in this way gives a new dimension to the problem since current action creates damages in the future, therefore intertemporal trade-offs should be taken into account. This chapter will examine these trade-offs and their implication for resource allocation over time and for the structure of environmental policy.

2 SOCIAL OPTIMUM UNDER STOCK POLLUTION

In analysing the social optimum under stock pollution, a market consisting of a fixed number of $i=1,\ldots,n$ firms is considered for the whole time horizon of the problem which is extended to infinity, $t\in[0,\infty)$. Using the ECM model it is assumed that the social planner or the environmental regulator seeks to choose time paths $e_i(t)$, $i=1,\ldots,n$ for the emissions of each firm in order to maximize the present value of aggregate benefits less environmental damages over an infinite time horizon. The problem can be stated as:

$$\max_{\{e_1(t),\ldots,e_n(t)\}} \int_0^{+\infty} e^{-rt}\left[\sum_{i=1}^{n} B_i(e_i(t)) - D(S(t))\right]dt$$
$$\text{s. t. } \dot{S}(t)=\sum_{i=1}^{n} e_i(t) - bS(t),\ S(0)=S_o \qquad \text{(P1)}$$
$$e_i(t)\geq 0 \text{ for all } i \text{ and } t$$

where $r>0$ is the regulator's discount rate. Thus the regulator's problem is a formal optimal control problem with the stock of pollution $S(t)$ as state variable and the individual emissions $e_i(t)$ as control variables. To solve this problem the current value Hamiltonian is defined as:

$$H(S(t),e_1(t),\ldots,e_n(t),\lambda(t))=\sum_i \left[B_i(e_i(t))-D(S(t))\right]+\lambda(t)\left(\sum_i e_i(t)-bS(t)\right)$$

According to the maximum principle an optimal solution for the regulator's problem consists of time paths for emissions $\{e_1^*(t),\ldots e_1^*(t)\}$ and an associated time path for the ambient stock of pollution $S^*(t)$, and a path for the costate variable $\lambda(t)$ that satisfy the following conditions:

(i) $e_i^*(t)$ maximizes $H(S(t),e_1(t),\ldots,e_n(t),\lambda(t))$ for all i, that is

$$\frac{\partial H}{\partial e_i}=B_i'(e_i^*(t))+\lambda(t)\leq 0,\ \text{with equality if } e_i^*(t)>0,\ \forall\ i \qquad (3.3.1)$$

(ii) $$\dot{\lambda}(t)=r\lambda(t)-\frac{\partial H}{\partial S} \text{ or } \dot{\lambda}(t)=(r+b)\lambda(t)+D'(S^*(t)) \qquad (3.3.2)$$

$$\dot{S}(t)=\sum_i e_i^*(t)-bS^*(t) \qquad (3.3.3)$$

(iii) The Arrow type transversality conditions at infinity

$$\lim_{t\to+\infty} e^{-rt}\lambda(t)S^*(t)=0 \qquad (3.3.4)$$

Since the Hamiltonian function is jointly concave in the state and the costate variables, the necessary conditions of the maximum principle (i) and (ii) along with the transversality condition are also sufficient for the maximization.

The costate variable $\lambda(t)$ which is negative by (3.3.1) for any interior solution has a natural interpretation as the shadow cost of the pollutant's stock. To see this consider the maximum value function for the regulator's problem (P1) which reflects the maximum achievable social welfare:

$$W^*(S_o,0)=\max_{\{e_1(t),\ldots,e_n(t)\}} \int_0^{+\infty} e^{-rt}\left[\sum_{i=1}^{n} B_i(e_i(t))-D(S(t))\right]dt \qquad (3.4)$$
$$\text{s. t. } (3.1)$$

Then $\lambda(0)=\partial W^*/\partial S_o$ or the value of the costate variable measures the extra cost in terms of welfare from increasing the initial stock of pollution by a small amount. This result can be generalized for any instant of time along the optimal path. Thus the optimal value of the costate variable is the social shadow cost of the particular stock.

Conditions (3.3.1) describe short-run equilibrium conditions. These conditions can be solved for interior solutions to obtain a short-run demand function for emissions, or

$$e_i^*(t) = e_i(\lambda(t)) \text{ with } e_i'(\lambda(t)) = -\frac{1}{B_i''(e_i^*(t))} > 0, \forall\ i \text{ such that } e_i^*(t) > 0$$

This function indicates the socially-optimal emission level at any instant of time as a function of the social shadow cost of the pollutant's stock. Since $\lambda(t) < 0$, a reduction in the absolute value of the social shadow cost of the pollutant will increase emissions.

Given the dynamic character of our model it is of interest to examine its long-run steady state equilibrium properties. By substituting the short-run demand functions for emissions into (3.3.2) and (3.3.3), we can obtain a dynamic system in the stock of the pollutant and its corresponding social shadow cost. This is the modified Hamiltonian dynamic system (MHDS), which is a system of differential equations defined as:

$$\dot{S}(t) = \sum_i e_i^*(\lambda(t)) - bS^*(t) \tag{3.5.1}$$

$$\dot{\lambda}(t) = (r+b)\lambda(t) + D'(S^*(t)) \tag{3.5.2}$$

with boundary conditions defined by $S(0)=S_o$ and the transversality condition (3.3.4). Solution of the above system will determine the socially-optimal path for the pollution stock $S^*(t) = S_S(t;r,b)$ and the corresponding social shadow cost $\lambda(t) = \lambda_S(t;r,b)$ as functions of the parameters r and b. Given the path for the social shadow cost the optimal emission path is determined as $e_{iS}^*(t) = e_{iS}^*(\lambda_S(t;r,b)) = e_{iS}^*(t;r,b)$.

Given the MHDS the usual issues associated with the analysis of the long-run equilibrium are:

(i) existence of solutions;
(ii) existence and number of long-run equilibria; and
(iii) stability of equilibria.

Since existence of solutions for S_S and λ_S can be shown on the basis of general results about differential equations, we concentrate on the existence and stability of equilibrium. The long-run equilibrium or steady state for the stock of the pollutant and its corresponding shadow cost are defined as values $(S_\infty^*, \lambda_\infty^*)$ for which S and λ are stationary, or $\dot{S} = \dot{\lambda} = 0$. The characterization of equilibrium can be better presented with the help of the phase diagram in Figure 3.1.

4. Nonpoint Source Pollution

The analysis of environmental policy presented in the previous chapters was developed under the basic assumption that the regulator has perfect information regarding the emissions generated by each potential polluter. That is, the source, the size and the distinctive characteristics of the emissions can be identified with sufficient accuracy at a nonprohibitive cost. A situation like this can be identified with pollution associated with large industrial or municipal emissions and is referred to in the literature as point source (PS) pollution.

In contrast to a PS pollution problem, in a nonpoint source (NPS) pollution problem neither the source nor the size of the individual emissions can be observed by an environmental regulator which seeks to implement a given environmental policy. NPS pollution problems relate mostly to emissions by small sources like farmers or households, or mobile sources such as vehicles. The pollution that these sources generate mainly includes nutrient pollution, pesticide pollution, sedimentation, vehicle pollution, and hazardous and solid wastes.

The significance of NPS type pollution is indicated by the fact that part of the degradation of many of the world's lakes and reservoirs can be traced to this type of pollution. Degradation is due to a number of factors including eutrophication which results from accelerated nutrient loading due to expanded farming practices; toxic substances entering the water bodies as agricultural run-off, along with forestry drainage which contains a range of toxic pesticides and herbicides; accelerated sedimentation caused by farming on fragile soils and steep slopes, forestry activities, construction activities and urban drainage; acidification of aquatic systems from emissions of sulphur dioxide and nitrous oxides which occurs due to acid rain or through leaching from affected land. In all of these cases monitoring of the individual emissions which are associated with farming or forestry activities, with acid rain, or with urban drainage, and which are responsible for environmental degradation, is not possible due to the number of sources and the diffused character of the pollution. In many cases critical pollution-generating inputs are not always observable and weather introduces stochastic elements into the pollution process, making identification of the polluting source and its contribution to the ambient pollution in the specific receiving body practically impossible. Thus in an NPS problem an environmental regulator can measure the ambient pollution at specific 'receptor points', but cannot attribute any specific portion of the pollutant's concentration to a specific discharger.

The problems that characterize NPS pollution are mainly informational, and have been distinguished into two broad classes: problems related to monitoring and measurement, and problems related to natural variability. Monitoring problems are associated with the inability to directly observe individual emissions or to infer them from observable inputs or from the ambient concentration of the pollutant. Then the pollution control agency cannot efficiently monitor emissions or abatement efforts by an individual polluter. This is due to a number of factors such as equipment and personnel limitations, or inability to enter the polluter's premises. On the other hand, while it is relatively easy to determine whether the polluter has installed adequate abatement capacity, it is difficult to make sure that this capacity is being operated at the desired level. As a result the development of efficient and relatively accurate measurement methods could be costly. Therefore the environmental regulator faces a situation in which it could be prohibitively costly to measure with sufficient accuracy the emissions of potential polluters as well as the pollution abatement efforts. The regulator can only measure ambient pollutant concentration at prespecified receptor points. It is not however possible to attribute any specified portion of the accumulation of the pollutant to a specific polluter in the case of many polluters of the same pollutant. Natural variability is associated mainly with weather or topographical conditions or technological uncertainty and results in stochastic pollution processes.

The informational asymmetries between the regulator and individual dischargers in an NPS problem could take the form of moral hazard characterized by hidden actions or/and adverse selection. A situation where the emissions of each potential polluter or his/her abatement efforts are not observable while the outcome of all polluters' actions – that is, the ambient concentration of the pollutant at the receptor point – is observed, implies moral hazard. The individual polluter can increase profits by choosing lower emission levels since his/her actions are not observable. On the other hand the inability to know the specific characteristics or type of each potential polluter – which is private information known only to the polluter and affects the polluter's emissions – is associated with adverse selection. In a situation which is characterized by these informational asymmetries, the environmental regulator cannot use the standard instruments of environmental policy – Pigouvian taxes, tradeable emission permits, emission standards – discussed above, as a means of inducing dischargers to follow socially-desirable policies. The potential polluters will choose higher than socially-desirable emission levels if by doing so they can increase their profits. Since their emissions cannot be observed the standard environmental policy instruments cannot be used to internalize external damages and to obtain the Pareto optimal outcome.

The inadequacy of the standard instruments of environmental policy to deal with NPS problems has resulted, in recent years, in increasing attention being given to the development of policy schemes appropriate for such problems. These schemes can be divided into two broad categories or types: first ambient taxes where the scheme is based on the observed ambient pollution or menus of ambient taxes and effluent fees, which are based on incomplete observability of individual emissions and self-reporting by potential polluters; and second input-based schemes, where the policy scheme is applied to observable polluting inputs. Policy schemes of both types capable of dealing with NPS pollution are presented in the rest of this chapter.

The analysis of ambient taxes suggests that payments by all potential polluters are triggered when measured ambient pollutant levels at receptor points exceed some desired cut-off level. This of course gives the ambient tax incentive scheme the character of a collective penalty. The collective penalty character can be further intensified by adding to the scheme a fixed penalty that is independent of the size of deviations between observed and desired ambient pollution levels. Collective penalty schemes can take the form of non budget-balancing (NBB) and budget-balancing (BB) contracts.

An NBB contract implies that the total payment to the polluters, which is positive in the case of a subsidy, or negative in the case of a tax, exceeds the social value of abatement or emissions. It can easily be seen that an ambient tax is an NBB type contract since each polluter pays the whole social value of deviation between the desired and the observed ambient pollution level.Under a BB contract total subsidies or taxes equal the social value of abatement or the social cost of pollution.

1 IMPERFECT OBSERVABILITY AND OPTIMAL TAXATION

To analyse the impact of imperfect observability on environmental policy we consider the ECM which was used to determine the optimal emission tax. We relax, however, the assumption that the individual emissions e_i are fully observable by the regulator, that is, e_i is the moral hazard variable.

As we already saw, a social planner seeking to maximize total benefit less environmental damages will choose the socially-optimum emission level for each firm, such that marginal benefit equals marginal damages for all $i=1,\dots,n$, or $B_i^{\prime}(e_i^*) = D^{\prime}$. Then the optimal level of ambient pollution is $e^* = \sum_i e_i^*$.

Let s_i represent the observed part of emissions by firm i, that is, $s_i \in [0, e_i]$. It is assumed that firm i's observed emissions depend on a parameter m_i.[10] Thus observed emissions are assumed to be determined according to an at least twice differentiable nondecreasing function $s_i = f_i(m_i)$.

The parameter m_i can be interpreted in different ways. It can be regarded as reflecting monitoring effort to determine physical characteristics of the polluter (e.g., location, types of inputs used, production practices) that permit the quantification of emissions, or as information provided by the polluting firm itself that can lead to a quantification of a certain part of its own emissions, or as the amount of installed monitoring equipment. The following assumptions are made about f_i, where for clarity we choose to interpret m_i as monitoring effort:

(i) $f_i(0)=0$. That is, there is no observability without monitoring effort.
(ii) A level of monitoring effort exists at which perfect observability can be obtained, or $\exists \bar{m}_i : f_i(m_i) = e_i,\ \forall\ m_i \geq \bar{m}_i$. The regulator will know that perfect individual monitoring has been achieved if $\sum_i s_i = e$, the observed ambient level of pollution.
(iii) $f_i^{\prime\prime}(m)<0$ reflecting diminishing returns in monitoring.

Assume that the environmental regulator tries to formulate a policy that will induce firms to emit at the socially-desirable level, e_i^*. Consider two possible policy instruments:

(a) An effluent fee or emission tax, τ_i, that is imposed on firm i per unit of observed emissions.
(b) An ambient tax which firms are liable to pay if measured total ambient emissions, e, at some receptor point exceed the desired cut-off level, e^*. The ambient tax is specified as a function of the observed emissions of each firm. That is, for firm i, the ambient tax is defined as $g(s_i) \equiv g_i(f_i(m_i)) \equiv h_i(m_i)$.

The following assumptions are made about the ambient tax function:

(i) When observability is complete, the ambient tax is zero. That is, $g_i(s_i)$ or equivalently $h_i(m_i)=0\ \forall\ m_i \geq \bar{m}_i$.
(ii) When firms' emissions cannot be observed, the ambient tax rate takes its maximum value. That is, $g_i(0)$ or equivalently $h_i(0)=\gamma_i$, $\gamma_i = \max\{h_i(m_i)\}\ \forall\ m_i \in M_i$.
(iii) The more emissions are observed, the less the ambient tax. That is, $g_i^{\prime}(s_i)<0$ or equivalently $h_i^{\prime}(m_i)<0$.
(iv) The ambient tax function is convex in monitoring effort. That is, $g_i^{\prime\prime}(s_i)>0$, which combined with $g^{\prime\prime}\left[f_i^{\prime}\right]^2 + g_i^{\prime} f_i^{\prime\prime}>0$ implies $h_i^{\prime\prime}(m_i)>0$.

If the firm faces a tax scheme consisting of both ambient and effluent taxes, its profit function will be:

$$\pi(e_i, m_i) = B_i(e_i) - h_i(m_i)(e - e^*) - \tau_i f_i(m_i) \tag{4.1}$$

The environmental regulator must choose the tax parameters $h_i(m_i)$ and τ_i to maximize total benefits less total damages. Furthermore, if firms follow its instructions about the environmental policy to be adopted, they should maximize their profits. The last requirement implies that in the regulator's problem the constraint that (4.1) is maximized for $e_i = e_i^o$, given the emission policies of the rest of the firms, should be imposed. This means that the regulator's problem takes the form:

[10] m_i is assumed to belong to a compact and convex set M_i.

$$\max_{\substack{(e_1,\dots,e_n)\geq 0\\(m_1,\dots,m_n)\geq 0\\(\tau_1,\dots,\tau_n)\geq 0}} \sum_{i=1}^{n} B(e_i) - D(e) \tag{4.2.1}$$

$$e=\sum_{i=1}^{n} e_i,\ m_i \subset M_i \tag{4.2.2}$$

$$e_i \in \underset{e_i}{\text{argmax}}\ B_i(e_i) - h_i(m_i)(e_i + \sum_{j \neq i} e_j^o - e^*) - \tau_i f_i(m_i) \forall\ i \tag{4.2.3}$$

$$\text{s. t } f_i(m_i) \leq e_i$$

In this problem e^* is not fixed in advance, as it appears in constraint (4.2.3), but it indicates the value of the optimal ambient pollutant concentration which is the solution to the regulator's problem (4.2.1). Thus the constraint is defined implicitly by the solution of the problem itself.[11] The optimal ambient and effluent fees in the two polar cases of nonobservability and complete observability are determined as solutions of the regulator's problem in the following way:

(i) If firms' emissions can not be observed at all – or equivalently for all i, m_i=0 – then the optimal ambient tax equals marginal damages at the optimum, $\gamma_i = D'(\sum e_i^*)$, and the optimal emission tax is zero, $\tau_i = 0$.

(ii) If firms' emissions are perfectly observable for all i, that is $m_i \geq \bar{m}_i$, then the optimal ambient tax is zero, γ_i=0, while the optimal emission tax is equal to marginal damages as in the perfect observability models, $\tau_i = D'$.

To show this result consider the regulator's problem (4.2.1). In this mathematical program constraints (4.2.3) and (4.2.4) represent firms' optimal choices. Since the firm's profit function is concave in e, and constraint (4.2.4) is linear in e, the problem (4.2.3, 4.2.4) has a global maximum.[12] This means that the constraint (4.2.3, 4.2.4) can be replaced by the corresponding first-order conditions. Cases (i) and (ii) above can be examined.

(i) Since m_i=0, it follows that $f_i(m_i)$=0 and $h_i(0)=\gamma_i$. The Lagrangean for this problem is:

$$\mathfrak{L} = \sum_{i=1}^{n} B_i(e_i) - D(e) + \sum_{i=1}^{n} \lambda_i \left[B'(e_i) - \gamma_i\right]$$

with first-order conditions

$$B_i' - D' + \lambda_i B_i'' \leq 0,\ e_i \geq 0$$

$$-\gamma_i \lambda_i \leq 0,\ \gamma_i \geq 0$$

$$B_i' - \gamma_i = 0$$

For interior solutions, we have $\lambda_i = 0$ and $\gamma_i = D'$.

(ii) Since $m_i \geq \bar{m}_i$, it follows that $h_i(m_i)$=0, $f_i(m_i)=e_i$. The Lagrangean for the problem is:

$$\mathfrak{L} = \sum_{i=1}^{n} B_i(e_i) - D(e) + \sum_{i=1}^{n} \lambda_i \left[B_i'(e_i) - \tau_i\right]$$

The first-order conditions are the same as before with γ_i replaced by τ_i. Therefore for interior solutions, $\lambda_i = 0$ and $\tau_i = D'$.

When there is no observability, the producers are liable for an ambient tax equal to marginal damages per unit deviation from the cut-off level. The producer facing this scheme will adjust its production and abatement process such that marginal benefits from emissions equal marginal damages, adopting therefore the socially-desirable emission levels. Under full observability the polluter discharges the socially-desired emissions when the

[11]This problem has been called an implicit programming problem by Feinstein and Luenberger (1981), and represents a well-defined mathematical programming problem.

[12]A global maximum further requires that the sets where individual emissions e_i are defined be compact and convex.

tax per unit of its own emissions is equal to marginal damages.

In this type of NPS pollution problem the regulator has no incentive to increase observability by increasing m_i since it can achieve the social optimum by setting the ambient tax to the optimal level. Furthermore there is no incentive from the firm's point of view to reveal information about its emissions and as a result of this pay an effluent fee in exchange for a low ambient tax rate. This can be demonstrated as follows.

The maximum profit of the firm is defined, as a function of m_i and for an optimal choice $e_i^o < f_i(m_i)$, by the concave function:

$$\pi_i(m_i) = \max_{e_i} \left[B_i(e_i) - h_i(m_i)(e - e^*) - \tau_i f_i(m_i) \right]$$

The optimal choice of $m_i \geq 0$, can be determined by the envelope theorem. The optimality condition requires that:

$$-h_i^/(m_i^o)(e - e^*) - \tau_i f_i^/(m_i^o) \leq 0, \; m^o \geq 0$$

If $e_i^o = e_i^*$ for all i, then $e = e^*$ and we have

$$-\tau_i f_i^/(m_i^o) < 0 \text{ therefore } m_i^o = 0$$

Thus the firm will not reveal any information about its emissions; furthermore if the regulator's choice is $m_i=0$, this value is optimal from the firm's point of view.

This result means that if the ambient tax is set at the level of marginal damages and there is no uncertainty, the firms that have adjusted their emissions to the desirable emission level are not willing to pay any effluent fee, by having their emissions measured or by revealing some information to the regulator, in order to be liable for a lower ambient tax rate. Since neither the regulator nor the firm have any incentive to increase m_i from zero, it is socially optimal to have individual emissions remain unmonitored (or unobserved) in an NPS pollution problem, and use ambient taxes alone.

5. Environmental Policy and Market Structure

1 INTRODUCTION

The analysis of environmental policy developed in the last two chapters focused on two departures from the basic model: first the introduction of the concept of stock externality that gives rise to dynamic considerations, and second the introduction of informational constraints which make necessary the use of alternative policy instruments. In both cases, however, the analysis was carried out under the explicit assumption of perfect competition in the product market.

Indeed the assumption of competitive product markets has been the most common one in the analysis of environmental policy during the last decades,[13] while some notable exceptions refer to the use of the monopoly assumption in the product market.[14] Much less attention, at least until recently,[15] has been given, however, to the analysis of environmental policy under the assumption of oligopolistic product markets, although this assumption could be regarded as the more realistic one for describing modern industrial societies.

The purpose of this chapter is to provide some insights into the structure of environmental policy when the product market is no longer competitive. The basic implications of the departure from the competitive market assumption is that more externalities in addition to environmental pollution enter the analysis, with the presence of these new externalities affecting – sometimes significantly – the effectiveness of the environmental policy instruments.

In particular when a second externality related to the structure of the product market is considered, this

[13]See for example Baumol and Oates (1988).

[14]It was Buchanan (1969) who first considered the implications of a monopolistic product market for environmental policy.

[15]See for example Levin (1985), Ebert (1991/2), Requate (1993), Conrad and Wang (1993) and the collected volume by Carraro, Katsoulacos and Xepapadeas (1996).

second externality affects the product side and relates to underproduction due to excessive monopoly power, as compared to the competitive case. In the case of two distortions, standard arguments suggest the use of two instruments in order to correct the two externalities: one instrument to correct for environmental pollution and another to correct for market imperfections. In most of the analysis that follows it will be assumed that the regulator cannot affect the firm's pricing policies, that is, the distortion in the product side cannot be corrected. In this case optimal second-best environmental policy instruments are developed. First-best instruments, that is instruments capable of correcting both externalities, are also derived in the context of optimal regulation of a natural monopoly.

The analysis in this chapter basically considers environmental policy under Cournot competition with homogeneous product. Further analysis of environmental policy in cases such as Bertrand competition or vertical product differentiation will undoubtedly be an important research area in the future.

2 ENVIRONMENTAL REGULATION UNDER MONOPOLY

When the output that generates environmental degradation is produced by a monopolist, there are two possible ways of considering environmental regulation. The first is to consider the pricing policy of the firm as given, that is not affected by the regulator, and then to determine a second-best emission tax as the only instrument available to the regulator, which is the traditional approach. The second is to consider the problem explicitly as a problem of optimal monopoly regulation. In this second case the emission tax is one element of the set of instruments that is used to achieve optimal regulation.

2.1 Emission Taxes under Monopoly

As shown earlier, emission taxes internalize the external damages associated with pollution-generating activities. The internalization is complete when the emission tax is equal to the marginal external damages of pollution, such as in the case of Pigouvian taxes. The socially-optimal degree of internalization depends however on the market structure. Under perfect competition, the desired internalization is complete (e.g., Baumol and Oates 1988), while under imperfectly competitive conditions, optimal taxes deviate from external damages, as was first noted by Buchanan (1969) for the case of monopoly.

Buchanan (1969) pointed out, in analysing the case of a polluting monopolist, that the use of effluent fees equal to marginal external damages of pollution, as in the case of competitive markets, will not lead to optimality and can even reduce social welfare. This is because the emission tax will reduce the already suboptimal monopoly output. Thus any gain in welfare due to reduced pollution might be outweighed by the welfare loss due to reduced output. This implies that complete internalization of the external pollution damages caused by a monopolist might not be desirable, but rather that the optimal policy requires underinternalization reflected in an emission tax less than marginal damages.

The optimal emission tax for the case of a monopolist can be derived as follows. Consider the output abatement choice model (OACM) presented in Section 2.2.2 of Chapter 2, but restrict the number of firms to $n=1$ and set $Q=q$. In such a case the regulator's problem is to choose output and abatement expenses to maximize social welfare defined as usual as the sum of consumer and producer surplus by:

$$\max_{(q,a)>0} \; W=\int_0^q P(u)du - c(q,a) - D(e), \; e=s(q,a) \tag{5.1}$$

The first-order necessary conditions for the optimal allocation (q^*, a^*) assuming interior solutions, can be written as:

$$\frac{\partial W}{\partial q}=0 \text{ or } P(q^*) - \frac{\partial c(q^*,a^*)}{\partial q} - D'(e^*)\frac{\partial s(q^*,a^*)}{\partial q} = 0 \tag{5.2.1}$$

$$\frac{\partial W}{\partial a}=0 \text{ or } -\frac{\partial c(q^*,a^*)}{\partial a} - D'(e^*)\frac{\partial s(q^*,a^*)}{\partial a} = 0 \tag{5.2.2}$$

The above conditions have a similar interpretation as conditions (2.2.1) and (2.2.2) in Chapter 2, and determine optimal emissions by the monopolist as $e^* = s(q^*, a^*)$. The monopolist facing an emission tax t solves the problem:

$$\max_{(q,a)\geq 0} \; \pi = P(q)q - c(q,a) - ts(q,a)$$

The first-order necessary conditions for the allocation (q^m, a^m) which maximizes the monopolist's profit, assuming again interior solutions, are:

$$P + q^m \frac{dP}{dq} - \frac{\partial c(q^m, a^m)}{\partial q} - t\frac{\partial s(q^m, a^m)}{\partial q} = 0 \qquad (5.3.1)$$

$$-\frac{\partial c(q^m, a^m)}{\partial a} - t\frac{\partial s(q^m, a^m)}{\partial a} = 0 \qquad (5.3.2)$$

Condition (5.3.1) implies that the monopolist equates marginal revenue with marginal production plus marginal emission costs. On the other hand, (5.3.2) implies that in choosing profit-maximizing abatement, the monopolist equates marginal abatement costs with marginal emission tax savings due to abatement. Combining (5.2.1) with (5.3.1), the following monopoly tax is obtained:

$$t^{m} = D'(e^{*}) - \frac{P}{|\varepsilon|}\frac{\partial q}{\partial e}$$
$$\text{with} \quad P + q\frac{dP}{dq} = P\left(1 - \frac{1}{\varepsilon}\right) = MR \tag{5.4}$$

where ε is the elasticity of demand. Using the definition for marginal revenue and the fact that under profit maximization, marginal revenue equals marginal cost (MR=MC), relation (5.4) becomes:

$$t^{m} = D'(e^{*}) - \left|(P-MR)\frac{\partial q}{\partial e}\right| = D'(e^{*}) - \left|(P-MC)\frac{\partial q}{\partial e}\right| \tag{5.5}$$

By either (5.4) or (5.5), the second-best emission tax for the monopolist is less than marginal external damages. The deviation between tax and marginal damages is equal to the welfare losses from reduced output. This loss is expressed as the value of the marginal output unit less its marginal cost, or $P - MC$, times the reduction in output associated with a unit decrease in emissions, ($\partial q/\partial e$). By comparing (5.2.2) to (5.3.2), it can be seen that t^m does not lead to the socially-optimal amount of abatement. That is, a trade-off exists between increasing abatement by using a higher emission tax and reducing output.

The monopoly tax t^m is a second-best optimal tax, as can be seen by examining the optimal taxation problem formally. Solving the first-order conditions (5.3.1) and (5.3.2), assuming that the appropriate second-order conditions are satisfied, optimal output and abatement expenses are defined as functions of the tax rate, as:

$$q^{m} = q^{m}(t),\ \frac{\partial q^{m}}{\partial t} < 0,\ a^{m} = a^{m}(t),\ \frac{\partial a^{m}}{\partial t} > 0$$

Substituting these values into (5.1), social welfare is defined as a function of t. The optimal second-best tax for the monopolist is defined as:

$$t^{m} = \underset{t}{\operatorname{argmax}}\, W(t)$$

The first-order condition for maximization is defined as:

$$\frac{\partial W}{\partial q}\frac{\partial q^{m}}{\partial t} + \frac{\partial W}{\partial a}\frac{\partial a^{m}}{\partial t} = 0$$

Using the derivatives of (5.1) and the derivatives $\partial c/\partial q$, $\partial c/\partial a$ from the first-order conditions (5.3.1) and (5.3.2) of the monopolist's profit-maximization problem, the optimal second-best emission tax is obtained as:

$$t^{m} = D'(e^{*}) + \frac{\frac{\partial P}{\partial q}\frac{\partial q}{\partial t}q}{\frac{\partial e}{\partial q}\frac{\partial q}{\partial t} + \frac{\partial e}{\partial a}\frac{\partial a}{\partial t}} = D'(e^{*}) - \frac{P}{|\varepsilon|}\frac{\partial q}{\partial e} \tag{5.6}$$

since the denominator of the second part of (5.6) is $\partial e/\partial t$.

The above results imply therefore that in a monopolistic market, the second-best optimal emission tax is less than marginal external damages of pollution.[16] This tax balances welfare losses from restricting the already suboptimal monopolist's output with welfare gains due to emission reductions.[17]

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[16]For these derivations see also Barnett (1980), Misiolek (1980) and Baumol and Oates (1988).

[17]The efficiency properties of Pigouvian taxes have been further examined under various organizational forms and under alternative assumptions about conditions prevailing in monopolistic markets. Oates and Strassmann (1984) examine the properties of a system of effluent fees when the polluter takes the form of a private monopoly, managerial firm, regulated firm or public bureau. They tentatively conclude that the efficiency of a fee system which is invariant to the organizational form, is not seriously compromised by deviations from competitive conditions. Misiolek (1988) demonstrates that when rent-seeking costs are present, the optimal Pigouvian tax for a monopolist could exceed marginal external damages.

2.2 Optimal Regulation of Polluting Monopolies

We consider the case of a natural monopoly producing a single output and generating pollution during the production activities. The objective of the regulator is to maximize social welfare by inducing the monopoly to produce at the socially-optimal production and emission levels.

In developing the regulatory mechanism the Laffont-Tirole approach to regulation is used.[18] This approach has the advantage of incorporating readily into the model issues of incomplete information, and in particular, moral hazard and adverse selection.

Consider a natural monopoly producing a single output and generating pollution as a byproduct, with a cost function defined as $C = C(q,z,e,\beta)$ where q denotes output produced, z denotes the level of effort undertaken by the firm (or more precisely the management of the firm) which reduces costs but creates disutility described by a function $\psi(z)$ with $\psi'>0$, $\psi''>0$, $\psi''' \geq 0$, e denotes generated emissions, and finally β is a productivity parameter. For the partial derivatives of the cost function it is assumed that $C_q>0$, $C_z<0$, $C_e<0$, $C_\beta>0$ and that C is strictly convex in (q,z,e). Thus a reduction in emissions and an increase in the productivity parameter β increase costs.

Let $p=P(q)$ be the demand function (inverse) for the monopolists's product and make the accounting convention that the regulator receives the proceeds from the sales of the firm's output defined as $R(q)=qP(q)$ and pays the firm total costs C plus a transfer T as compensation for the disutility of engaging in production. Thus the monopolist's utility or rent is defined as:

$$U = T - \psi(z)$$

As usual the regulator tries to maximize consumer and producer surplus; assume also that public funds have a social price of $(1+\lambda)$ with $\lambda>0$ because of distortionary taxation. Then social welfare is defined as:

$$W = \left[\int_0^q P(u)du - qP(q)\right] + (1+\lambda)qP(q) - (1+\lambda)(C+T) + U - D(e) \tag{5.7}$$

where as before $D(e)$ denotes environmental damages.

The first term on the right-hand side denotes net consumer surplus, the second term reflects the regulator's revenue evaluated at the social price of the public funds (because the revenues reduce the need for distortionary taxation), the third term reflects the total amount paid to the firm by the regulator valued again at the social price of public funds, the fourth term reflects producer's net rents, and the last term reflects environmental damages. After some rearrangement and writing $S(q) \equiv \int_0^q P(u)d(u)$, $T = U + \psi(z)$, (5.7) becomes:

$$W = S(q) + \lambda qP(q) - (1+\lambda)(C + \psi(z)) - \lambda U - D(e) \tag{5.7.1}$$

It can be seen from the above definition of social welfare that rents left to the monopolist reduce social welfare since the social price of the public funds exceed unity, or $\lambda>0$.

The objective of optimal regulation under complete information, that is knowledge of β and z, is to choose the triplet (q^*, z^*, e^*) to maximize (5.7.1) subject to the participation constraint $U \geq 0$. Assuming interior solution the optimal regulation is characterized as:

(i) $\dfrac{p^* - MC}{p^*} = \dfrac{\lambda}{1+\lambda}\dfrac{1}{\varepsilon_p}, \quad p* = P^*(q^*), \quad MC = C_q$

where ε_p is the elasticity of demand. The above condition is a form of Ramsey pricing for the regulated utility.

(ii) $\psi'(z^*) = -C_z$

The marginal disutility of effort is equal to the marginal cost savings due to increased effort.

(iii) $D'(e^*) = -(1+\lambda)C_e$

Marginal damages from pollution equal the marginal cost of pollution reduction evaluated at the social price for public funds.

(iv) $U^* = 0$

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[18] See Laffont and Tirole (1993), Laffont (1994a). The approach in this section follows Laffont (1994b).

No rents are left to the monopolists at the optimal regulation.

The above-defined optimal regulation can be implemented by the following mix of instruments (Laffont 1994b):

(a) A subsidy per unit of commodity sold

$$s^* = \frac{p^*}{(1+\lambda)\varepsilon_p} \tag{5.8.1}$$

(b) An emission (Pigouvian) tax

$$\tau^* = \frac{D'(e^*)}{1+\lambda} \tag{5.8.2}$$

(c) A lump-sum tax on profits

$$T^* = \left(P(q^*) + s^*\right)q^* - C(q^*, z^*, e^*, \beta) - \tau^* e^* - \psi(z^*) \tag{5.8.3}$$

The three instruments solve the three externality-related problems. The subsidy ensures that the monopoly will not underproduce, the Pigouvian tax fully internalizes environmental marginal damages scaled by the social value of public funds, while the lump-sum tax on profits solves the distribution problem by not leaving any rents to the monopoly.[19]

It is interesting to note that in the context of a more general optimal regulatory scheme there is no need for a second-best emission tax. The optimal tax under the optimal regulation fully internalizes marginal external damages after scaling down for the social cost of distortionary taxation.[20]

Optimal regulation of the monopoly can be extended to take into account the possibility of incomplete information, that is, unobservable effort, z (moral hazard), and the unobservable productivity parameter, β (adverse selection). The optimal scheme can be implemented again by a mix of subsidies, emission taxes and transfers. The emission taxes are however modified compared to (5.8.2) in order to take into account the need for incentive correction.[21]

3 ENVIRONMENTAL REGULATION IN OLIGOPOLISTIC MARKETS

As mentioned earlier, the framework of oligopolistic product markets has been disregarded in the majority of cases in the development of environmental policies. One reason for this could be the complications involved when one departs from the simplifying assumption of perfect competition or monopoly. According to Baumol and Oates (1988, p. 84), '... the rules for other market forms [oligopolists, monopolistic competitors] may be yet more complicated' [than for competitive firms or monopolists].

Under conditions of oligopoly, more externalities, in addition to output distortion and pollution, may be present. This could result both in drastic changes in the qualitative characteristics of the traditional environmental policy instruments used for the cases of perfect competition and monopoly,[22] and also in a need for additional instruments.

3.1 Emission Taxes in Fixed Number Oligopolies

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[19]The optimality of the instrument mix can easily be seen by considering the monopolist's problem under the incentive scheme which is:

$$\max_{q,z,e}\, [P(q) - s^*]q - \tau^* e - C(q, z, e, \beta) - \psi(z)$$

The optimality conditions under the incentive scheme reproduce the optimal regulations (i) to (iv).

[20]This result is compatible with the results obtained in Section 3.1.1 of Chapter 2 under general equilibrium considerations, where again the optimal tax is less than marginal damages due to distortionary taxation.

[21]For a detailed analysis of regulation under incomplete information see Laffont (1994b) in which additional issues such as nonverifiable pollution level, nonpoint source pollution and location choice are discussed.

[22]See also Levin (1985) for some counterintuitive results in the case of taxation under oligopoly.

In this section we examine, following Katsoulacos and Xepapadeas (1996a), optimal emission taxes for the case of an n-firm homogeneous product oligopoly with fixed entry costs F, using the OACM framework.

The standard Cournot-Nash solution obtained when firms maximize their profits with respect to output q and abatement a, taking the actions of their rivals as given, is considered, for any emission tax t. Denoting the inverse demand function by $p=P(Q)$, as before, with Q denoting now total output produced by the $i=1,\ldots,n$ firms, or $Q=\sum_i q_i$, the problem for the firm is:

$$\max_{q_i, w_i} \pi_i = P(Q)q_i - c(q_i,a_i) - F - ts(q_i,a_i) \tag{5.9}$$

The first-order necessary conditions for a symmetric Cournot-Nash equilibrium choice of output and abatement (q^N, a^N) can be written as:

$$P(nq^N) + q^N P'(nq^N) = \frac{\partial c(q^N,a^N)}{\partial q} + t\frac{\partial s(q^N,a^N)}{\partial q} \tag{5.9.1}$$

$$\frac{\partial c(q^N,w^N)}{\partial a} = -t\frac{\partial s(q^N,a^N)}{\partial a} \tag{5.9.2}$$

Conditions (5.9.1) and (5.9.2) have the same interpretation as the first-order conditions for profit maximization of a monopoly derived earlier in this chapter. Solving the system of first-order conditions, by assuming that the second-order conditions are satisfied, the Nash equilibrium values of q and a are defined as functions of the tax rate, t, and the number of firms, n, as:

$$q^N = q^N(t,n),\ \frac{\partial q^N}{\partial t}<0,\ a^N(t,n),\ \frac{\partial a^N}{\partial t}>0$$

Thus an increase in the emission tax decreases the Nash equilibrium values of output and increases the Nash equilibrium value of abatement expenses.

The environmental regulator chooses the optimal second-best emission tax, t^N, by maximizing the usual welfare indicator defined as consumer and producer surplus. In this welfare function output and abatement are functions of the tax t and the number of firms n since output and abatement are substituted by their Nash equilibrium values defined above.

$$\max_t W = \int_0^{nq^N} P(u)\,du - nc(q^N,a^N) - D(ne^N) - nF, \tag{5.10}$$

where $\quad e^N = s(q^N,a^N)$

The first-order necessary condition for maximum implies:

$$\frac{\partial W}{\partial q}\frac{\partial q^N}{\partial t} + \frac{\partial W}{\partial a}\frac{\partial a^N}{\partial t} = 0$$

After some manipulations similar to those in Section 2.1 of this chapter, the second-best emission tax is defined as:

$$t^N = D'(ne^*) - \frac{P}{n|\varepsilon|}\frac{\partial q}{\partial e} = D'(ne^*) - \left|(P-MC)\frac{\partial q}{\partial e}\right| \tag{5.11}$$

In the above formulation the level of optimal emissions e^* is defined from the solution of the welfare maximization problem for the n-firms market where the regulator is not constrained by the pricing policy of the firms. Thus e^* is the first-best emission level derived by the solution of the problem:

$$\max_{q,a} W = \int_0^{nq} P(u)\,du - nc(q,a) - D(ne) - nF,\ \ e = s(q,a)$$

The second-best tax defined in (5.11) generalizes the optimal emission tax obtained for monopoly (Barnett 1980, Misiolek 1980) for the case of oligopoly. The fixed number oligopoly emission tax is identical to the monopoly tax when $n=1$.[23] Thus, as in the case of monopoly, in a fixed number homogeneous product oligopoly, the second-best

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[23]For a similar result see Ebert (1991/92). For the effects of the emission tax on the output of an oligopolistic industry see Conrad and Wang (1993).

optimal emission tax is less than marginal external damages of pollution.

6. The International Dimension of Environmental Policy

1 INTRODUCTION

In the analysis of environmental policy presented in the previous sections it was assumed that emissions, or more generally environmental pollution, does not cross national boundaries.

When this assumption is relaxed we are able to analyse environmental problems that go beyond cases where pollution and its effects are concentrated in one country only, and move to cases where activities in one country create negative externalities not only in the country itself but also in other countries. Such problems include the pollution of rivers and lakes that border more than one country[24] – a transboundary pollution problem – and regional or global environmental problems, such as acid rains, ozone depletion and global warming.

Acid rains relate to the emission of sulphur and nitrogen oxides which are transported by wind in the atmosphere. Chemical processes transform sulphur oxide into sulfates which are removed from the atmosphere by direct 'dry' deposition or by rains' 'wet' deposition. These depositions damage the ecosystems, mainly the forests, of countries different from those in which emissions originated.

Ozone depletion refers to the depletion of the earth's stratospheric ozone,[25] which acts as a shield for the earth by absorbing harmful infra-red radiation. Chlorofluorocarbons (CFCs), which are chemical compounds present in a large number of industrial processes – such as aerosols, home refrigerators, air conditioning – are responsible for ozone depletion.

Global warming, also referred to as the 'greenhouse problem', is associated with the accumulation in the atmosphere of the greenhouse gases (GHGs) and water vapour which trap part of the earth's outbound radiation (longwave radiation), thus increasing the earth's average surface temperature. Anthropogenic emissions from the burning of fossil fuels have led to a rise in the concentration of carbon dioxide by about 25 per cent as compared to the preindustrial level. The increase in the earth's temperature is expected to produce major and potentially disastrous changes in the long run, such as a rise in the sea level, change in rainfall and wind patterns, shift in agricultural zones.[26]

2 GLOBAL POLLUTION AND ENVIRONMENTAL POLICY

From the point of view of resource allocation, the problem associated with transboundary or global pollution belongs to the theory of the voluntary provision of public goods, or more precisely 'public bads', since global pollution satisfies the basic characteristics of a public good, namely nonrivalry in consumption and nonexcludability.

The general methodological approach in dealing with these problems is to: (i) determine the laissez-faire equilibrium where countries choose their emission levels without taking into account the external costs imposed on other counties; (ii) determine a cooperative equilibrium where countries determine their emissions so that a Pareto efficient outcome is obtained; (iii) establish the inefficiency of the laissez-faire or noncooperative equilibrium compared to the cooperative case; and (iv) propose a course of action that can achieve the efficient outcome, which is the global pollution level that satisfies the Pareto criterion.

This approach is similar to the one used to deal with local pollution problems, where the inefficiency of

[24]More than two hundred river basins are multinational, and in more than fifty countries 75 per cent of their total water areas lie in international basins. This is in addition to ocean bodies which are common access international resources

[25]Ozone in the troposhere, which is located below the stratosphere, is a regular air pollutant that relates to health effects such as respiratory problems, and agricultural damages.

[26]A common characteristic of the three problems mentioned above, but also of transboundary pollution problems in general, is that they have common or open access characteristics, since the environmental resource is used by more than one country. As is well known, in such cases outcomes related to laissez-faire are inefficient, leading to overemission of pollutants, since each country chooses its emissions by ignoring the cost imposed by its behaviour on other countries. These inefficiencies will be examined in the subsequent sections.

competitive markets as compared to the social welfare optimum is established and then appropriate policy is designed to secure the welfare-maximizing outcome. This similarity would imply that, in principle, the general policy framework for correcting environmental externalities developed in the previous chapters of this book can be used as a basis for designing policies capable of dealing with global pollution problems. There is, however, one important institutional difference stemming from the 'voluntary provision' aspect of the global pollution problems. When dealing with a pollution problem which is confined within the boundaries of one nation, whatever policy is chosen by the environmental regulator can be enforced (within of course the limitations imposed by the enforcement and informational constraints discussed in previous chapters), given the legal framework of the country which describes the ways in which such policies are implemented. When, however, a global environmental problem is examined, there is not a regulator *per se* vested with the power to enforce a given policy in a number of nations. This would require the existence of some supranational authority with the legal power to enforce policies on different nations.[27] In the absence of such an authority capable of imposing and enforcing the policy, the policy needs to be agreed upon. So, when international environmental problems are examined, the analysis should shift from the context of government intervention – the regulation approach – to the context of negotiations between nations and international policy coordination.

Negotiations among nations should lead to some international agreement specifying policies which should be adopted by countries participating in the agreement. For example the 1985 Helsinki Protocol required the signatory countries to reduce SO_2 emissions by 30 per cent as compared to the 1980 levels, while the Montreal Protocol, signed in 1987 and further amended in London in 1990, required a complete ban on production and consumption of certain CFCs by the year 2000. The proposed European carbon tax would require EU counties to impose a tax on the carbon context of fossil fuels. Thus an international agreement should refer either to the adoption by all countries of a specific policy instrument, like an international tax on emissions or some internationally applied quota system, or to the adoption by the signatory countries of the obligation to reduce domestic emissions in a uniform or a discriminatory way by following some type of national environmental policy.[28]

A major problem however with international agreements either to adopt an internationally-designed instrument or to reduce emissions through domestic policies, is the free-riding incentives which develop because of the common access character of the environmental problem and which can seriously impede the sustainability of the agreement. It might be in a country's best interest not to participate in the agreement to reduce emissions when the rest of the countries participate, since by doing so it can reduce its own cost of abating pollution and enjoy the benefits from the overall pollution reduction brought about by the cooperation of the rest of the countries. If countries have strong free-riding incentives, the agreement cannot be sustained.

This situation corresponds to the well-known prisoners' dilemma. For a transboundary pollution problem involving two countries, the game is shown in the pay-off matrices (a) and (b) below.

Country 2

		D	C
	D	(n_1,n_2)	(z_1,v_2)
Country 1	C	(v_1,z_2)	(b_1,b_2)

(a)

Country 2

		D	C
~~Country 1~~	D	(0,0)	(5,-1)

[27]The European Union can be regarded as such an authority. However in the EU, policies need to be agreed upon, and as discussions in recent years about the introduction of a European carbon tax reveal, agreement on environmental policies which could impose a financial burden on the member states in exchange for global environmental benefits is by no means guaranteed.

[28]The United Nations Environmental Programme lists 132 multilateral agreements adopted before 1991 and several that were adopted afterwards.

	C	(-1,5)	(3,3)

(b)

In these matrices D means 'defect' from the agreement to reduce emissions and C means 'cooperate' in reducing emissions. Assume that the values of net benefits (or welfare levels) corresponding to the different courses of action available to the countries are as in the pay-off matrix (b). In this game defect is the dominant strategy, since it maximizes the pay-off of each country for any strategy that the other country might follow. So the Nash equilibrium for this game is (0,0): no agreement for emission reduction can be reached or sustained in this one-shot game.

However, both countries would have been better off by cooperation. That is, by entering the agreement and cooperating in emissions reduction, the pay-offs for each country under cooperation are individually rational as compared to the pay-offs under mutual defection, or $(b_1,b_2)>(n_1,n_2)$. So, if the time horizon is extended in the context of an infinitely repeated game, then the folk theorem can be invoked to show that cooperation can be sustained. Let π_{it} be the pay-off of country i at time t. Then the present value of the pay-off for the country using α as the discount factor is given by:

$$PV_i = \sum_{t=0}^{\infty} \alpha^t \pi_{it}$$

According to the folk theorem, if countries maximize the present value of their pay-off, then the cooperative solution can be sustained, for a sufficiently low discount rate, by using an appropriate trigger strategy as long as the condition $(b_1,b_2)>(n_1,n_2)$ is satisfied. Using for example the values of the pay-off matrix (b), and a discount factor equal to 0.90, cooperation results in a pay-off for each country of $3(1+0.9+0.9^2+...)=30$. Consider the following strategy: Country 1 cooperates to reduce emissions at the beginning of the horizon and continues to cooperate as long as both countries have cooperated in the past. If, however, country 2 defects then country 1 will forever resort to the policy of defection (no agreement). If country 2 follows the same strategy then both counties will have a pay-off of 30 each. If country 2 takes advantage of country 1's willingness to cooperate (reduce emissions) and cheats at the beginning of the time horizon, it will receive 5 at the beginning and zero at each subsequent time period, for a total pay-off of 5. It is clear that in the context of a repeated game with an appropriate trigger strategy, free riding can be eliminated and cooperation to reduce emissions through an international agreement can be sustained. A trigger strategy can be recognized in the 1957 North Pacific Seal Treaty (Article 12).

Cooperation however cannot be sustained, even in the repeated game framework, if moving from the noncooperative equilibrium to cooperation creates gainers and losers, as can be seen in pay-off matrix (c).

		Country 2	
		D	C
	D	(0,0)	(5,-3)
Country 1	C	(-1,2)	(4,-1)

(c)

Although cooperation to reduce pollution increases the joint pay-off, since $(b_1+b_2)>(n_1+n_2)$ in terms of the notation of pay-off matrix (a), cooperation is not however individually rational since country 2 is better off without the agreement. Under this situation of asymmetries among countries, extension of the time horizon cannot sustain cooperation to reduce emissions, and free riding incentives prevent international agreement unless further elaborations are made.

Thus this analysis suggests that international agreements among countries should be designed to be sustainable, that is, to overcome countries' incentives to cheat or defect from the agreement, when asymmetries require the use of side payments or issue linkage, in addition to trigger strategies, or when the repeated game framework cannot be regarded as appropriate. Therefore in the subsequent sections we mainly focus on: (i) how agreements leading to international cooperation regarding global environmental problems can be formed and sustained, and (ii) how some standard environmental policy instruments can be extended to international environmental problems so that both the structure of the policy scheme and the type of the agreement necessary for the implementation of the scheme are determined.

2.1 INTERNATIONAL ENVIRONMENTAL AGREEMENTS

The basic question in the case of international environmental agreements is whether sovereign countries can voluntarily – since there is no authority to force them to cooperate – reach an agreement to protect the international commons by cutting down domestic emissions.

Three main approaches have been developed in the literature regarding this issue. The first approach analyses the problem in terms of agreements of subgroups of countries, which seek to expand the agreement to reduce emissions by inducing other countries to join the agreement through self-financing welfare transfers. The second analyses the problem in the context of a cooperative game with externalities and derives conditions under which a group of countries can agree to reduce emissions to a desired level in a cooperative way, and share total costs including abatement costs and environmental damages in such a way that every country is better off by cooperation. The third refers to issue linkage where agreement on the environmental issue is linked to agreement on another issue in such a way that the agreement on both issues is sustainable.

Bibliography

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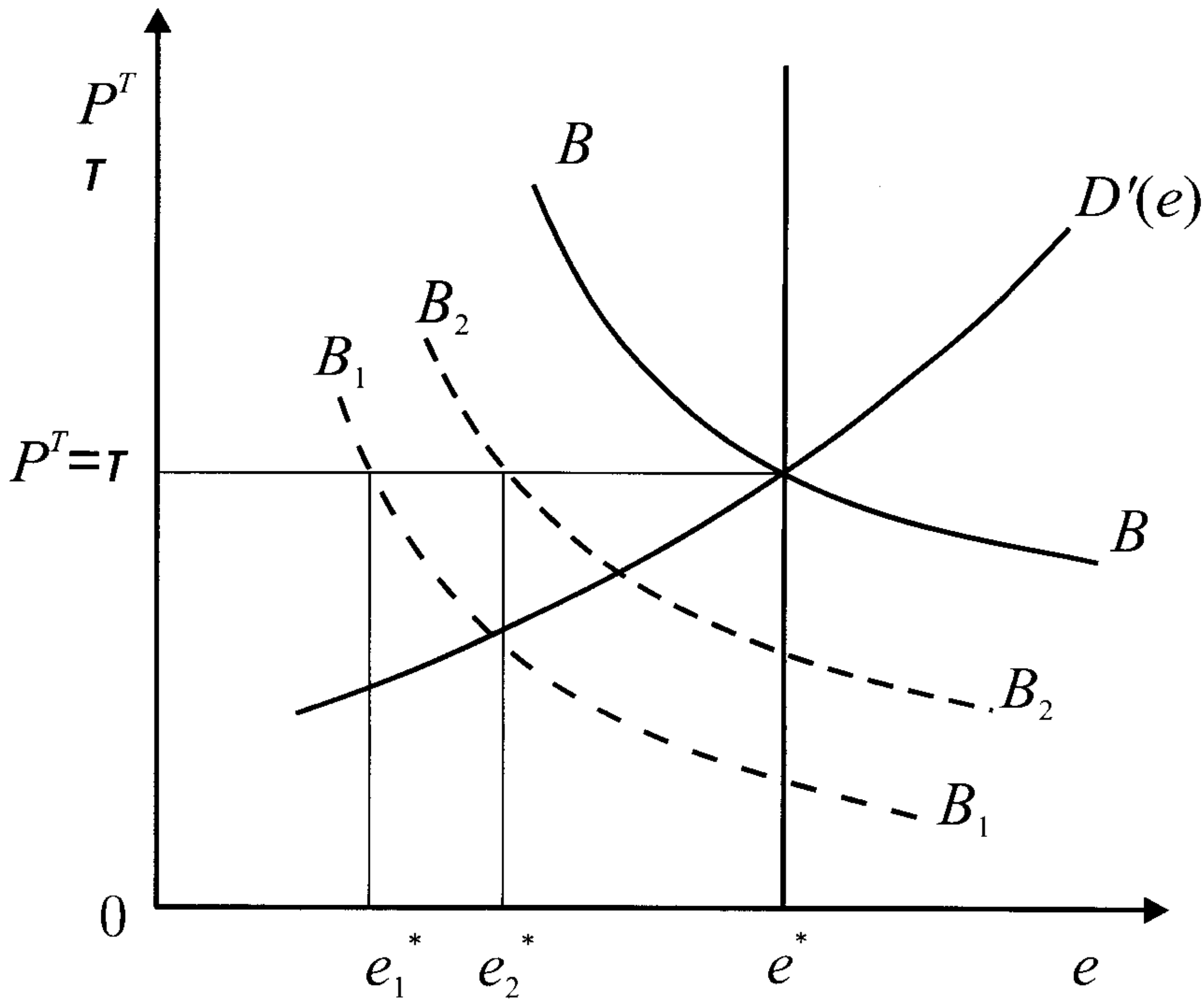
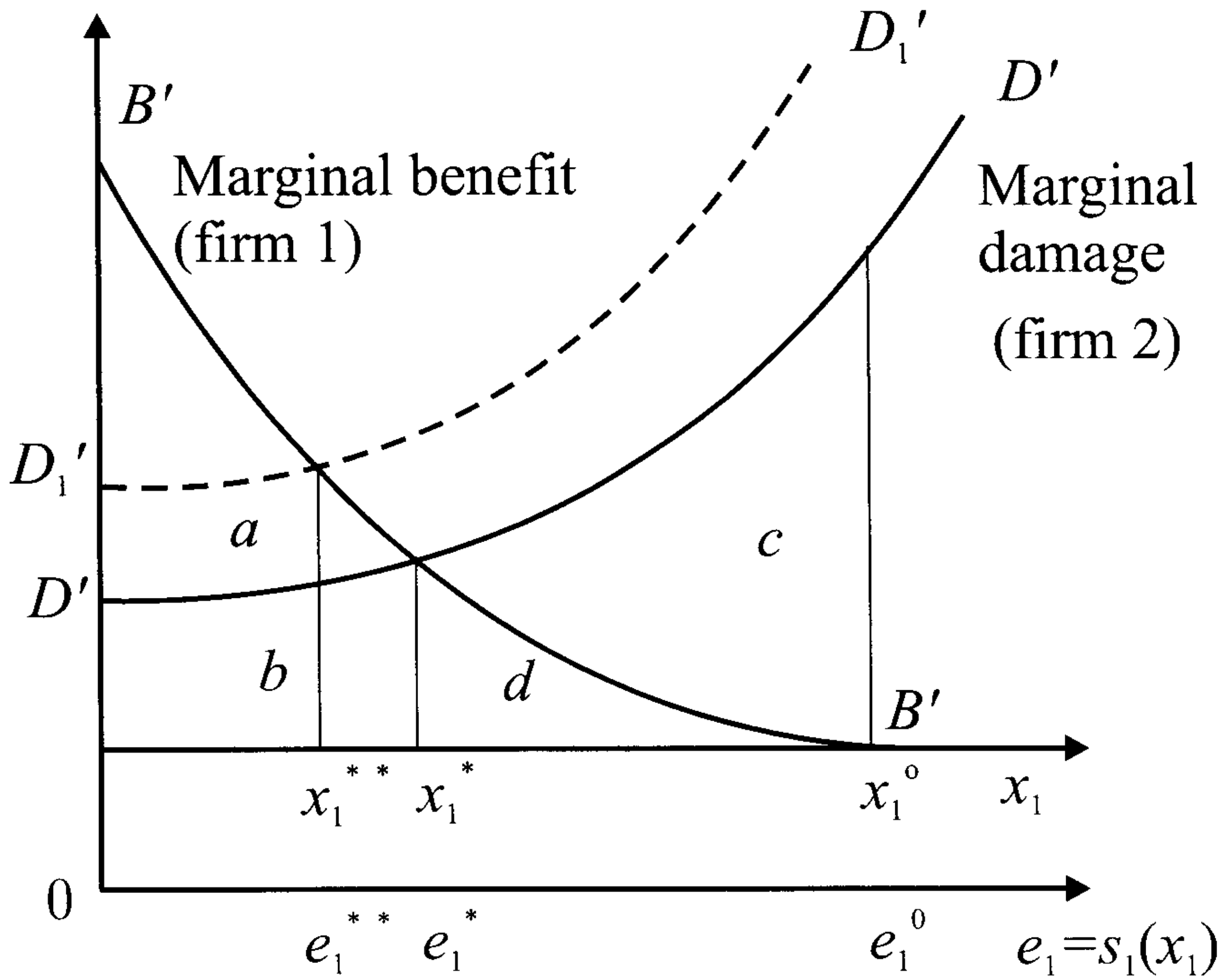
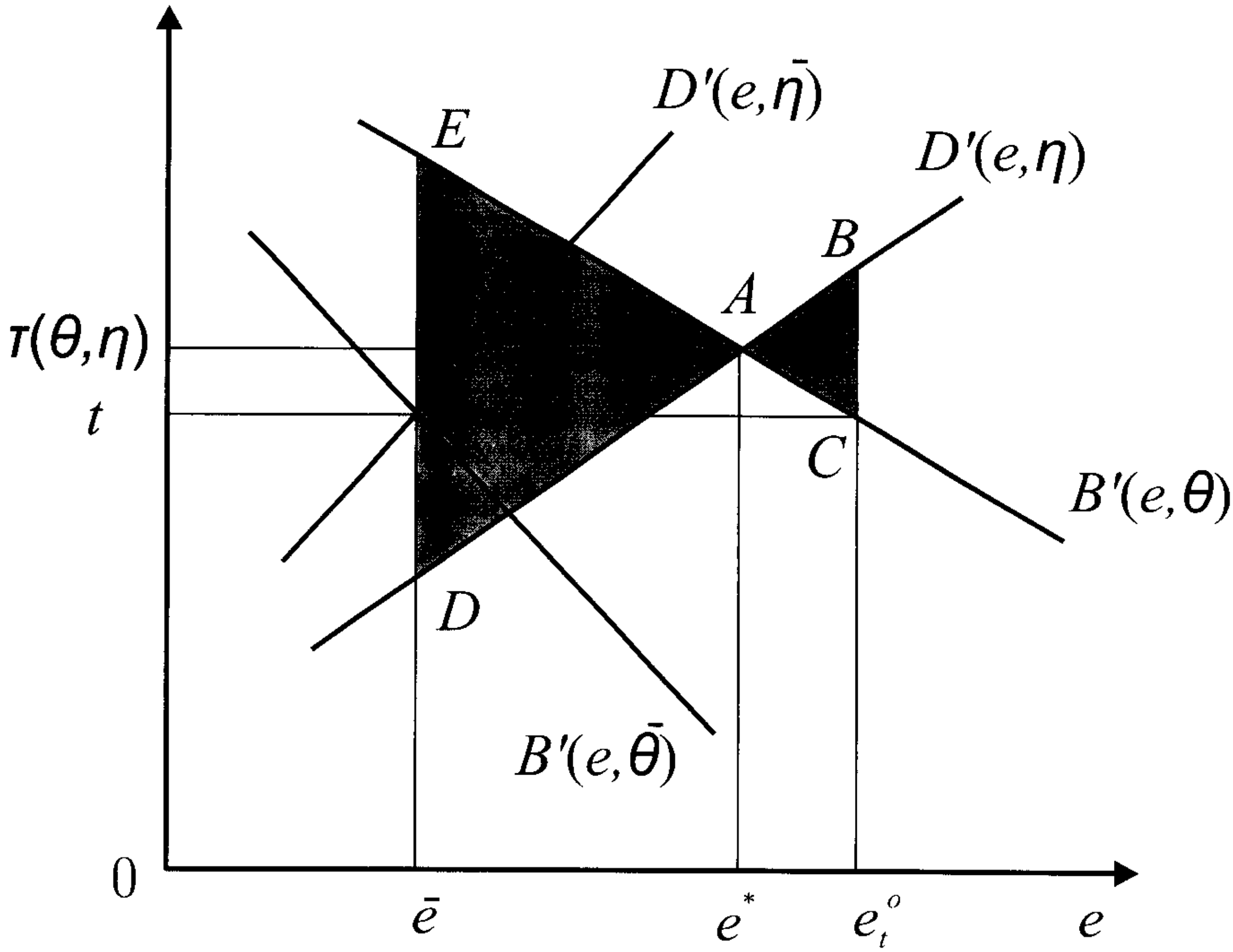


F2.1



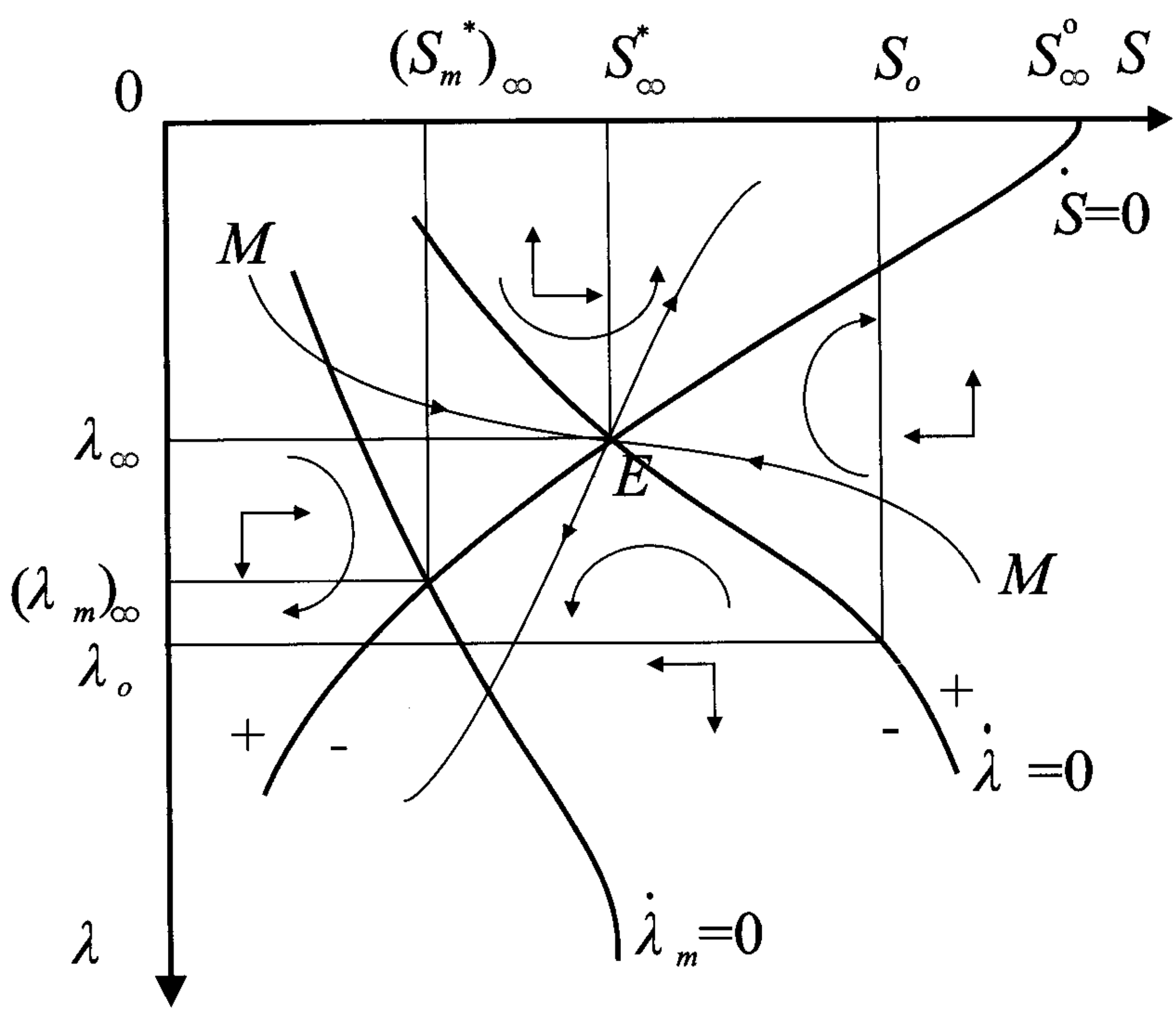
D_1'
D'
B'
Marginal benefit
(firm 1)
Marginal
damage
(firm 2)
D_1'
a
c
D'
b
d
B'
x_1^{**} x_1^{*}
x_1^{o}
x_1
0
e_1^{**} e_1^{*}
e_1^{0}
$e_1 = s_1(x_1)$

Fig. 2.2



$D'(e,\bar{\eta})$
$D'(e,\eta)$
E
B
A
$\tau(\theta,\eta)$
t
C
$B'(e,\theta)$
D
$B'(e,\bar{\theta})$
0
$\bar{e}$
e^*
e_t^o
e

F2.3



0
$(S_m^*)_\infty$
S_∞^*
S_o
S_∞^o
S
$\dot{S}=0$
M
M
E
λ_∞
$(\lambda_m)_\infty$
λ_o
λ
+
-
+
-
$\dot{\lambda}=0$
$\dot{\lambda}_m=0$

Fig. 3.1