Lecture Notes in
Environmental Policy: Theory and Applications

by

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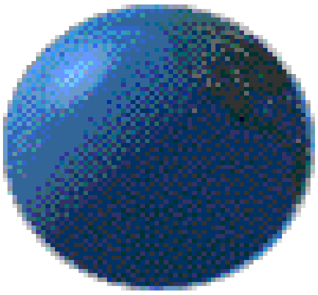

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1 Basic Environmental Policy Framework

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.

A basic framework for environmental policy design is developed, 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. As it can be shown, when more distortions, such as informational asymmetries or market imperfections, are included along with the environmental externality, then more complex instruments become necessary.

The models and the policy instruments developed in this chapter, although relatively straightforward, provide the basis for the extensions necessary to analyse issues such as stock pollution and dynamics, informational constraints, market imperfections or international considerations.

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.[1]

2.1 Descriptive Models of Industrial Pollution and Social Damages

We start the exposition by considering a market of $i=1,\ldots,n$ firms that behave competitively. The firms produce a homogeneous output q_i and during production generate emissions e_i. Let $x_i=(x_{i1},\ldots,x_{iM})$ 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:

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[1] As it will become clear later on, when the objective is to explore pollution dynamics, an emission choice model could be used for a better exposition of the dynamic characteristics of the model. An output-abatement choice model is better suited to analysing the effects of market imperfections and strategic behavior among firms, while an input choice model is more useful when the impact of environmental policies on the input choices of the firms is examined.

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

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:

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

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

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

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.[2] 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 $e_i^G = s_i(x_i^p)$.[3] 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:

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

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

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[2] The cost function is convex by the concavity of the production and the abatement functions.

[3] The same symbol s_i is used to denote the gross emissions function as well as emissions after abatement. This method of notation was adopted in order to have a uniform notation of marginal emissions since by the separability of net emissions in productive and abatement inputs, marginal gross emissions changes are also marginal net emissions changes. However, it is always indicated in the text whether the net (that is, after abatement) or gross emissions function is used.

his/her utility by purchasing the traded goods at a price $\varrho=(\varrho_1,\ldots,\varrho_N)$, is defined as:

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

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

Assuming a quasi-linear utility function in a numeraire commodity the derived utility function can be written, as:

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

where we assume that ϕ_j is twice-differentiable with $\phi_j^{/}<0$, and $\phi_j^{//}<0$. Define the individual damage function for the jth consumer as $d_j(E)=-\phi_j(E)$. 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 $D^{/}(E^*)=\Sigma_{j=1}^{J} d_j^{/}(E^*)$, which is the sum of the consumers' marginal damages from emissions, condition (2.1) is Samuelson's optimality condition for a public bad.

2.2.2 Output-abatement choice model (OACM)

In this model social welfare is defined as the sum of consumers' and producers' surplus less environmental social damages. Let $p=P(Q)$, $Q=\Sigma_{i=1}^{n} q_i$ be the market inverse demand function.[4] Thus, the social planner (or regulator) solves the problem:

$$\max_{(q_i,\alpha_i)\geq 0}\ \int_0^{\Sigma_i q_i} P(Q)\,dQ-\sum_{i=1}^{n} c_i(q_i,\alpha_i)-D(E)$$

$$E=\sum_{i=1}^{n} e_i,\ e_i=s_i(q_i,\alpha_i) \tag{OACM}$$

The optimality conditions require:

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[4] The demand function is independent of emissions if it is assumed that the individual utility functions are quasilinear with respect to emissions.

$$P(Q^{*}) - \frac{\partial c_i(q_i^{*},\alpha_i^{*})}{\partial q_i} - D'(E^{*})\frac{\partial s_i(q_i^{*},\alpha_i^{*})}{\partial q_i} \le 0, \quad \text{with equality if } q_i^{*} > 0 \tag{2.2.1}$$

$$-\frac{\partial c_i(q_i^{*},\alpha_i^{*})}{\partial \alpha_i} - D'(E^{*})\frac{\partial s_i(q_i^{*},\alpha_i^{*})}{\partial \alpha_i} \le 0, \quad \text{with equality if } \alpha_i^{*} > 0 \tag{2.2.2}$$

For interior solutions, condition (2.2.1) indicates that at the social optimum output should be chosen so that marginal benefits equal marginal production costs plus marginal external damages, that is marginal social costs. From (2.2.2), at the optimal level of abatement, marginal abatement costs should be equal to marginal external damage savings due to abatement.

The same model can be used to analyse long-run considerations. Assume that firms are identical, that free entry exists, and that newly established firms incur positive fixed costs *F*. The social planner not only seeks the socially-optimal emission level in the short run, but also the optimal pollution in long-run equilibrium. This implies choice of the socially-optimal number of firms in long-run equilibrium. Under symmetry $Q = nq$ and the planner solves:

$$\max_{(q,\alpha,n)\ge 0} \int_0^{nq} P(Q)\,dQ - nc(q,\alpha) - nF - D(ne)$$

The optimality conditions for the output and abatement choice are similar to (2.2.1) and (2.2.2), with $q_i^{*} = q^{*}$, $\alpha_i^{*} = \alpha^{*}$ for all *i*, and $E^{*} = ne^{*}$. The condition for the optimal choice of the number of firms *n*, assuming an interior solution, is:

$$P(n^{*}q^{*})q^{*} - c(q^{*},\alpha^{*}) - F - D'(n^{*}e^{*})e^{*} = 0 \tag{2.3}$$

This is the zero profit condition indicating that at the social optimum private revenues equal private costs plus social damages.

2.2.3 Input choice model (ICM)

In this model the planner chooses productive and abatement inputs to maximize social welfare defined as above by net surplus. The problem is:

$$\max_{(x_i^{p},\,x_i^{a})\ge 0} \int_0^{\Sigma_i f(x_i^{p})} P(Q)\,dQ - \sum_{i=1}^{n}\left(w^{p}\cdot x_i^{p} + w^{\alpha}\cdot x_i^{\alpha}\right) - D\left(\sum_{i=1}^{n}\left[s_i(x_i^{p}) - h_i(x_i^{\alpha})\right]\right) \tag{ICM}$$

The optimality conditions imply that:

$$p\frac{\partial f_i(x_i^{*p})}{\partial x_i^{p}} - w_i^{p} - D'\frac{\partial s_i(x_i^{*p})}{\partial x_i^{p}} \le 0, \quad \text{with equality if } x_i^{*p} > 0 \tag{2.4.1}$$

$$D'\frac{\partial h_i(x_i^{*\alpha})}{\partial x_i^{\alpha}} - w_i^{p} \le 0, \quad \text{with equality if } x_i^{*\alpha} > 0 \tag{2.4.2}$$

Thus for interior solutions the marginal value product of the productive (and polluting) inputs equals marginal social costs, while marginal damage savings due to abatement inputs equal their competitive prices.

It is clear that all three models described above lead to equivalent results, implying always equality between marginal benefits and marginal social costs. Suppose that we are in an unregulated competitive equilibrium. It can easily be shown that this equilibrium is suboptimal in the sense that emissions exceed the socially-optimal emission level. Consider for example the ECM. The unregulated firm solves the problem $\max_{e_i} B(e_i)$ with necessary and sufficient first-order condition:

$$B_i'(e_i^{o}) \le 0, \quad \text{with equality if } e_i^{o} > 0$$

Comparing this condition with (2.1) it is clear that for interior solutions, that is $e_i^o > 0$, we have $e_i^o > e_i^*$ for all i. The same result extends to the other two models. In fact with quasi-linear individual utilities in emissions, unregulated firms will do zero abatement, and thus maximize total emissions.

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.[5]

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

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

Since $\tau = D'\left(\sum_i e_i^*\right)$, 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 $e_i^o = e_i^*$.

This result can be formally proven in an optimal taxation set-up. The social planner or environmental regulator seeks to maximize social welfare by choosing emission levels and tax rates under the constraint that firms maximize profits under the given tax regime. The problem can be written as:

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

$$\text{subject to}$$

$$e_i = \operatorname*{argmax}_{\mathrm{e_i}} B_i(e_i) - \tau e_i \text{ for all } i$$

Since the optimization constraints correspond to strictly concave optimization problems, they can be replaced by the corresponding first-order conditions. Then the problem becomes:

$$\max_{e_i, \tau_i \geq 0} \sum_i B_i(e_i) - D(\sum_i e_i)$$

$$\text{s. t. } B'(e_i) - \tau \leq 0$$

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[5] OECD has played an important role in advocating the use of economic instruments for environmental management.

The Lagrangean function for this problem is written as:

$$\mathcal{L}=\sum_i B_i(e_i)-D\left(\sum_i e_i\right)-\sum_i \lambda_i\left(B_i^{\prime}(e_i)-\tau\right)$$

where λ_i is the Lagrangean multiplier. The first-order condition implies that $(e_i^*,\tau^*,\lambda_i)\geq 0$ exists for all *i* such that:

$$B^{\prime}(e_i^*)-D^{\prime}\left(\sum_i e_i^*\right)-\lambda_i B_i^{\prime\prime}(e_i^*)\leq 0,\ \text{with equality if } e_i^*>0 \tag{2.5.1}$$

$$\lambda_i\leq 0,\ \text{with equality if } \tau^*>0 \tag{2.5.2}$$

$$B_i^{\prime}(e_i^*)-\tau^*\leq 0,\ \lambda_i\left(B_i^{\prime}(e_i^*)-\tau^*\right)=0,\ \lambda_i\geq 0 \tag{2.5.3}$$

Thus from (2.5.2) and (2.5.3), $\lambda_i=0$ for all *i* and from (2.5.1) and (2.5.3) for firms with positive emissions we have $\tau^*=B_i^{\prime}(e_i^*)=D^{\prime}\left(\sum_i e_i^*\right)$.

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

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

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

By taking the first-order conditions it can be shown that for $\tau=D^{\prime}$:

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

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

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 $\tau=D^{\prime}(n^*e^*)$, the optimal allocation under the regulated market equilibrium will reproduce the socially-optimal allocation, or $(q^o,\alpha^o,n^o)=(q^*,\alpha^*,n^*)$.

3.2 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:

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

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 $v=D^{\prime}(n^*e^*)$, 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 $e^{*}=\Sigma_i e_i^{*}$ be the total number of permits issued by the environmental regulator and let $\tilde{e}_i$ with $\Sigma_i \tilde{e}_i = e^{*}$ 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. Using comparative statics, we obtain:[6]

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

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

where $D = P^{T}(c_{q_i q_i}s_{\alpha_i\alpha_i} - s_{\alpha_i q_i}c_{\alpha_i q_i}) > 0,\; c_{q_i q_i},\; s_{a_i a_i} > 0,\; s_{\alpha_i q_i} > 0,\; c_{\alpha_i q_i} > 0$

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 $P^{T} = D^{\prime}(e^{*})$. The market creates the correct incentive for firms which

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[6] Subscripts denote partial derivatives.

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:

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

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 *i*th 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. Assume 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:

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

with necessary and sufficient first-order conditions:

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

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

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:

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

with necessary and sufficient first-order conditions

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

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

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:

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

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

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

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 $\tau = \left[D's'(x^{*p})\right] / \left[f'(x^{*p})\right]$, 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.

Carraro and Siniscalco in analysing voluntary agreements, suggest that their use 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:

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

The Lagrangean function for this problem is defined as:

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

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:

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

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

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

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.[7]

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:

$$\max_{q_i\geq 0,\,\alpha_i} \; pq_i - c_i(q_i,\alpha_i) \qquad \text{s t. } \alpha_i \geq \bar{\alpha}_i$$

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

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[7] The discussion about the comparison between charges and command and control is extensive; it will be analysed in more detail later in this chapter. One of the major difficulties with the application of charges is the size of the informational requirements necessary for its application. Although these requirements are inherent in any application of optimal policies, nevertheless they acquire important practical significance when the optimal policies need to be transformed into actual policies. In this respect emission permits may possess some informational advantages.

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

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

$$(\alpha_i^o - \bar{\alpha}_i) \geq 0, \ \mu_i(\alpha_i^o - \bar{\alpha}_i) = 0, \ \mu_i \geq 0 \tag{2.15.3}$$

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 $f_1(x_1)$.[8] 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[9] 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

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[8] Since no abatement inputs are considered, x refers to productive inputs only and the superscript p is omitted to simplify the notation.
[9] Interior solutions are assumed throughout this problem.

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 $D(e_1)$.[10] Thus the regulator solves the problem:

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

The first-order conditions for an interior maximum are:

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

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

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 *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 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.[11] 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.[12] 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

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[10] 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.

[11] 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.

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

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. Consider the problem in the framework of Section 4, in which party 1 is the upstream firm (the factory which pollutes the water), while party 2 is the downstream firm (the farmer who uses the polluted water for irrigation), and set more general environmental damages at zero, $D(e_1)=0$. Assume that the farmer has the right to clean water. In this case, the property rights are assigned to the farmer and the firm can not emit without the farmer's permission. The firm engages in negotiations and makes the farmer an offer of a payment T in order to obtain permission to emit. Party 2 (the farmer) must decide how much pollution to accept in the water and how much payment to ask, while party 1 (the firm) will meet the farmer's demand as long as the firm is as well-off by paying T for a certain allowable level of emissions as in the case in which no emissions would have been allowed, that is $e_1=0$. Since emissions are related to the use of the polluting input x_1, the firm will pay the farmer T if and only if:

$$p_1 f_1(x_1) - w_1 x_1 - T \geq 0, \text{ since } e_1 = 0 \Rightarrow x_1 = 0 \text{ and } f_1(0) = 0$$

Under these circumstances, party 2 solves the problem:

$$\max_{(x_2, e_1) \geq 0,\, T} \; p_2 f_2(x_2, e_1) - w_2 x_2 + T, \; e_1 = s_1(x_1)$$

$$\text{s. t. } p_1 f_1(x_1) - w_1 x_1 - T \geq 0$$

In the above problem the constraint is binding at any solution, thus $T = p_1 f_1(x_1) - w_1 x_1$. By substituting for T in the objective function, the problem for party 2 – the farmer – is to choose the levels of (x_1, x_2) that solve:

$$\max_{x_1, x_2 \geq 0} \; p_2 f_2(x_2, e_1) - w_2 x_2 + p_1 f_1(x_1) - w_1 x_1 \tag{2.19}$$

But as shown in the previous section the solution to this problem determines the socially-optimal levels of the two inputs for $D(e_1)=0$.

Consider now the case where party 1 has the property rights, which means that there are no rights for clean water, and the factory can emit at the level that maximizes profits or at x_1^o with $e_1^o = s_1(x_1^o)$ as determined in Section 4. Party 2 enters negotiations and offers T to party 1 to reduce emissions below e_1^o. The offer of T should be such that party 2 will be at least as well-off as in the case where profit-maximizing emissions e^o were generated by party 1. Thus party 2 will pay party 1 the amount T if and only if

$$p_2 f_2(x_2, e_1) - w_2 x_2 - T \geq p_2 f_2(x_2^o, e_1^o) - w_2 x_2^o \tag{2.20}$$

Party 1, the factory, then solves the problem:

$$\max_{(x_1, x_2) \geq 0,\, T} \; p_1 f_1(x_1) - w_1 x_1 + T, \text{ subject to } (2.20)$$

Since the constraint is always binding at the solution, the above problem is equivalent to:

$$\max_{x_1, x_2 \geq 0} \; p_1 f_1(x_1) - w_1 x_1 + p_2 f_2(x_2, e_1) - w_2 x_2 + p_2 f_2(x_2^o, e_1^o) - w_2 x_2^o \tag{2.19.a}$$

which again leads to the socially-optimal input levels.

In both cases above, that is with property rights to either 1 or 2, the outcome of the bargaining is not affected by the initial allocation of the property rights. The initial allocation of the property rights affects the profits of the parties at the solution.

Coase's theorem can be shown diagrammatically in Figure 2.2. The $B'B'$ curve reflects marginal benefits to party 1 from using the pollution generating input x_1. Thus $B'B'$ is defined by $(p_1 f_1'(x_1) - w_1)$ and has a negative slope because of the assumptions about the production function. Damages to party 2 are determined by the marginal damage function $D'D'$, which is determined by the maximum profit function of party 2, as:

$$\pi_2(x_1) = \max_{x_2} \; [p_2 f_2(x_2, s_1(x_1) - w_2 x_2] \tag{2.21}$$

By the envelope theorem $\pi_2'(x_1) = p_2(\partial f / \partial s_1) s_1'(x_1)$. Assume also that $\pi_2''(x_1) < 0$, then the marginal damage curve $D'D'$ is determined by $-\pi_2'(x_1)$ and is upward sloping. Since emissions are determined by the strictly increasing emission function $e_1 = s_1(x_1)$, equilibrium in Figure 2.2 can be defined either in terms of the input or in terms of emissions. If the property rights belong to party 2 then party 1 will be willing to pay up to $a+b$, which is the total benefit from using the input up to level x_1^*, in order to use this amount of input with corresponding emissions e_1^*. Party 2 will accept anything above b in order to suffer damages implied by emissions at level e_1^*. On the other hand if party 1 has the property rights, then party 1 will be willing to accept anything above d (which represents total losses from reducing the input use from x_1^o to x_1^*) in order to reduce emissions from e_1^o to e_1^*, while party 2 will be willing to pay up to the area $c+d$ (which represents total damage savings from reduced emissions) for these reduced emissions. The socially-optimal emission level is obtained independently of the allocation of the property rights and no regulation is necessary.

Although Coase's theorem suggests that there is no need for intervention in the form of regulation to control environmental externalities, there are objections to the assumptions made in order to obtain the results. These assumptions reduce the importance of the theorem as a practical solution for controlling environmental problems.

In the example used above, as well as in Coase's examples, there are only two parties involved and no transaction costs. In the majority of environmental problems, however, more than two parties are involved. In our example pollution of the water by firm 1 can create more general environmental damages in the form, for example, of diminishing recreational opportunities or adversely-affected wildlife. These damages can be represented by the environmental damage function $D(e_1)$ which was assumed to be zero before. But when these damages are considered, the objective functions (2.19) or (2.19.a) are no longer the social welfare functions. Thus private negotiations between the two parties will not lead to the social optimum. In terms of Figure 2.2 general environmental damages mean that the marginal damage curve shifts upwards to $D_1^{\prime}D_1^{\prime}$. The social optimum is now at the point $x_1^{**} < x_1^*$. To reach the social optimum through negotiations, all the affected parties should be involved. This however definitely implies high transaction costs which have been assumed zero before. It can be shown that the existence of sufficiently high transaction costs may block private bargaining. Suppose that the property rights belong to firm 1 and that total damages to firm 2 and general environmental damages exceed the benefits from emitting at the profit-maximizing level x_1^o for firm 1. In order for the affected parties to make an offer to firm 1 to reduce pollution, these parties have to meet and agree upon the payment. If the transaction costs associated with the agreement among the affected parties are sufficiently high, the offer might not materialize. In this case there is excess pollution and the final outcome depends on the assignment of the property rights.

A deviation from the socially-optimal emissions level can also be the result of the bargaining process if one of the affected parties is a consumer, while the other is the polluting firm. In this case if the property rights belong to the firm, then the consumer's ability to make an offer is constrained by his or her income. This income constraint, if it is effective, could lead to a deviation from the social optimum. Assume that a firm with a reduced profit function $B(e)$ generates emissions that cause damages $d(e)$ to a consumer. If the property rights are assigned to the firm it will emit at a level e^o that maximizes its benefit function or $e^o = \operatorname{argmax}_e B(e)$. The consumer will make an offer T to the firm to reduce emissions to some level e if and only if $d(e)+T \le d(e^o)$, and $T \le M$, where M is the consumer's income. The firm will choose the level of emissions and a payment to demand from the consumer, that solves the problem:

$$\max_{(e,T)\ge 0} \; B(e)+T$$

$$\text{s. t. } d(e)+T \le d(e^o), \; T \le M$$

The Lagrangean for the problem is:

$$\mathcal{L} = B(e)+T+\lambda\left[d(e^o)-T-d(e)\right]+\mu(M-T)$$

The first-order condition for the above problem implies that (e^+, T^+, λ, μ) exist such that:

$$B'(e^{+})-\lambda d'(e^{+})\leq 0, \text{ with equality if } e^{+}>0 \tag{2.22.1}$$

$$1-\lambda-\mu\leq 0, \text{ with equality if } T^{+}>0 \tag{2.22.2}$$

$$d(e^{o})-T-d(e^{+})\geq 0,\ \lambda\left[d(e^{o})-T-d(e^{+})\right]=0,\ \lambda\geq 0 \tag{2.22.3}$$

$$M-T^{+}\geq 0,\ \mu(M-T^{+})=0,\ \mu\geq 0 \tag{2.22.4}$$

Suppose that at the solution $0<T^{+}<M$, then from (2.22.4) $\mu=0$ and from (2.22.2) $\lambda=1$, in which case (2.22.1) implies that $e^{+}=e^{*}$. That is, the socially-optimal level of emissions is obtained at the point where marginal benefits equal marginal environmental damages. Suppose now that $T^{+}=M$ and $0<\mu<1$, then from (2.22.2) $\lambda=(1-\mu)$ and from (2.22.1) $B'(e^{+})=(1-\mu)d'(e^{+})$, which implies that $e^{+}>e^{*}$.[13] Thus when the consumer faces a binding income constraint regarding payment demanded by the firm, the outcome of the bargaining process is inefficient.

The above results seems to suggest that although Coase's theorem offers some important insights into dealing with externalities through negotiations of the affected parties and without the need for government regulation, the assumptions that are necessary for the validity of the theorem are not in general satisfied in the great majority of environmental problems. As a result Coase's theorem does not seem to offer a practical alternative to environmental policy based on Pigouvian tradition.

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 $\tau(\theta,\eta)=D'(e^{*}(\theta,\eta),\eta)$. 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 in general, 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).

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[13] Using the implicit function theorem in $B'(e^{+})-(1-\mu)d'(e^{+})=0$, we have that $de^{+}/d\mu>0$. Thus an increase in μ from the value of zero will increase emissions.

7 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.

2 Dynamics and the Design of Environmental Policy

1 INTRODUCTION

The analysis of the environmental policy developed in the previous chapter 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.[14] 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,[15] 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:[16]

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

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

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

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.

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[14] 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 per cent or even 2.5 per cent.

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

[16] In a discrete time formulation, pollution accumulation is described by the first-order difference equation $S_t = e_t - (1-b)S_{t-1}$.

2 SOCIAL OPTIMUM AND MARKET EQUILIBRIUM 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:

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

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

$$\frac{\partial H}{\partial e_i} = B_i^{\prime}(e_i^*(t)) + \lambda(t) \leq 0, \text{ with equality if } e_i^*(t) > 0, \; \forall\, i \tag{3.3.1}$$

(ii)

$$\dot{\lambda}(t) = r\lambda(t) - \frac{\partial H}{\partial S} \text{ or } \dot{\lambda}(t) = (r+b)\lambda(t) + D^{\prime}(S^*(t)) \tag{3.3.2}$$

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

(iii) The Arrow type transversality conditions at infinity

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

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:

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

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.

3 The International Dimension of Environmental Policy

1 INTRODUCTION

In the analysis of environmental policy presented in the previous chapters, two assumptions were maintained. First it was assumed that emissions, or more generally environmental pollution, does not cross national boundaries. Second it was also assumed that the effects of environmental policy on international trade among countries, as well as the effects of trade policies on environmental quality in a given country, are not taken into account.

When the first 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[17] – 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

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[17] 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.

forests, of countries different from those in which emissions originated.

Ozone depletion refers to the depletion of the earth's stratospheric ozone,[18] 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.[19]

When the second assumption is relaxed, that is, along with the environmental considerations, trade among countries is also considered, the analysis can be conducted on two levels. The first concentrates on local pollution problems and focuses on the effects of environmental policy on environmental quality and countries' competitiveness. It has been argued for example that trade liberalization – the single European market, GATT – will result in a larger ratio of consumption of natural and environmental resources. It is also felt that in the absence of traditional trade policies, owing to trade liberalization, some countries could use lax environmental policies to improve their international competitiveness. Thus trade liberalization could create excess pollution in countries, and 'flight of capital' and loss of international market shares of countries that follow relatively tougher environmental policies. The second level of analysis considers trade policy in the context of transboundary or global pollution problems and analyses how trade policy can help to design and enforce international agreements for the protection of the environment in the presence of transboundary or global pollution problems.

The purpose of this chapter is to present economic policies relevant to transboundary or global pollution problems, as well as to examine some aspects of the interrelationships between international trade and environmental policy.

2 GLOBAL POLLUTION AND ENVIRONMENTAL POLICY

As noted by Chander and Tulkens, 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 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

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[18] 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.

[19] 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.

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.[20] 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.[21] 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.[22]

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**
	D	(0,0)	(5,-1)
Country 1	**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

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[20] 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.

[21] Further negotiations in Copenhagen moved the phase out of CFCs up to 1996.

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

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 $3(1+0.9+0.9^2+\ldots)=30$. 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.

3 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.

The above approaches to analysing environmental agreement rely on the concepts of cooperative and noncooperative games among countries and thus it is helpful to define these two concepts more precisely. A cooperative game reflects emission decisions taken together by all countries in cooperation, while a noncooperative game reflects emission decisions that satisfy the objectives of each single country itself, without the country taking into account the environmental damages caused by its emissions on the rest of the countries in the group.

4. Environmental Policy in Practice

The following section presents information from varius OECD publications on the applications of environmental policy

Box 1. **DEFINITIONS OF ENVIRONMENTAL TAX INSTRUMENTS**

Emission taxes involve tax payments that are directly related to the measurement (or estimation) of the pollution caused, whether emitted into air, water or on the soil, or due to the generation of noise. Emission taxes generally deal with one type of emission at a time. They are directed to the last link in the chain, that is, to those actually emitting a certain substance into the environment, and are usually only suitable for stationary sources because of their high monitoring and administrative costs.

Product charges or taxes can be a substitute for emission taxes when direct measurement of emissions is not possible. More generally, product taxes may be levied to price environmental effects correctly, and could be used to correct externalities other than pollution. A product tax may be levied on the units of harmful substance contained in products: for instance, a carbon tax is based on the carbon content of each particular fossil fuel. The product tax may also be levied per unit of the product, if the objective is to reduce usage of the product generally. Product charges may be applied to raw materials, intermediate, or final (consumer) products. When applied to consumer products, they are often called **consumption taxes** or final-product taxes. Consumption taxes may be used when pollution is closely linked to consumer demand, such as disposable products that compete with reusable alternatives, or non-fuel efficient cars. In this case, the taxation may be linked to the product itself or part of its contents that are detrimental to the environment. When applied to raw material (*e.g.* coal to produce electricity) or intermediate products (*e.g.* polyvinylchloride to produce plastic), product taxes are referred to as **input taxes**. Emission taxes on production activities and input taxes are referred to as **production taxes**.

Tax differentiation relates to variations in existing indirect taxes, such as excise duties, sales taxes, or value added taxes for environmental ends. Goods and services that are associated with environmental damage in production and consumption may be taxed more heavily (*e.g.* most OECD countries apply different excise tax rates to leaded and unleaded petrol).

User Charges are payments related to the service delivered. Only those connected to the relevant public service are charged. The revenues raised are used to provide a service, such as the collection and public treatment of effluents. They are considered environmental tax instruments because the service they fund seeks to improve the quality of the environment and to reduce the use of natural resources such as water and land. Given their cost recovery nature, user charges are a direct application of the polluter-pays-principle.

Tax reliefs consist of various provisions in income tax systems designed to encourage some kind of behaviour, either by consumers or businesses. The most common form of tax relief is accelerated depreciation, but many countries also provide investment tax credits for certain types of investment, such as pollution control equipment, or for research and development.

Box 2. **THE SULPHUR TAX IN NORWAY**

The case of the sulphur tax in Norway illustrates the importance of using a comprehensive approach to determine the optimum policy instruments, particularly of having a clear understanding of the particularities of the pollution problem and the industry. An Interdepartmental Committee commissioned a study at the end of 1992 on the environmental effectiveness and economic efficiency of policies to reduce sulphur emissions. The study identified large differences in marginal SO_2 abatement costs for different sources, ranging from NKr 29 per kg for reduction of sulphur content of fuel oil and diesel oil, to NKr 100 per kg in the aluminum industry, following the fitting of scrubbers, and from NKr 5 to NKr 15 per kg in the ferrous alloys industry. This compares with the SO_2 tax rate of NKr 17 per kg. Three factors determine the structure of marginal abatement costs: emissions regulations, either direct limits on emissions or restrictions on certain production methods; regulations on the permitted sulphur content of fuel oil; and the range of taxes on fuel oil, including the sulphur tax.

The Norwegian study noted that the difference in marginal abatement costs might indicate a source of economic inefficiency in the allocation of abatement between polluters, although uneven abatement may be appropriate for pollution problems in given localities. In this particular case, ferrous alloys was judged to be the only industry with a significant degree of localised damage remaining. Higher marginal abatement costs in this sector, rather than the lower costs recorded, may have been appropriate. The study attributed part of the difference in marginal abatement costs between sectors to a lack of coordination between policy instruments operated by different authorities, and part to differences in the competitive position of different industries, both of which were taken into account in implementing the policy. The ferrous alloys industry had been in a weak competitive position throughout the period, and was therefore largely exempted from taking costly abatement measures required in other sectors. The study also reports that the effects of the SO_2 tax in this period were not large. (The rate of tax has since been increased.) The refunds of SO_2 tax conditional on abatement investment were therefore likely to be mainly deadweight expenditures, with little impact on investment decisions due to the low rate of the tax.

Box 3. THE NO_x CHARGE IN SWEDEN

The nitrogen oxide charge in Sweden is a direct charge on measured emissions from a limited group of large sources. The choice of a charge based on measured emissions, as opposed to one based on the characteristics of input fuels (as in the carbon case), was governed by the nature of the process by which combustion gives rise to nitrogen oxides emissions. Nitrogen oxides are formed in two ways: first, as a result of a reaction between atmospheric oxygen and the nitrogen contained in the fuel, and, secondly, through a reaction between atmospheric nitrogen and oxygen. The significance of the second source of nitrogen oxides depends on the conditions under which combustion takes place, including the precise operating conditions. Direct measurement of emissions will lead to a much more precisely-focused incentive than charges based on fuel characteristics or other emissions proxies. However, the measurement technology is costly. The Committee on Environmental Control Charges, which considered the initial proposal, estimated the annual costs, including inspecting and checking equipment, at 350 000 SKr per plant. As a result, the NO_x charge was confined to a relatively small group of sources, for whom measurement costs were likely to be low relative to the potential abatement cost saving: on large heat and power producers with a capacity in excess of 10 MW and annual output of more than 50 GWh. Smaller installations and industrial processes involving combustion were not charged As a result, only about 4 per cent of NO_x emissions were being taxed.

From 1 January 1996, the system will be extended to include plants with energy production over 40 GWh, and from 1 January 1997 with an energy production over 25 GWh. Although the NO_x charge did not come into force until January 1992, its incentive effect appeared to start as soon as Parliament decided its introduction. Several measures were taken by plants, reducing emissions by 35 per cent in between 1990 and 1992. Although some of the reduction results from administrative regulations, investments in new equipment, optimisation of combustion, and the development of new control systems, all contributed to the reduction of NO_x emissions.

Source: The Swedish Experience – Taxes and Charges in Environmental Policy, Ministry of the Environment and Natural Resources, Stockholm 1994, Sweden.

Box 4. **EXAMPLES OF PRODUCT TAXES IN DENMARK**

In Denmark, the retail sales of *pesticides* sold in containers less than 1 kg or 1 litre is subject to a tax. The rate is 1/6 of the wholesale value including the tax but excluding VAT. The tax on imports is 20 per cent of the producer price. Pesticides sold in larger quantities are subject to a tax of 3 per cent of the wholesale price excluding discounts and VAT.

A tax is also levied on rechargeable nickel/cadmium *batteries*. The revenues from the tax are earmarked for covering the costs of a collection arrangement for used rechargeable batteries. The rate is DKr 2 per single battery and DKr 8 per battery attached to a technical device or apparatus.

There is a tax on ordinary *lightbulbs* whereas energy saving bulbs are exempt to encourage energy efficiency.

The use of *CFCs* and *Halons*, and products containing them are subject to an excise duty of DKr 30 per kg.

Plastic and paper cups, plates, cutlery etc. are taxed at a rate of one-third of the wholesale value including the tax rate but excluding VAT. Imports face a rate of 50 per cent.

Source: OECD (1995*a*), *Environmental Taxes in OECD Countries*. OECD, Paris.

Box 5. CHARGES ON BATTERIES IN SWEDEN

In Sweden, following a Government Bill which stated that the use of mercury and lead must be gradually dismantled and the use of cadmium reduced substantially, batteries with the detrimental substances became subject to a new charge system. The charges amount to SKr 23 per kg for alkaline batteries and mercury oxide batteries, SKr 25 per kg for nickel-cadmium batteries and SKr 40 per lead battery (6-8% of the sales price). Producers and importers must register with the Swedish National Environmental Protection Agency (SEPA), and retailers are compelled to collect/take back used batteries. In addition, the batteries can only be sold if they are properly labelled.

The income from the *lead* batteries is divided between the firms that collect the batteries and those that recycle the lead. Administrative costs are about the same for the firms as for the government, *i.e.* 1% of the total revenues of SKr 42 million in 1992. In the same year, there was more than 360 000 batteries collected above those that were sold. The charge itself does not reduce consumer demand as there is no substitute available, but it encourages collection and recycling. Moreover, administrative costs are relatively low. As a result, a Nordic project has been set up to coordinate the collection and recycling of used lead batteries in Denmark, Finland, Norway and Sweden, which is expected to be more cost effective.

Since the charge on small batteries containing NiCd reached only about half of those sold in 1992, special initiatives were taken to improve compliance. A system of collection premiums is also being considered. Administrative costs for the SEPA have been estimated to SKr 0.3 million. The environmental problem resulting from these batteries seems to be diminishing as less harmful alternatives become available.

Source: The Swedish Experience: Taxes and Charges in Environmental Policy, Ministry of the Environment and Natural Resources, Stockholm 1994.

Box 6 EFFECTIVENESS OF ECOTAXES WITH BTA

The case of CFCs, identified as greenhouse gases, may help illustrate how various factors may affect the effectiveness and efficiency of an environmental tax, and how the tax may affect domestic consumption and production patterns and trade flows. In this example, it is assumed that the country introducing the tax represents a small share of world markets and thus has no influence on world prices; that the country is the only country to introduce such policy; and that the revenues raised from the tax are used in a non-distortionary fashion.

Domestic taxation of CFCs would most likely increase the production costs of refrigerators, especially if no other alternatives are easily available. That would reduce the demand for domestically-produced refrigerators, but given trade, domestic consumers will likely switch to cheaper imports. This phenomenon is known as *leakage*. If the release of CFCs into the air occurs not at the production levels but when used refrigerators are being disposed of, then domestic emissions of harmful CFC emissions will not fall, making the tax environmentally ineffective in addition to reducing domestic output. If the harmful emissions of CFCs occurred during production, then the taxing country would be successful at reducing domestic emissions of CFCs, but global emissions of CFCs would likely remain the same (and could even increase if foreign producers are not as successful as domestic producers at limiting CFCs emissions during production process). In a similar situation where environmental damage arises at the local level only and from consumption patterns, a tax imposed on domestic producers would be rendered ineffective in view of trade flows.

Countries might consider using *border tax adjustments* (BTAs), whereby taxes paid by domestic producers are reimbursed if the products are exported, and whereby taxes are imposed on imports. This assumes that BTAs would be allowed under international trade agreements and that they could easily be assessed even when pollution arises from production methods. Border tax adjustments would increase the effectiveness of an environmental tax aimed at reducing emissions that arise out of consumption patterns, but not emissions that arise out of domestic production processes. There are a number of possible scenarios, say for a small country where there are no terms of trade effects to consider:

- If the externality is local and arises out of consumption, then the tax imposed on domestic consumption (with BTAs) would be effective.
- If the externality is local or global but arises out of production processes, then the tax imposed on domestic consumption (with BTAs) would not reduce domestic emissions, since producers can sell their products offshore.
- If the externality is global and arises out of consumption, then the success of the tax imposed on domestic consumption with BTAs is limited to the extent that domestic consumption is reduced, but this is unlikely to solve any global pollution problem.

Box 7 THE CASE FOR INTERNATIONAL AGREEMENTS

Correcting for cross-border externalities requires multilateral cooperation. To take an example, protection of the stratospheric ozone layer is a global public good, such that when protected for one country, the ozone layer is protected for all. Efficiency is likely to demand that all countries reduce their emission of ozone depleting substances. However, while each country would bear the full cost of such an emission reduction programme, each would only share a fraction of the total benefit. For this reason, there may exist incentives for countries to free-ride on the abatement by cooperating countries. Free-riding not only harms the cooperating countries but also blocks achievement of an efficient environmental policy. To deter free-riding, cooperating countries may consider imposing a non-neutral border adjustment on trade in certain goods with free-riding countries. This difference is important, not least because under the rules of the international trading system GATT, border tax adjustments would be allowed for taxes imposed on consumer products but not on production processes. The objective of the tax, that is whether environmental or revenue raising, is not considered to determine whether BTAs should be allowed. Besides, it may not be possible to estimate how much imports should be taxed.

The Montreal Protocol bans trade between parties and non-parties in controlled substances (such as CFCs); bans imports from non-parties of products containing controlled substances (such as refrigerators); and contains provisions for parties to determine the feasibility of banning or restricting imports from non-parties of products produced with, but not containing, controlled substances (such as electronic components which use CFCs as a cleaning solvent). These restrictions are not analogous to border tax adjustments. They do more than correct for competitive disadvantage and leakage. They are intended to provide an incentive to countries to participate in the Protocol with a view to ensuring the effectiveness of the agreement.

Table . 1 Charges on air pollution

Country	**Charge base and rate**	**Incentive**		**Revenue spending**
		Int	**Act**	
(Canada$_{reg}$)	Permit fee for air pollution	-/+	..	Air quality control
France	Acidifying emissions: ECU 19.0/ton (SO_2, NO_x, H_2S, N_2O, HCl)			
Japan	SO_x-emissions: rates differ regionally, between ECU 0.5-4.5/Nm^3	+	#	Compensation of health damage
Portugal	SO_2, NO_x	..	..	Air quality control
Sweden	NO_X-emissions of energy producers: ECU 4.7/kg NO_2	+	+	Rebated to energy producers
(USA)	Criteria pollutants, > = ECU 16.4/ton	-/+	..	Air quality control

Notes: Key to symbols:

+ = Yes
- = No
.. = No data available
# = Unclear

(Canada)= The instrument will be in operation in Canada on or before 1-1-1993.

Table 2 **Water effluent charges**

Country	**Charge base**	**Incentive**		**Measurement method**
		Int	**Act**	
Australia$_{reg}$	F: Pollution load acc. to permit	+	#	AM
Belgium (Fla)	F: Pollution load	+	#	AM
(Wal)	F: Pollution load	..	..	FR/AM
Canada	F: Pollution load	+	#	AM
France	F: Pollution load	#	..	AM
Germany	F: Pollution load related to discharge standard	+	#	AM
(Netherlands)	F: Pollution load	#	+	AM
Portugal	H: Pollution load	..	..	FR
	F: pollution load	..	..	
Spain	F: Pollution load acc. to permit	..	..	AM
USA$_{reg}$	F: Pollution load	..	..	..

Notes : Key to symbols:
H = Households
F = Firms
FR = Flat rate
AM = Actual measurement
FR/AM = Both FR and AM occur

Table 3 Charges on fertilizers

Country	Charge base, rate and percentage of price	Incentive		Revenue spending
		Int	Act	
Austria	N-, P- and K- content: ECU 0.31, ECU 0.18, and ECU 0.09 per kg.	-	-	Subsidies, environmental expenditure
Finland	N- and P- content: ECU 0.41 and 0.27/kg. (5-20% of price).	+	#	Agricultural subsidies, general budget
Norway	N- and P- content: ECU 0.13 (19% of price) and ECU 0.24/kg. (11% of price)	+	#	General budget
Sweden	N- and P- content, ECU 0.07 and 0.14/kg. (10% of price).	+	+	Subsidies, environmental expenditure
USA$_{reg}$	ECU 0.07-1.11/ton (<=2.5% of price)	..	..	Environmental expenditure

Table 4 Charges on lubricant oil

Country	Rate	Incentive		Revenue spending
		Int	Act	
Finland	ECU 0.04/kg	-	-	Waste oil treatment
France	ECU 0.009/lr	-	-	Waste oil treatment
Italy	ECU 0.003/lr	-	-	Waste oil treatment
Norway	ECU 0.055/lr	-	-	General budget
USA$_{reg}$	..	-	-	Waste oil treatment

Table 5 Charges on ozone depleting chemicals

Country	Charge base and rate	Incentive		Revenue spending
		Int	Act	
Australia	CFC's: ECU 0.07/kg	-	-	CFC phase out
(Austria)	Appliances containing refrigerants	-	-	Environmental expenditure
Denmark	CFC's and Halons: ECU 3.3/kg.	#	#	General budget, environmental expenditure
USA	Ozone depleting chemicals: chemicals: ECU 2.0-2.4/kg CFC-11	#	+	General budget

Table 6 Deposit-refund on car hulks

Country	Item	(V) or (M)	Deposit	Refund	Return percentage
Greece	Car hulks older than 15 yr.	M	-	-	
Norway	Car hulks, snowmobiles	M	ECU 77	ECU 110	80-90%
Sweden	Functioning cars < 3.5 ton	M	ECU 101	ECU 178	80-90%
	Car hulks < 3.5 ton	M	ECU 101	ECU 59	80-90%

Table 7 **Deposit refund on metal cans**

Country	Item	Rate (perc. of price)	Return percentage
Australia$_{reg}$	Beer cans	ECU 0.02 (4%)	89%
	Soft drink cans	ECU 0.02 (5%)	89%
Canada$_{reg}$	Metal containers	ECU 0.03-0.11	> 40%
Portugal	Beverage containers	..	..
Sweden	Aluminium cans	ECU 0.07	80-90%
USA$_{reg}$	Soft drinks	..	..

Tradeable Permits in the USA

In the USA tradeable permit systems have been functioning since 1976. Experiences have been extensively documented by EPA and independent researchers [Tietenberg (1985), Hahn (1989), Kete (1991), U.S. EPA (1992))]

Emissions Trading, the first major U.S. application involving tradeable permits, is superimposed on a program of direct regulation that remains the nucleus of air quality policy. The Emissions Trading Policy, issued in 1982 and revised in 1986, allows the trading of Emission Reduction Credits (ERC's), which are surplus emission reductions achieved beyond baseline emission levels. ERC's can be used for "bubbles", giving sources flexibility in satisfying regulatory standards that have been defined on an emission point basis. "Offsets" enable major new sources to locate in areas where ambient quality is below federal standards, on condition that they satisfy the strictest standards themselves and compensate for their new emissions by obtaining ERC's from other sources in the area. "Netting" exempts modifications of major existing sources from certain new source requirements, so long as no significant net increase in emissions occurs within a facility. "Banking" enables sources to store ERC's for future use.

The offset and netting programs have been extensively utilized. The extent of trading under the limited program has been limited so far, with virtually all trades intra-plant. This is due largely to a problem of timing. The release of the revised Emissions Trading Policy in December 1986 came too late with respect to pre-established (1987 or earlier) industry compliance deadlines. Limited use of the bubble program is also explained by the program's restricted scope and the complexity created by grafting a market-based approach onto an existing command-and-control framework [Hahn and Hester (1989), Merrifield (1990)]. Nevertheless, some significant savings have occurred.

The use of bubbles and other forms of emissions trading will increase substantially under the 1990 amendments to the Clean Air Act. Many States and local areas are already developing or exploring trading programs to meet new air quality mandates. In February 1993, EPA issued proposed Economic Incentive Program Rules which will expand upon the previous options for emissions trading.

Table 8 **Results of the US emission trading program**

Activity	Internal transactions (estimate)	External transactions (estimate)	Cost savings (mln. dollars)
Netting	5000-12000	Not allowed	\$25-300 in permitting costs \$500-12000 in emission control
Offsets	1800	200	no estimate available
Bubbles	129	2	\$ 435
Banking	< 100	< 20	Small

Source: Hahn and Hester [1989]

Table 9 **Tradeable permit systems**

Country	**Description**
Australia$_{reg}$	Salt reduction credits
Canada	CFC's Acid rain control
Germany	Air pollution: offsets and netting
USA	Production and consumption rights of ozone depleting chemicals Acid Rain Allowance Trading Oxygenated Gasoline Credits Low Emissions Vehicle Credits Emissions Averaging
USA$_{reg}$	Air pollution: Emissions Trading Water Pollution Wetland Mitigation Banking

Table 10 Enforcement incentives

Country	Description	Proportional to
Australia$_{reg}$	Performance bonds on obligation to rehabilitate landscape after mining Performance bonds on feedlots and marine environment protection	Expected cost of rehabilitation Expected damage
Canada	Violations of Environmental Protection	Estimate of monetary benefits
Canada$_{reg}$	Security deposits for resource exploration and land reclamation and land reclamation	Amount of land disturbed and cost of rehabilitation
Sweden	Discharges of oil ships Environmental protection charge	amount of discharge, tonnage Non-compliance benefits
USA	Liability for release of hazardous waste Non conformance penalty for emissions by heavy vehicles and engines	Damage inflicted Degree of non-compliance
(USA)	Acid Rain Control: Emissions of SO_2 in excess of (tradeable) allowances	US$ 2000/ton plus offsets to compensate

Table 11 Economic instruments per country on 1-1-1992

	Charges on emissions (of which user charges)	Charges on products (of which tax differentiations)	Deposit refunds	Tradeable permits	Enforcement incentives
USA	5 (2)	6 (1)	4	8	2
Sweden	3 (2)	11 (2)	4		2
Canada	3 (2)	7 (3)	1	2	2
Denmark	3 (2)	10 (2)	2		
Finland	3 (2)	10 (2)	2		
Norway	4 (2)	8 (2)	3		
Australia	5 (2)	1 (0)	3	1	2
Netherlands	5 (2)	4 (2)	2		
Austria	3 (1)	4 (2)	3		
Germany	5 (2)	3 (3)	2	1	
Belgium	7 (2)	2 (2)	1		
France	5 (2)	2 (1)			
Switzerland	3 (2)	2 (2)	1		
Italy	3 (2)	2 (0)			
Iceland	1 (1)	1 (1)	2		
Japan	3 (1)	1 (1)			
Portugal	2 (0)	1 (1)	1		
Ireland	2 (2)	1 (1)			
Greece		2 (1)	1		
Spain	3 (2)				
UK	1 (1)	1 (1)			
New Zealand	1 (1)				
Turkey			1		

Table 12 Overview of environmentally-related taxes and chargesin OECD countries
As from 1/1/95

Environmental Tax Measures	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Iceland	Ireland	Italy	Japan	Luxembourg	Mexico	Netherlands	New Zealand	Norway	Portugal	Spain	Sweden	Switzerland	Turkey	United Kingdom	United States
Motor Fuels																									
Leaded/Unleaded (Differential)	•		•		•	•	•	•		•	•	•		•	•	•	•	•	•	•	•	•	•	•	
Diesel (Quality differential)					•	•												•			•				
Carbon/Energy Taxation					•	•										•		•			•				
Sulphur tax																		•			•				
Other excise taxes (other than VAT)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Other Energy Products																									
Other excise taxes	•	•	•		•	•	•	•	•		•	•	•	•	•	•		•		•	•	•		•	•
Carbon/Energy taxation					•	•										•		•			•				
Sulphur tax					•		•											•			•				
NOxCc charge							•														•				
Vehicle Related Taxation																									
Sales/Excise/Regist. tax diff. (cars)			•	•	•	•			•	•	•	•			•	•		•	•		•	•	•		•
Road/Registration tax diff. (cars)			•	•	•			•		•	•	•	•		•	•		•		•	•	•	•		
Agricultural Inputs																									
Fertilisers																		•			•				
Pesticides					•	•												•			•				
Other goods																									
Batteries			•		•																•				
Plastic Carrier Bags					•					•															
Disposable containers			•			•				•								•							
Tires				•	•																				•
CFCs and/or halons	•				•																				•
Disposable razors			•																						
Disposable cameras			•																						
Lubricant Oil Charge						•												•							
Oil Pollution Charge	•					•																			
Direct Tax Provisions																									
Env. Investments/Accelerated depreciation	•			•	•	•	•									•		•	•						•
Employer-paid commuting expenses part of taxable income	•				•	•		•											•	•	•			•	•
Free parking part of taxable income	•																								•

Table 13. An Overview of Environmentally-related taxes and charges in OECD countries (cont't d)
As from 1/1/95

Environmental Tax Measures	Australia	Austria	Belgium	Canada	Denmark	Ffinland	France	Germany	Greece	Iceland	Ireland	Itaaly	Japan	Luxembourg	Mexico	Netherlaands	New Zealand	Norway	Portugaal	Spain	Sweden	Switzerland	Turkey	United Kingdom	United States
Commuting expenses deductible from tax. Income only if pub transport used																									•
Air transport																									
Noise charges	•		•				•	•								•		•				•			
Other taxes				•												•		•	•		•				•
Water Charges and Taxes																									
Water charges	•					•	•	•	•						•	•		•						•	•
Sewage charges	•					•	•		•		•				•	•		•	•	•	•		•	•	•
Water effluent charges	•							•	•										•						
Water Disposal and Management Charges																									
Municipal waste	•	•	•	•		•	•	•	•		•	•				•		•	•	•	•	•	•	•	•
Waste disposal charge	•		•			•		•	•							•		•	•	•		•		•	
Hazardous waste charge	•						•	•	•		•							•	•						•

Source: **OECD (1995):** *Environmental Taxes in OECD Ccountries*, **OECD, Paris, 1995, and country notes**

Taxes/excises with environmental implications in **Norway** as per cent of total tax revenue.

	1980	1985	1990	1991	1992	1993
From 5121 Excises:						
Excise on petrol	1.72	1.70	2.31	2.47	2.86	2.78
Vehicles transfer tax	2.06	3.15	1.49	1.28	1.54	1.54
Electric energy	1.13	1.04	1.12	1.05	1.06	1.12
Oil and gas products	2.78	4.99	2.87	2.96	2.64	2.52
Mineral oil	0.08	0.04	0.36	0.64	0.61	0.52
CO_2 tax	-	-	-	0.25	0.59	0.68
5211 Motor vehicles tax paid by households	0.34	0.46	0.58	0.67	0.79	0.83
5212 Motor vehicles tax paid by others	0.52	0.55	0.68	0.69	0.77	0.76
Total in per cent of total tax revenue	8.64	11.94	9.40	9.99	10.86	10.75
Total in per cent of GDP	4.07	5.68	4.35	4.70	5.05	4.92

Source: OECD, Revenue Statistics of OECD Member Countries.

Taxes/excises with environmental implications in **Sweden** as per cent of total tax revenue.

	1980	1985	1990	1991	1992	1993
From 5121 Excises:						
Taxes on Petrol and Fuel	1.63	2.73	2.27	2.29	2.47	3.00
Sales Tax on Motor Vehicles	0.21	0.28	0.26	0.21	0.20	0.18
Tax on Energy Consumption	1.99	3.01	2.16	2.07	2.17	2.07
Taxes on Electricity From Certain Sources	-	0.25	0.13	0.12	0.14	0.14
From 5211: Motor Vehicles Tax Paid by Households	0.48	0.34	0.26	0.27	0.26	0.28
From 5212: Motor Vehicles Tax Paid by Others	0.96	0.72	0.67	0.74	0.69	0.67
Total in per cent of total tax revenue	5.27	7.33	5.77	5.69	5.92	6.34
Total in per cent of GDP	2.57	3.67	3.20	3.00	2.96	3.17

Source: OECD, Revenue Statistics of OECD Member Countries.