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# **SOME CRITICAL TOPICS OF ENVIRONMENTAL ECONOMICS\***

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### Abstract

Environmental economics has made significant achievements over the past twenty-five years. They rest on the solid assessment that all major environmental problems and ecological disruptions are economic in character, and in need of economic tools for problem solving. This review surveys some critical issues of environmental economics, and assesses some ways to approach more satisfactory solutions for policy analysis.

*Key Words Environmental Economics, Externalities, Pollution, Policy Analysis.*

## 1 INTRODUCTION

When one examines the broad coverage of the economics of environmental pollution, one is immediately struck by the frequency of partial equilibrium analysis (Cropper and Oates, 1992). The widespread reliance on this particular mode of economic analysis probably stems from the pivotal role which the concept of 'external effect' plays in many discussions of pollution.

Externalities are normally defined as the effects upon the output levels of firms and the utility levels of households which result directly from the activities of other firms and households, i. e. without having been mediated by market pricing mechanisms.

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The tendency to conceive of environmental pollution as a particular case of external effects practically dictates the use of partial equilibrium modes of analysis because of the fact that the general theory of external effects has always been conducted within a partial equilibrium framework (Mishan, 1971). It is, in large part, this analytical constraint which has encouraged discussions of pollution at the firm and industry level and discouraged analysis at the general equilibrium and aggregative levels. One of the dangers in pursuing partial equilibrium analyses of pollution is that, since pollution (and other) externalities are pervasive, one cannot assume that optimum conditions are already satisfied in the rest of the economy and consequently cannot specify what kinds of adjustments are required in any particular sector in order to attain a Pareto-optimum. Despite its theoretical limitations, I shall first sketch the partial equilibrium analysis of environmental pollution before turning to general equilibrium and dynamic formulations of the problem.

The organisation of the review is as follows. In the next section we analyse some of the major achievements and shortcomings of partial equilibrium analysis. Section 3 shows the welfare economic implications of general equilibrium analysis vis-à-vis environmental pollution.

Section 4 explores the dynamics of interactive production/pollution processes. By way of conclusion I investigate in Section 5 the validity of the zero-growth hypothesis in view of mounting environmental pressures.

## 2 PARTIAL EQUILIBRIUM AND POLLUTION EXTERNALITIES

It is generally agreed that one of the consequences of failing to correct a pollution externality is a static misallocation of resources among firms

and industries.

Note that the equation of competitive price with social marginal cost is a necessary, but not sufficient condition for an allocative optimum. Attainment of an allocative optimum also requires that total, as well as marginal, conditions to be met : after adjustment for the externality, the total benefits derived from the production and use of the equilibrium output measured by the sum of factor and consumer surpluses-must exceed the externality imposed losses which remain.

Two maxims derived directly from neoclassical micro-economic theory have been suggested as general guidelines for correcting pollution externalities. The first is that any particular level of pollution abatement should be obtained with the least costly combination of available means by applying the equimarginal principle of resource allocation. In particular, it is argued that a percentage reduction in waste emissions applied equally to all firms and industries would be inefficient because of their different costs of abatement at the margin. And Ruff (1970) has observed, 'the cost of reducing total pollution by 10 percent is *not* the total cost of reducing each pollution source by 10 percent. Rather, (one should seek) ...the pattern of control such that an additional dollar spent on control of any pollution source yields the same reduction. This will minimize the cost of achieving any given level of abatement'.

The second abstract guideline is that the optimum level of pollution abatement is that level at which the cost of further emission controls would exceed the value of additional gains in environmental quality. This maxim has been invoked to point out that pollution abatement entails the use of scarce resources which might otherwise be devoted to producing more conventional 'goods' and consequently that we should never aim to get rid of ab-

solutely all external effects of one activity upon another, since the net gain from doing so would be negative. Rather, minimization of total pollution costs involves choosing a correct balance between expenditures on preventing pollution, expenditures to avoid damage caused by pollution, and suffering the welfare damages of pollution.

An interesting question in the economics of comparative systems is what particular sets of socioeconomic institutions are more likely to generate pollution externalities in the first place. Several authors have argued that private market economies have faced increasingly severe pollution diseconomies because of an inadequately comprehensive system of property rights. According to Dales (1969), property 'ownership always consists of (1) a set of rights to use property in certain ways (and a set of negative rights or prohibitions, that prevent its use in other ways): (2) a right to prevent others from exercising those rights, or to set the terms on which others may exercise them : and (3) a right to sell (ones's) property rights'.

In market economies, a highly developed system of property rights to such assets as producer durables, consumer durables, land sites, labour power, mineral deposits, and even knowledge already exists. For the most part, these property rights are privately held by individuals and business corporations, rather than by democratic collectivities or state institutions, although there had been a strong trend toward state ownership of various assets in capitalist countries during the twentieth century.

For many of these assets, it is a matter of political choice whether the property rights to their use are individually, corporately, or communally held. One can easily imagine a wheat farm, secondary school, or steel mill being operated as either a public or private enterprise, for example. Air and

water, however, seem to be owned in common because there is no alternative. There is no feasible way of separating a cubic yard of water from other cubic yards. Thus it seems to be the physical characteristics of air and water, the fact that they are fluids and are naturally mobile over the face of the earth, that make it inevitable that they be owned in common.

Although the general legal principle that the atmosphere, lakes, rivers and coastal waters are common property assets is well established in many capitalist societies, *enforcement* of the public right to ration private (and public) use of these common properties is less well established.

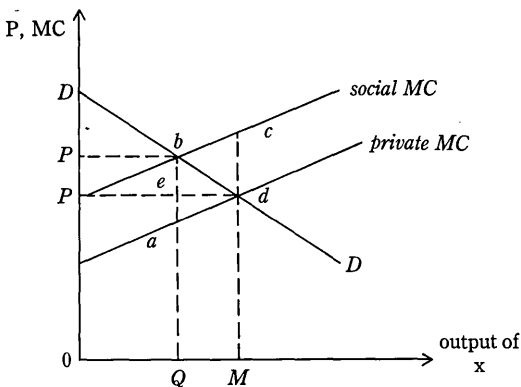
The existence of private property rights to most real assets ensures that the relative scarcity of these assets will be taken into account by their private users, even though these users may be motivated solely by private material gain. However, the failure to ration the use of 'common property resources of great and increasing value' means that they 'will be over-used relative to both private property and to public property that *is* subject to charges for its use or to rules about its use'.

Although a market economy certainly generates substantial pollution externalities because of their failure to adequately ration private use of watersheds and the atmosphere, it does not follow that this is the only contemporary system afflicted by pollution costs. As we know from pollution in the former Soviet Union abolishing private property will not mean an end to environmental disruption. Just the opposite. In many ways, state ownership may actually exacerbate the situation. Empirical evidence for this thesis appears to be widespread, however, there are also plausible theoretical reasons for believing that individual state enterprises might impose pollution costs on households and other enterprises even though there is central planning of the economy. Soviet enterprise managers often received produc-

tion targets from the central planning authorities which 'have been set so high that one third of all enterprises failed to fulfil their annual plan'. In addition, the principal managerial incentive in Soviet industry was the bonus paid for overfulfillment of (production) plan targets. As a result, one found Soviet managers allocating their input quotas without much regard for controlling waste emissions (Pryde 1983).

Although this topic has not yet been carefully enough analysed, a variety of procedural means for correcting pollution externalities in market economies have already been outlined in the literature. One line of argument is that pollution control could conceivably occur without public intervention as a result of voluntary contractual agreements between polluters and those adversely affected by waste emissions. If the costs of identifying polluters and fellow victims, of forming coalitions of aggrieved parties, and of bargaining over the distribution of abatement costs were negligible, one would expect to see those who bear pollution externalities

Figure 1  
Determination of Optimal Output  
In Presence of Externality



offering to pay polluters to reduce their effluent discharges.

In Figure 1, for example, there is an incentive to move from output OM to OQ since by doing so there will be a gain equal to the area of triangle *ebd* to be shared by the beneficiaries of product X and the externality victims. The maximum sum the externality victims would be willing to pay to reduce the market output by MQ is equal to the area of the parallelogram *abed*, while the loss to producers and consumers from reducing the output is equal to the area of the triangle *abd*.

In practice, however, one does not often observe the consummation of such private contracts within the current framework of statutory and common law. Their absence is *prima facie* evidence of substantial transactions costs which deter individual victims from bargaining directly with polluters in order to realise some sort of relief. A key economic feature of pollution externalities is that they pose a problem not so much as between firms or industries, but as between, on the one hand, the producers and/or users of spillover-creating goods and, on the other hand, the public at large. Thus, even though an individual victim may suffer welfare losses because of a nearby pollution source, he will probably tolerate the emissions because he alone cannot afford to buy pollution abatement from the polluter and because organising a coalition to finance the compensation would be personally expensive.

It is fairly clear, then, that the existing system of private property rights and legal remedies has been inadequate and that public action of some sort is required in order to 'internalize the externalities' of pollution. Perhaps the least radical departure from existing legal and economic institutions is Mishan's suggestion that the state creates private 'amenity rights,' i. e. private property rights to privacy, quiet, and clean air and water



(Mishan, 1967). After appropriate modifications of the law of torts and trespass, individuals could demand financial compensation for the infringement of their 'amenity rights'. The prospect of having to pay compensation would presumably induce polluters to reduce the magnitude and virulence of their external effects.

Mishan's institutional reforms are too modest, however, to be effective. If 'amenity rights' were defended before traditional courts, the litigation costs necessary to obtain compensation would surely discourage most individuals from bringing suit. The creation of specialised courts which could hear 'amenity rights' cases expeditiously and the facilitation of class action suits against polluters would increase the efficiency of a judicial approach to reducing pollution externalities, but many uncorrected external effects might remain nonetheless (Cornes and Sandler, 1986). In addition, unless the courts developed rules of thumb for awarding compensation in various types of cases, there would be an incentive for pollution victims to claim compensation far in excess of their actual pecuniary and subjective losses.

Probably the most frequent line of argument in the literature has been that the imposition of an 'effluent tax', that is, an excise tax on waste emissions, would suffice to correct pollution externalities and thereby eliminate the problem of environmental pollution. A rigorously developed example of this taxation approach is a model of pollution, waste purification, and external effects by Peter Bohm (1970). He begins by postulating that the flow of pollution attributable to some firm A varies directly with its rate of output :

$$P_A = F(Q_A), \quad F(0) = 0, \quad F' > 0 \text{ and } F'' < 0, \quad (1)$$

where  $P_A$  and  $Q_A$  are the effluent and output flows, respectively, of firm A.

The value of consumer welfare losses directly attributable to the pollution externality of firm A also varies directly with its effluent flow :

$$L_C = f(P_A), \quad f(0) = 0, \quad f' > 0, \quad \text{and} \quad f'' < 0, \quad (2)$$

where  $L_C$  is the consumer welfare loss.

Ceteris paribus, the output of some other firm, B, varies inversely with the effluent flow of firm A :

$$Q_B = g(P_A), \quad g(0) = \bar{Q}_B, \quad g' < 0, \quad \text{and} \quad g'' < 0, \quad (3)$$

where  $Q_B$  is the value of the output of firm B.

Summing these negative effects on households and firm B, we find the total value of firm A's pollution externalities,  $h$  :

$$h(Q_A) = L_C + (\bar{Q}_B - Q_B) = f(P_A) - g(P_A) + \bar{Q}_B \quad (4)$$

where  $h(0) = 0$ .

By substituting (1) into (4) and differentiating with respect to  $Q_A$ , one obtains the marginal external effect,  $E$  :

$$E = h'(Q_A) = P'(f' - g'), \quad h' > 0, \quad \text{and} \quad h'' < 0. \quad (5)$$

Assuming that firm A is a perfect competitor in a perfect market (except for the pollution externality), the traditional remedy is to tax the out-

put of firm A, so that the tax corresponds to the marginal value E at that level of output which is optimal after the imposition of the tax. In other words, after the levying of the output tax to correct the pollution externality, it must be true that

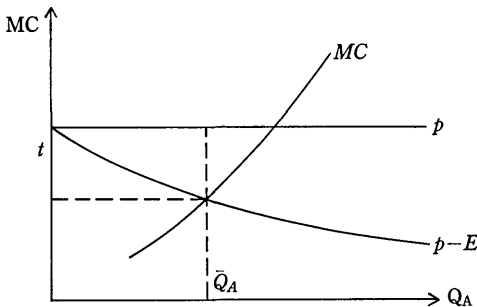
$$MC = p - t = p - E, \tag{6}$$

where  $p$  is the competitive product price which firm A faces,  $t$  is the excise tax rate per unit output, and  $MC$  are the marginal costs of output other than the tax.

Figure 2 depicts the choice of an optimal tax rate and the consequent choice of optimal output flow for the case of rising marginal external effects, i. e. where  $h'' > 0$ .

As mentioned earlier, setting the tax rate  $t$  equal to the marginal externality  $E$  is not a sufficient condition for optimal correction of the externality. For example, in the case of declining marginal externalities (i. e.,  $h'' < 0$ ), the marginal external effect may equal zero at the output where

Figure 2  
Optimal Tax Rate in Presence of  
Increasing Marginal Externality



competitive price equals private marginal cost. If one referred only to the marginal condition (6), one would conclude that production should continue totally free of taxation. Actually, as depicted in Figure 3, this conclusion would be in error because of the net losses of welfare occurring for most infra-marginal units of production.

Thus, in addition to inspecting the marginal condition (6), one should also consult the criterion that total benefits net of private production costs and the value of total external effects be positive at the equilibrium output following the imposition of the tax, i. e.

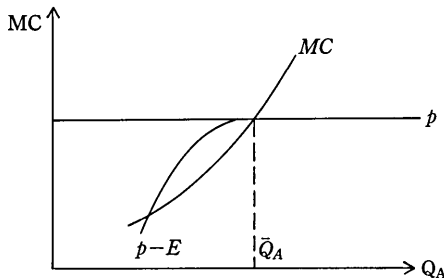
$$\pi_t = p \cdot \bar{Q}_A - C(\bar{Q}_A) - h(\bar{Q}_A) > 0, \quad (7)$$

where  $C$  is the private production cost of the firm and  $\pi_t$  denotes the total net benefits at equilibrium output.

If the condition is not satisfied, one should prescribe a total shutdown of the firm even if the marginal condition is met.

It would be premature, however, to conclude that one has chosen an optimal emission control program simply by having satisfied conditions (6)

Figure 3  
Equality of Tax Rate and Marginal Externality  
Insufficient for Optimum



and (7). The reason is that there are pollution control instruments other than an effluent tax to which public authorities might turn. In particular, it may be economically preferable to have firms purchase waste purification services from a central treatment facility rather than have the firms pay an output excise which reflects the external costs of their untreated wastes.

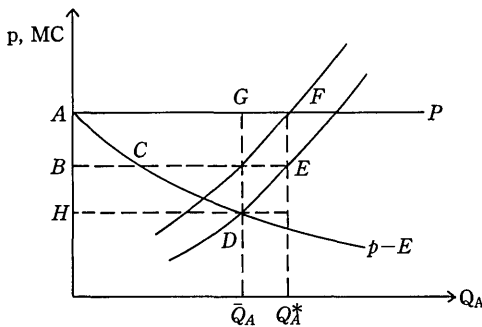
Suppose, for example, that the waste treatment services of a publicly owned or regulated purification plant were available to firm A at the plant's marginal cost,  $r^+$  per unit of effluent treated. In effect, the purification charge per unit of output  $Q_A$  would be equal to

$$r = F' \cdot r^+ \tag{8}$$

Assuming that the purification facility's marginal costs,  $r^+$ , are constant over a wide range of waste loads and that firm A's 'marginal propensity to pollute',  $F'$  is also constant, connection to the purification facility would add a constant value,  $r$ , to the marginal cost curve of firm A.

In the case of rising marginal externalities depicted in Figure 4, firm A can choose between releasing untreated wastes and paying an output

Figure 4  
Optimal Output in Presence of  
Increasing Marginal Externality



tax rate AH or connecting to the purification plant and paying a treatment fee of EF dollars per unit of output. The purification option is a feasible solution as long as net revenues (which are equal to the social net benefits) are positive :

$$\pi_r = p Q_A^* - C(Q_A^*) - r Q_A^* > 0, \quad (9)$$

where  $Q_A^*$  is the equilibrium output of firm A if it chooses to pay  $r^+$  per unit of effluent treated.

From the social welfare point of view, the purification solution is superior to the tax approach if the net social benefits of purification exceed those of taxation, i. e.

$$\begin{aligned} \pi = \pi_r - \pi_t = [p Q_A^* - C(Q_A^*) - r Q_A^*] \\ - [p \bar{Q}_A - C(\bar{Q}_A) - h(\bar{Q}_A)] > 0. \end{aligned} \quad (10)$$

Whether firm A would freely choose the purification option depends, however, on whether the firm's net *revenues* after purification exceed those after taxation, i. e.

$$\pi^* = \pi_r - [p Q_A - C(Q_A) - t Q_A] > 0. \quad (11)$$

In the case where the net benefits of purification exceed those of the tax solution, i. e.  $\pi > 0$ , the net revenue to firm A if it chooses purification are necessarily also greater, i. e.  $\pi^* > 0$ . This follows immediately from the fact that, when marginal externalities are rising, the total excise tax liability,  $t\bar{Q}_A$ , is necessarily greater than the value of remaining external effects,  $h(\bar{Q}_A)$  (One can verify this proposition by comparing the area of the tax liability, AHDG, with that of the total external effects, AGD, in Figure

4 . Note that this outcome depends on the assumption of constant marginal purification costs.)

On the other hand, when the net benefits of purification are less than those of the tax solution, i. e.  $\pi < 0$ , there is no guarantee that the net revenues after purification will be similarly inferior. Thus, in the absence of supplementary regulation, there is a tendency for firm A to choose the purification alternative when the tax solution is actually socially optimal.

Despite the analytical popularity of the effluent tax proposal, several authors have expressed doubts about its administrative feasibility. According to Baumol and Oates(1988), we simply do not have the ability to calculate the marginal external cost of various waste emissions.

These problems of calculation are not just a reflection of the costs of collecting and classifying large sets of statistical data. There are also several factors which, in principle, precluded the precise measurement of pollution externalities. First, we are presently unable to model and predict many of the immediate and future physical repercussions of current waste emissions. Scientists cannot judge, for instance, whether or not the growing carbon dioxide content of the atmosphere will lead to significant global climatic changes. In addition, it is also difficult to evaluate the known physical effects of environmental pollution because observed market prices reflect both monopolistic pricing and substantial income inequalities, two difficulties common to other economic welfare valuations.

The substitute reform which Baumol and Oates propose is that the public authorities select physical targets for particular effluent flows e. g. sulphur dioxide, and that they enforce these physical standards by imposing sufficiently high unit taxes on each type of emission. This combination of physical standards and emission taxes will not, in general, lead to Paretoeffi-

cient levels of the relevant activities. It is nevertheless true that the use of unit taxes to achieve the specified quality standards is the least-cost method to realize these targets. This cost-minimization result occurs because each pollution source reduces its own waste discharges to the level where its marginal costs of further reductions equal the (common) unit tax.

A very similar proposal is Dales' (1968) suggestion that an administrative board be created to fix aggregate ceilings for permissible effluent flows and to sell a "certain number of Pollution Rights, each Right giving whoever buys it the right to discharge one equivalent ton of wastes during the current year. In effect, the pollution control board would be responsible for identifying a 'reasonable' set of emission flows, and private bidding would allocate the limited number of waste discharge licenses among potential polluters. If the pollution right were renewable and transferable among private owners, one would expect the emergence of a private market in pollution rights, not unlike the private markets in radio frequency license and taxicab medallions which already exist (Tietenberg, 1990).

### 3 ENVIRONMENTAL POLLUTION AND GENERAL EQUILIBRIUM

During the past several years, a number of authors (see, for example, *The Journal of Environmental Economics and Management*) have turned to discussions of environmental pollution which are cast in a general equilibrium framework. Whereas the predominance of partial equilibrium analyses no doubt reflects the propensity of the theoretical literature to view externalities as exceptional and minor, these recent contributions assume that the disposal of waste materials and energy is a pervasive task



facing all economic actors. According to Ayres and Kneese(1969), ‘despite ... a tendency in the economics literature to view externalities as exceptional cases ... we believe that at least one class of externalities ... those associated with the disposal of residuals resulting from the consumption and production processes ... must be viewed ... (as) a normal, indeed, inevitable part of these processes’. The impacts of such processes have been described in an early seminal paper by Commoner(1972).

The least abrupt of these theoretical shifts has been undertaken by Ruff(1970), who has continued the Pigouvian discussion of optimal pricing and ideal outputs within a modified Walrasian system. Briefly, Ruff argues that after some political process has determined the permissible physical flows of various types of effluents(e. g. carbon monoxide, particulate matter), the imposition of a vector of emission taxes is ‘capable of achieving specified pollution levels ‘efficiently’ in a competitive general equilibrium model...’ In this discussion an allocation is said to be *efficient* if it is feasible, and if there is no feasible allocation which has the same aggregate pollution levels, and yet is Pareto preferred. However, it is questionable whether such discussions of the existence of optimal price vectors in a perfectly competitive economy are very meaningful once one admits the empirical frequency of oligopolistic elements in contemporary market economies.

General equilibrium models of environmental pollution have more commonly been developed within an input-output or a materials-balance context, rather than a market exchange framework. Leontief(1970), for example, has sketched the modifications which permit the theoretical incorporation of waste residuals into input-output models of the economy. The technical interdependence between the levels of desirable and undesirable

outputs can be described in terms of structural coefficients similar to those used to trace the structural interdependence between all the regular branches of production and consumption.

These technical inter-dependencies can be represented by a structural matrix of input-output coefficients. Suppose, for example, that productive activity falls into three categories, agricultural output, manufactured output, and pollution abatement. Suppose further that each activity generates waste residuals, i. e. potential pollution, and that each productive sector requires the input of technically-determined quantities of agricultural and manufactured goods and labour per unit of activity.

In principle, the primary application of an input-output model of environmental pollution is in making short-term projections of waste loads, given sectoral technologies, the income-elasticities of demand for various commodities, and the anticipated growth of national income. Given these potential waste loads, one can then project the magnitude of abatement activity necessary to maintain environmental quality at a particular level. A static input-output model however, is not an adequate instrument with which to analyze problems of economic growth and environmental pollution. In the first place, the notion that there is a technically fixed ratio between the flows of output and waste residuals is a strong assumption, even in the short run. For example, there are opportunities for input substitution which can substantially alter the observed ratio of production to waste loads. Second, once one admits that different input combinations may lead to substantially different waste disposal problems, the rigid analytical dichotomy between sectoral waste loads and a separate pollution abatement sector is difficult to maintain. The construction of a municipal waste treatment plant is fairly obviously an 'abatement investment', but it is less clear whether the

cost of insulating a steam boiler to reduce its fuel combustion is a 'productive' or 'abatement' outlay (Gottinger, 1991).

A theoretical approach intimately related to the input-output technique is the materials-balance analysis of Ayres and Kneese (1969). A basic criticism of the Ayers-Kneese model is that the physical mass-balance approach ignores the variety of physical and chemical forms which a particular mass of waste emissions can assume. For instance, the combustion of fossil fuels (e. g. coal, natural gas, fuel oil) can lead to relatively heavy emissions of either carbon monoxide or carbon dioxide, depending upon how fully the fuel is oxidized. The pollution costs per unit mass of emission are much higher, however, for carbon monoxide gases than for carbon dioxide emissions. In general, one can lower the economic costs resulting from waste emissions by recycling more materials, by altering the distribution of discharges among alternate environmental media, and by changing the *form*, but not necessarily the *mass*, of residuals. An additional criticism of which Ayres and Kneese are fully aware is that their fixed-coefficient production model precludes analyzing substitutions among input combinations which could substantially alter both the mass and forms of waste emissions.

Analytical parallels between the Leontief and Ayres-Kneese models are strong : both approaches emphasize sectoral interdependencies, intermediate and final production stages, and linear production coefficients. Ayres and Kneese recognize, however, that untreated waste discharges do not necessarily result in pollution externalities, i. e. that the natural environment has some capacity to reduce waste residuals to harmless forms. Finally, Leontief talks rather generally about 'pollution abatement' whereas Ayres and Kneese discuss waste recycling and waste treatment as economic alternatives. If the government had complete information about the effects

of unregulated waste discharges on factor proportion and output decisions within firms and on the utility of consumption bundles within households, it might be able to devise a set of excises, subsidies, and prohibitions which would result in the attainment of a Pareto-optimum. Difficulties arise, however, in empirically determining the production relationships, materials balances, environmental assimilative capacities, and utility functions needed to establish the optimal set of environmental standards. It is very likely that costs of obtaining the required information would far exceed the gains from *exactly* achieving the Pareto conditions.

However, without complete knowledge of utility functions and production relationships, one runs into the problem of second-best adjustments. Unless one knows how to satisfy simultaneously all Pareto-optimality conditions across the entire economy, one cannot be certain that satisfying some subset of those conditions will result in social welfare improvement. This conclusion reinforces the earlier thesis that minimization of abatement costs together with the costs of pollution, and not Pareto-optimality, is the more appropriate and feasible welfare criterion in the specification of environmental standards.

#### 4 DYNAMIC ANALYSIS OF ENVIRONMENTAL POLLUTION

Only more recently have economists begun to characterize environmental pollution as a dynamic problem intimately related to economic growth as well as a problem of static resource misallocation. After the emphasis on sectoral disaggregation in the previous general equilibrium analyses of pollution, one is immediately struck by the high level of aggrega-

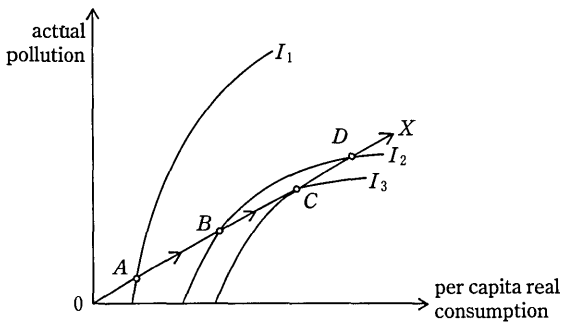
tion.

Because pollution is a 'bad' rather than a good, the social indifference curves which depict alternative levels of social welfare are positively sloped. In the standard presentation, as depicted in Figure 5, Donaldson and Victor (1970) require that the indifference curves,  $I_i$ , display the conventional convexity assumption about utility or welfare trade offs. Convexity is a particularly good assumption in this model because equal increments to the physical flow of pollution will lead to ever *larger* incremental pollution costs. It is very likely, therefore, the smaller and smaller physical increases in environmental pollution would be socially acceptable, at the margin, in return for constant increments in per capita real consumption.

The first theorem which Donaldson and Victor derive is that if pollution grows at the same rate as consumption per head or at a higher rate, economic growth will always lead to a diminution of social welfare after some point of maximum social welfare is reached.

In the case where pollution and per capita consumption grow at the same rate, the time path of the economy is a linear ray from the origin. The con-

Figure 5  
Social Indifference Curves Between  
Pollution Level and Per Capital Consumption

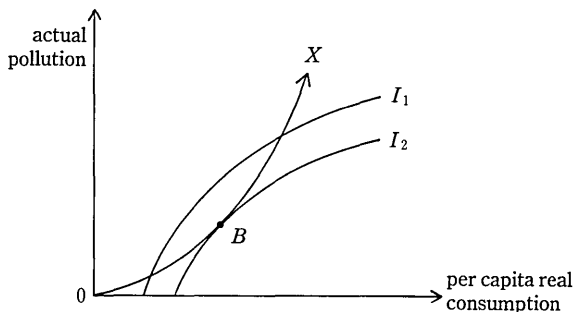


vexity assumption about social indifference curves ensures the existence of a unique tangency (point C in Figure 5) at which a social welfare maximum is reached and beyond which social welfare declines.

In the absence of pollution abatement efforts, one would actually expect pollution to grow more rapidly than per capita consumption once the limited capacity of the environment to absorb wastes had been exhausted. Unless the income elasticities of demand for final products are such that the sectoral composition of aggregate output continues to shift toward activities with relatively low effluent propensities, pollution will grow at least as fast as aggregate output. If one assumes a constant average propensity to consume, it will also grow at least as fast as *total* consumption, which exceed the growth rate of per capita consumption as long as the population is growing. In this case, the time path of the economy, OX, will curve upward and a social welfare maximum (point B in Figure 6) will still be uniquely determined.

This welfare theorem is a rather weak proposition. If one respecifies the social welfare function as being positively dependent on both per capita

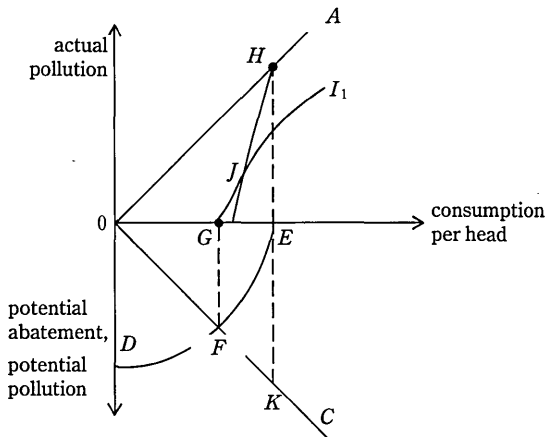
Figure 6  
Welfare Tangency with Relatively  
Rapid Growth of Pollution



real consumption and environmental quality, where environmental quality varies inversely with the flow of pollution, then the theorem is equivalent to saying that environmental quality will not be treated indefinitely as an inferior good. In other words, as aggregate output grows, maintenance of, and even increases in, environmental quality will be demanded along with higher real consumption standards.

We discuss the economic tradeoff between environmental quality and real consumption standards by introducing the concept of a production possibilities curve for consumption goods and 'pollution abatement'. In Figure 7, the locus DE represents the alternative combinations of per capita consumption and pollution abatement which are possible with current factor endowments and production techniques. The level of pollution abatement is defined as that quantity of harmful pollutants which would have been discharged into the natural environment were it not for waste purification

Figure 7  
Alternative Feasible Combinations of  
Pollution and Per Capita Consumption



and recycling efforts. The observed flow of pollutants is conceived of as the algebraic difference between 'potential pollution' and the level of pollution abatement activity. Since the pollution abatement sector requires the use of real resources otherwise available for the production of consumption goods, additional pollution abatement is available only at the expense of reduced consumer goods output.

The linear rays OA and OC depict the technical relationship between per capita consumption and the accompanying flow of potential pollution. The proportionality of this relationship apparently reflects an assumption that potential pollution per unit of aggregate output is a fixed coefficient. Let us suppose that

$$E = a_0 Q, \quad (12)$$

where E is the potential flow of pollution, Q is aggregate output, and  $a_0$  is the technical constant.

In the short run, aggregate output is also proportional to per capita consumption because population and the savings ratio are fixed :

$$Q = \frac{N}{(1-s)} \cdot \sigma, \quad (13)$$

where N is population size, s is the average propensity to save, and  $\sigma$  is consumption per head.

It follows immediately that

$$E = a_0 \cdot \frac{N}{(1-s)} \cdot \sigma = a_1 \cdot \sigma, \quad (14)$$

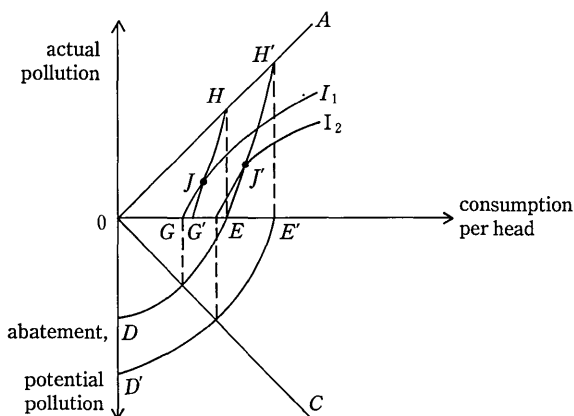
where  $a_1$  is also a fixed coefficient.



Returning to Figure 7, if no resources are allocated to pollution abatement, then per capita consumption will equal OE, and both potential and actual pollution will equal EH. If, on the other hand, all potential pollutants are treated or recycled, consumption per head will equal OG and the scale of pollution abatement will be GF. Between these two extremes, there is a locus of combinations of consumption per capita and actual pollution, GH, which can be derived by subtracting pollution abatement from potential pollution at intermediate levels of per capita consumption. One would normally expect a social welfare maximum at some intermediate point, J, where potential pollution is partially abated at the opportunity cost of somewhat reduced consumption standards.

Over time, the production possibilities curve DE will shift outward because of capital accumulation, labour force growth, and technical innovations. The relationship between per capita consumption and aggregate

Figure 8  
Changes in Optimal Levels of  
Pollution and Per Capita Consumption over Time



potential pollution,  $OA$ , may also shift because of technical innovations and changes in the sectoral composition of aggregate output.

The economic consequence of these shifts is that there exists a new locus,  $G' H'$ , of alternative combinations of actual pollution and consumption standards. Depending upon the particular position of  $G' H'$  and the particular distribution of social indifference curves, the optimal flow of pollution may either increase or decrease. (The former case is depicted in Figure 8). Over the long run, however, one would expect some ceiling on the optimal flow of pollution except in the unlikely case where the slope of  $OA$  rises secularly.

This type of formulation, although highly aggregative, is not very dynamic : its emphasis on static resource allocation is reminiscent of the partial and general equilibrium models discussed earlier. Although Donaldson and Victor certainly intended a dynamic model of environmental pollution, their reliance on indifference and production possibilities curves, both of which are essentially static analytical devices, severely constrains the theoretical scope of their model. In particular, their preoccupation with per capita consumption results in the neglect of stock accumulation, both of which need to be examined explicitly in a dynamic analysis of pollution.

An extremely ingenious approach, which nonetheless fails to discuss adequately the dynamic aspects of environmental pollution, is the model of generic congestion developed by Rothenberg(1970).

'Generic congestion' is a rather inclusive concept which subsumes popular notions of congestion and pollution. According to Rothenberg's definition, pure congestion occurs when all users of a common medium generate identical rates of quality interference per unit of activity and share equally in the resulting quality impairment. Pure pollution, on the other

hand, is the case where some users generate very high rates of per unit interference while others generate zero rates and only the latter experience quality impairment. Most commonly, one finds that all users both generate impairment and share in it, but they differ from one another in magnitude in both respects.

This approach proceeds by developing a formal two commodity model, commodity X being subject to generic congestion and commodity Z being free from interactive disturbances in its use. He also postulates three classes of users of the public-good medium which is required in the consumption of commodity X : these three classes generate low, moderate and high levels of interactive disturbance per unit of X consumed, respectively. As long as the total interactive disturbance resulting from the use of the public facility is less than its assimilative capacity, the three classes of users enjoy its use with no quality impairment. If, however, their levels of X consumption are such that the total interactive disturbance they generate is greater than medium capacity, then generic congestion sets in, and they must either undertake remedial expenditures or tolerate the impaired quality of the public-good service.

Rothenberg constructs a rudimentary dynamic model by making demand for X and Z dependent on per capita and population, as well as relative prices, and then letting income and population grow over time. As one might expect, generic congestion also rises over time because of the growing consumption of commodity X. However, X-consumption grows less rapidly than one might expect from the pure income effect alone because individual remedial outlays and deterioration of the public medium increase the effective relative price of X.

Rothenberg fails to inquire whether the indefinite worsening of

various forms of congestion, in particular environmental pollution, would be socially tolerable and, if not, what regulatory measures would be required in order to halt the growth of congestion and pollution. Nevertheless, his work is a start toward a dynamic framework because it shows how growth *per se* could increase congestion and pollution despite the previous introduction of congestion of effluent charges (Folmer and Ireland, 1989)

One of the few articles to characterize environmental pollution as primarily a problem of saving and capital accumulation is an essay by Ralph d' Arge (1971).

Building on his distinction between the natural assimilative capacity of the environment and the augmentation of that capacity through capital accumulation, d' Arge develops a Harrod-Domar model of economic growth and environmental quality. He begins by postulating that both production and consumption generate waste residuals :

$$W = g_c \cdot (F - S) + g_f \cdot F, \quad (15)$$

where  $W$  denotes a homogenous waste flow,  $F$  the current flow of final product, and  $S$  saving from current product. The coefficients  $g_c$  and  $g_f$  are the quantities of wastes generated per unit of consumption and production, respectively.

Unfortunately, d' Arge falls prey to theoretical ambiguity. Adopting the average density of wastes as a measure of environmental quality, he asserts that

$$D = \frac{1}{V} \cdot W - h \cdot I_r - \delta, \quad (16)$$

where  $D$  denotes average waste density,  $V$  a volume measure of the

natural environment,  $I_r$  current investment in the stock of assimilative capacity-augmenting capital, and  $\delta$  a decay rate in waste density attributable to the natural waste assimilative capacity of the environment.

It is not clear, however, how d' Arge derived this relationship. One can imagine two alternative theoretical cases, neither of which leads to equation (16). The first case assumes that 'unassimilated' waste emissions damage environmental quality at the time of their discharge and then decay immediately thereafter into harmless materials. In this event, one ought to stipulate that

$$W_0 = W - h_0 \cdot K_r - A, \quad (17)$$

where  $W$  is the current emission flow,  $W_0$  is the unassimilated portion of that discharge,  $A$  is the flow of wastes naturally assimilated, and  $K_r$  is the non-depreciating stock of assimilative capacity-augmenting capital.

The appropriate measure of environmental quality in this case is  $D_0 = W_0/V$  and, consequently,

$$D_0 = \frac{1}{V} \cdot W - h \cdot K_r - \delta, \quad (18)$$

where  $h = h_0/V$  and  $\delta = A/V$ .

Since  $I_r = \dot{K}_r$ , it follows that

$$\dot{D}_0 = \frac{1}{V} \cdot \dot{W} - h \cdot I_r, \quad (19)$$

which is substantially different from (16). This result implies that the time rate of change of waste density is unaffected by the fixed natural assimilative capacity and that changes in environmental quality vary with changes in, not the level of, total waste emissions.

The other theoretical case assumes that 'unassimilated' wastes are persistent in their harmful forms and that they continue to impair environmental quality until their assimilation. In this case, the appropriate measure of environmental quality is  $D_1 = P/V$ , where  $P$  is the accumulated stock of unassimilated wastes. The stock of pollutants varies according to

$$\dot{P} = W - h_0 \cdot K_r - A. \quad (20)$$

Since  $\dot{D}_1 = \frac{1}{V} \cdot \dot{P}$ , it follows that

$$\dot{D}_1 = \frac{1}{V} \cdot W - h \cdot K_r - \sigma, \quad (21)$$

which again differs significantly from (16). In this case, it is the accumulated stock of assimilative capital, and not the current investment in that stock, which helps to determine the time rate of change in environmental quality.

Let us replace (16) by (19), for example, and then utilize the remainder of the d' Arge model. Differentiating (15) with respect to time and substituting into (19), one finds that

$$\dot{D}_0 = \frac{1}{V} \cdot [(g_c + g_f) \cdot \dot{F} + g_c \cdot \dot{S}] - h \cdot I_r. \quad (22)$$

Savings is a fixed fraction,  $s$ , of total production and is embodied as either assimilative or productive capital :

$$S = s \cdot F = I_f + I_r. \quad (23)$$

where  $I_f$  is the current accumulation of non-depreciating capital goods which will be devoted to production, and where  $I_f = \dot{K}_f$ .

Following Harrod and Domar, we specify that

$$\dot{F} = \sigma \cdot I_f \quad (24)$$

where  $\sigma$  is the incremental output-capital ratio.

By substituting (23) and (24) into (22), one can express the time rate of change of environmental quality in terms of various structural coefficients and final output variables :

$$\begin{aligned} \dot{D}_0 &= \frac{1}{V} \cdot [[g_c \cdot (1-s) + g_f] \cdot \dot{F}] - h \cdot [s \cdot F - \frac{\dot{E}}{\sigma}] \\ &= \left[ \frac{g_c \cdot (1-s) + g_f}{\nu} + \frac{h}{\sigma} \right] \cdot \dot{F} - h \cdot s \cdot F \end{aligned} \quad (25)$$

In the interest of environmental protection, we now impose the political constraint that  $\dot{D} = 0$ , i. e. that environmental quality be maintained at some target level. As a result, equation (25) reduces to

$$\dot{F} - \alpha \cdot F = 0, \text{ where} \quad (26)$$

$$\alpha = \frac{h \cdot s}{\frac{g_c \cdot (1-s) + g_f}{\nu} + \frac{h}{\sigma}}$$

This elementary differential equation has the solution

$$F(t) = H e^{\alpha t}, \quad (27)$$

where H is some constant reflecting the initial conditions of the economy.

The exponent  $\alpha$  can be interpreted as the warranted rate of growth of final output subject to the environmental quality constraint. This warranted rate of growth is necessarily positive, but the particular value it assumes depends upon the values of  $g_c$ ,  $g_f$ ,  $h$ ,  $s$ ,  $V$ , and  $\sigma$ . The effects which variations in these parameters would tend to have on the warranted rate of growth are summarized in Table 1.

Table 1  
The Partial Effects on  
the Warranted Growth Rate  
of Structural Parameter Changes

$g_c$	—
$g_f$	—
$h$	+
$s$	+
$\sigma$	+

Not unexpectedly, relatively high waste discharge propensities for both consumption and production activities tend to depress the warranted rate of growth of final output. On the other hand, relatively high marginal productivities of assimilative and productive capital and a relatively high savings ratio tend to stimulate the warranted growth rate. It is important to remember that this optimistic finding of a positive (though perhaps small) warranted growth rate hinges on the assumption that unassimilated wastes decay immediately after they have generated pollution costs. As we see in Gottinger(1992), this is actually a far-fetched assumption. Some environmental pollutants are persistent over time, which suggests that(21) may be theoretically superior to both(16) and(19).



## 5 REMARKS ON ENVIRONMENTAL POLLUTION AND THE ZERO-GROWTH HYPOTHESIS

There is a somewhat distinct school of thought on the economics of environmental quality which, in addition to formulating pollution as a dynamic problem, reaches the theoretical conclusion that a global 'stationary state' economy will eventually be a social and biological necessity. This literature stems, in part, from an essay by K. Boulding (1968) on the economics of the 'coming spaceship earth'. Boulding's basic premise is that neither raw material supplies nor the waste-assimilating capacity of the natural environment is infinite in scope and consequently that we cannot expand indefinitely the flows of natural resource exploitation and environmental waste disposal. The apparent implication of this proposition is that the rate of growth and the level of national income are becoming increasingly unreliable and even perverse social welfare indicators.

This line of argument has been echoed and extended by Daly (1968) and Daly and Cobb (1989), who have suggested that we broaden our concept of capital to include natural biological and physical systems. This analytical extension is meant to reflect the 'common biophysical foundations' of the life sciences.

Because of the costly impacts of economic waste discharges on these natural forms of 'capital', Daly concludes that 'a definite limit to the size of maintenance flows of matter and energy is set by ecological thresholds which if exceeded cause system-breaks. To keep flows below these limits we can operate on two variables: the *size* of the stocks and the *durability* of the stocks... 'Durability' means more than just how long a particular commodity lasts. It also includes the efficiency with which the after-use 'cor-

pses' of a commodity can be recycled...'

Although these essays by Boulding and Daly are suggestive, the most systematic discussion of the stationary state hypothesis has been provided by Meadows et al. in their 1972 report to the Club of Rome.

The authors contend that it will be necessary to 'establish a condition of (global) ecological and economic stability' in which population size and the capital stock are constant and in which flows of births, deaths, investment and depreciation are kept to a minimum.

These predictions depend upon a number of strong empirical assumptions about the interactions between ecological processes and economical activity. For one thing, the Meadows and their co-authors assume that there is an absolute limit to agricultural yields per acre which is double current yields. They also make the 'optimistic' assumption that 'new discoveries or advances in technology can *double* the amount of resources economically available'.

In other words, they counterpose exponential growth in population and industrial production against one-shot increases in agricultural yields and raw material reserves and then draw the conclusion that economic collapse is unavoidable sometime in the future. In addition to doubts on theoretical validity, as a number of critics (Cole et al., 1973) have pointed out, both of these assumptions are highly restrictive and without solid empirical support, but both still seem to live on in a new strand of 'ecological economics'.

## REFERENCES

- d' Arge, R., 'Essay on Economic Growth and Environmental Pollution', *Swedish Journal of Economics*, March 1971, pp. 25–41.
- Ayres, R. M. and Kneese, A. V., 'Production Consumption and Externalities', *The American Economic Review* 59, 1969, pp. 282–297.
- Baumol, W. J. and Oates, W. E., *The Theory of Environmental Policy* Cambridge University Press : Cambridge, 1988.
- Bohm, P., 'Pollution, Purification, and the Theory of External Effects', *Swedish Journal of Economics* 1970.
- Boulding, K., 'The Economics of the Spaceship Earth', in H. Jarrett (ed.), *Environmental Quality in a Growing Economy*, Baltimore, Johns Hopkins University Press 1966.
- Burrows, P., *The Economic Theory of Pollution Control*, Cambridge : MIT Press 1980.
- Cole, H. S. D. et al., (eds.), *Models of Doom : A Critique of the Limits to Growth*, Praeger : New York, 1967.
- Commoner, B., 'The Environmental Costs of Economic Growth' in R. Dorfman and N. Dorfman (eds.), *Economics of the Environment*, Norton : New York, 1972.
- Cornes, R., and Sandler, T., 'The Theory of Externalities, Public Goods, and Club Goods', Cambridge : Cambridge University Press, 1986.
- Cropper, M. L., and Oates, W. E., 'Environmental Economics : A Survey', *Journal of Economic Literature* 30, 1992, pp. 675–740.
- Dales, J. H., *Pollution, Property and Prices*, Toronto : University of Toronto Press, 1968.
- Daly, H., and Cobb, J. B., *For the Common Good*, Beacon Press : Boston, 1989.
- Daly, H., 'On Economics as a Life Science', *Journal of Political Economy*, May 1968, pp. 390–402.
- Donaldson, D., and Victor, P., 'On the Dynamics of Air Pollution Control', *Canadian Journal of Economics*, August, 1970, pp. 418–432.
- Folmer, H., and van Ireland, E., (eds.), *Evaluation Methods and Policy Making in Environmental Economics*, Amsterdam : North Holland, 1989.
- Gottinger, H. W., 'Global Environmental Economics : Economic Growth, Technological Change and Sustainability', Oxford Institute for Energy Studies, EV15, 1992.
- Gottinger, H. W., *Economic Models for Solid Waste Management with Applications*; Gordon and Breach, Science Publishers, New York 1991.

- Leontief, W., 'Environmental Repercussions and the Economic Structure : An Input-Output Approach', *Review of Economics and Statistics*, August 1970.
- Meadows, D. et al., '*The Limits of Growth*', New York : University Books, 1972.
- Mishan, E. J., 'The Costs of Economic Growth', Praeger, New York, 1967.
- Mishan, E. J., 'The Postwar Literature on Externalities', *Journal of Economic Literature*, 9, March 1971, pp. 2–12.
- Pryde, P. R., 'The Decade of the Environment in the USSR', *Science* 220, 15 April, 1983, pp. 274–279.
- Rothenberg, J., 'The Economics of Congestion and Pollution : An Integrated View', *American Economic Review*, May 1970, pp. 113–122.
- Ruff, L., 'The Economic Common Sense of Pollution', *The Public Interest*, 1970.
- Schmidheiny, St., *Changing Course*, Cambridge : MIT Press, 1992.
- Tietenberg, Th. H., 'Economic Instruments for Environmental Regulation', *Oxford Review of Economic Policy* 6, 1990.