A SURVEY OF THE ECONOMIC THEORY OF POLLUTION

By N. G. BOLWIG*

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and 43)[1], Buchanan and Stubblebine (1962, p. 372)[1], Bohm (1964, p. 14)[2], and himself, Mishan stresses that although the external effect has a direct[3] impact on the welfare of others, it is characterized by being "an unintentional product of some otherwise legitimate employment". (Mishan 1969 *b*, p. 343).

External effects internal or external to an industry

A distinction is made between external effects *internal* to an industry and those *external* to an industry.

In the former case, a scarce factor has a too low price so that it is more intensively used than it would be if the proper rent was imputed to it[4]. The result is a non-optimal factor combination in the industry. One example is fishing in the open sea: no economic rent is charged for the right to use the fishing water, even if it is a scarce economic resource; accordingly a marginal fisher does not take into account that by exploiting the free fishing possibility he causes a diminished catch on the part of the fishers already there. From the point of view of society too many resources are allocated to fishing. One solution suggested by Pigou (1946) is to obtain optimal output by taxation; another proposed by Knight (1924) is to introduce private ownership to the scarce factor so that a rent equal to its marginal product value would be imputed to it. The external diseconomy would cease to exist in both cases, but the change of income and wealth distribution might be different.

In the latter case of such effects that are external to the industry production or utility functions outside the industry are altered. Even if corrections of outputs are made by proper pricing or otherwise, the external effect does not cease existing as in the internal-to-the-industry case.

"*Pecuniary*" *external effects*[5]. The technological external effects mentioned are covered by the suggested definition which pecuniary external effects are not. These are e.g. supposed to cover cases of factor supply prices rising with exanding outputs (ext. diseconomies), and cost reductions to an expanding industry because of factor supplies from another falling cost industry. (Viner 1931, pp. 217 and 220). Mishan classifies the two cases as examples of the reaction of the market to inelastic factor supplies, and of external economies internal to the industry[6].

1. Both define in terms of dependence of a production function or a consumption function on the activities of others.
2. Who finds the unability of the firm to control the factor to be the decisive characteristic.
3. i.e. not indirect – through changes in factor and commodity prices.
4. Worcester (1969, p. 876) has an illuminating graphic exposition of the case of external effects internal to an industry.
5. Also see Worcester (1969, pp. 880–82).
6. Already Young (1913) corrected Pigou's mistaken suggestions to tax an industry with a rising supply curve. (Samuelson 1970, p. 457, note 11).

Interdependent utility and external effects in consumption

In the utility function $U_1^i = U_1^i (X_1^i, \ldots, X_n^i; X_k^j)$ the welfare or utility of person no. i depends not only on the amounts of the n goods he consumes, but also on the amount of the k'th good consumed by the j'th person[7]. The utility function above could, however, also be interpreted as a technological external effect in consumption. Mishan favours the exclusion of the interdependent utility case from the concept of external effects, arguing that a generally acceptable social-welfare function – as used in economic policy and cost-benefit studies (Mishan 1969 *b*, p. 330) – would include the tangible external effects in consumption, but not the psychic effects of the Duesenberry envy type. (Mishan 1965, pp. 187 and 197-200). In the 1969-paper they are also ignored (1969 *b*, pp. 329-30 and p. 346). This distinction may be useful, but it seems as if the two classes of direct interdependence between consumers may not cover all cases of interdependence. Should the aesthetic pleasure you derive from the colour of your neighbour's house or the moral joy you feel from observing his conventional consumption pattern be classified as a technological or psychic external effect?

Partial equilibrium analysis and general optimum

In the many cases where the analysis of corrections for external effects in order to obtain an optimal output is made in a partial equilibrium model, it is normally implicitly assumed that the remaining sectors of the economy are optimally organized so that the social value of the marginal product is the same for each factor. If, for some reason, this is not the case, second-best problems arise (Mishan 1965, p. 188). Thus, some or all of the other sectors may be monopolistically organized.

If the particular industry needing adjustment in its output because it is generating external diseconomies itself is monopolistically organized, a correction of its output by means of a tax may lead to a reduction in welfare as demonstrated by Buchanan (1969)[8].

Corrective measures. (Mishan 1965, p. 190, pp. 204-11, and pp. 214-18). One possible solution of the external effect problem is the *creation of a market* for the by-product if it could be appropriated and marketed. In Meade's (1952, p. 57) example of an apple-growing industry giving rise to the positive external effect of apple blossoms which benefit a neighbouring bee-honey industry, it is technically impossible to appropriate and market the by-product, but some system of *taxes or subsidies* on either factors or products in the two

7. Duesenberry (1949, p. 97) used a similar function to describe interdependent utility, but in his three person community the utility of each person depends on his own income and on those of the other two persons.
8. Wellisz (1964, p. 349, note 3) has a similar argument.

industries could give the optimal output. Another possibility is a *merger* of the two industries, as suggested by Davis and Whinston (1962, pp. 242-44).

In the case of external diseconomies, say an industry polluting the water of a lake which is used by an urban community as drinking water, no market would be created for the polluted water, because its price would be negative, as long as the law permitted the industry to continue its pullution. But a tax or merger solution would be possible. Only if the industry was made responsible for the damages inflicted by its harmful residuals, a market might develop, e.g. purification firms specializing in buying the residuals of the pollutors at certain (negative) prices. Mishan (1965, p. 189, note 8) mentions the theoretical possibility of internalizing the external economy by allocating property rights of the common property goods like fresh air, quiet, etc., but emphasizes the practical difficulties of organizing fresh air markets, etc. Because of the character of these common property goods as indivisible, each potential seller of his share of the clean air would have a kind of monopoly towards the potential air-polluting buyer.

The classification of external effects external to an industry or to a group of consumers can be made on different distinctions: (1) between the effect-generating and the effect-absorbing agent, and (2) between fixed and output-variable external effects (Mishan 1965, p. 190). The necessary adjustments for optimal outputs could involve either both or none of the parties, dependent on the character of the external effect (Meade 1952; Buchanan and Stubblebine 1962).

Coase (1960, p. 15) has taken into consideration also the *transaction costs* of making adjustments to the socially optimal output. They have the character of additional social costs (Mishan 1965, p. 190-91). Mishan (1967, p. 241-44) mentions a different kind of transactions costs, namely those of reaching and maintaining a voluntary agreement on a Pareto-optimal improvement between the damaging and the inflicted part in a unilateral external effect situation[9]. The problem of transaction costs is dealt with more thoroughly on pp. 201-02.

Who compensates whom?

An optimal output in a situation of negative external effects can be effected *either* by a payment from the externality generating agent equal to the marginal damage to the inflicted party, *or* by a payment – a bribe so to say – from the absorbing agent to the producer of the externality to make him abstain from his harmful activity (Mishan 1965, p. 191; Mishan 1971 *b*; Buchanan and Stubblebine 1962). The dependence on the law, i.e. if it is permissive or prohibitive with respect to generation of harmful externalities, on the direc-

9. See also Burrows (1970, pp. 43-46).

tion of a compensation payment is stressed both by Coase (1960), Mishan (1967 *a*), and Burrows (1970)[10].

Efficiency of production and the existence of diseconomies

As a final point Mishan stresses that "the existence of external diseconomies external to an industry, though consistent with optimal outputs .... involves some loss of social value compared with a situation in which such diseconomies are absent" (Mishan 1965, p. 192).

If producers or consumers were compelled to compensate the losers for the burden of the externalities remaining after adjustment of production or consumption to the optimal size they would more likely look for alternative production and consumption processes which involved a reduced level of diseconomies (Mishan 1965, p. 192-93). Similarly, research in pollution-reducing methods, appliances and devices would be more profitable. Whenever the reduced compensation payments following the introduction of a more "clean" process could more than pay for the change in technology, such a change would be profitable.

Pollution and external effects

The theory of external diseconomies covers a wider class of phenomena than what is normally called pollution.

Congestion can also be analyzed in terms of external diseconomies. A non-optimal congested situation will arise because the single user of some freely available facility with a limited capacity does not take into account the increasing costs of delay, inconvenience, obstruction, etc. to others following his marginal use of the facility, say a highway, beach, or fishing ground. Congestion can sometimes be analyzed in terms of external diseconomies internal to an industry. Thus, an optimal density of traffic or degree of utilization could be reached after optimal pricing of the scarce factor.

Pollution could be defined broadly as harmful residuals arising from production and consumption processes, such as noise, heat, airborn and waterborn residuals, and solid waste. These phenomena have the character of technological external effects. An excessive amount of pollution is the result of the zero pricing of potentially harmful elements, even if they increase the cost of production to other producers and reduce the welfare directly of individuals, and therefore ought to have negative prices (Ayres and Kneese 1969, p. 292, note 24).

From another point of view *environment* is a scarce factor, and pollution as defined above is only one dimension of the deterioration of the environment. Our environment could be thought of as a stock of exhaustible resources of

10. On the dependence on the law of the ultimate solution, see pp. 198-201.

a given quality and combined structurally in certain ways. Mines, soil, air, fresh water, oceans and space are used as inputs in man-made conversion processes, and as stores for disposal of both the beneficial outputs and the harmful residuals. Thus, the gradual using up of the stock of natural resources or the deteriorating of their quality could be considered as the most general problem of pollution, or rather of environmental quality. As the quality of the environment deteriorates, the production and utility functions are made less efficient. To some degree increasing man-made capital stock structures and stocks of education attached to human beings could be thought of as substitutes for environment, but not all quality elements of environment are equally substitutable, and as the environment is getting more scarce relative to inputs of man-made capital and labour, it becomes increasingly important to economize with the stock of environment.

Pollution models

Partial equilibrium models. The tradition of Marshall and Pigou of analyzing external diseconomies in terms of partial equilibrium models is still influential, even if general equilibrium models are increasingly used as a consequence of the all-pervasiveness of the production residuals at the present level of industralization and urbanization.

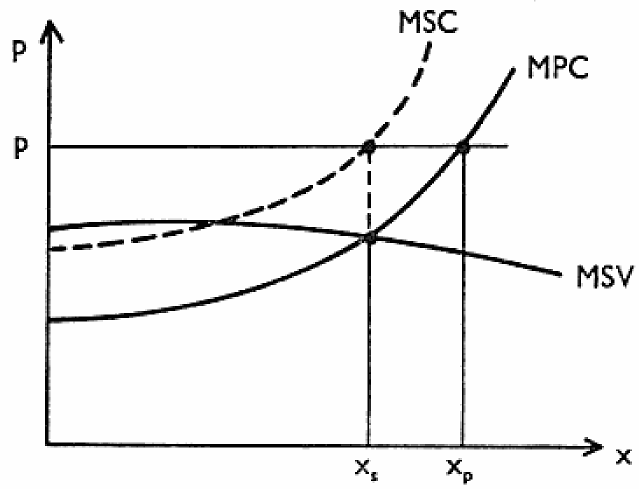

Fig. 1. Source: Bohm 1970, p. 155, fig. 2.

In fig. 1 a typical partial equilibrium external diseconomy is analyzed in the Pigovian way (Bohm 1970, p. 155, fig. 2). x is produced and sold in a perfectly competitive market at a price p.[11] From the point of view of a single producer who disregards the diseconomy generated the optimal production

11. The assumption of a perfectly competitive market has been chosen for convenience, and it is not crucial for the argument.

is x_p, for which the price – expressing the marginal private value (*MPV*) of the product – is equal to the marginal private cost (*MPC*). The diseconomy could be considered *either* as a deduction from the (private) value *or* as an addition to the (private) costs:

1. From p we deduct the marginal social loss of producing x from p and arrive at the marginal social value (*MSV*) of x. The optimal output x_s is determined at the intersection of the *MSV* curve with the marginal private cost curve (*MPC*).

2. Alternatively the marginal social loss is considered a cost to society from producing x and added to the *MPC* curve. The optimal output is then determined at the intersection of the *MPV* curve ($= p$) and the marginal social cost curve of *MSC*.

   The correction in the simple mathematical notation could be made either as a deduction on the left-hand side or as an addition on the right-hand side:

$$MPV - MSL = MPC \qquad (1)$$

$$MPV \qquad = MPC + MSL. \qquad (2)$$

Another more general exposition of external diseconomies in a partial equilibrium setting is given by Mishan (1969 *b*, p. 340). The following expression summarizes the equilibrium condition

$$v_{k1}{}^{ii} + \sum_{j=1}^{s} v_{k2}{}^{oj} = c_k \qquad (i = 1, 2, \ldots, s).$$

$v_{k1}{}^{ii}$ is the marginal value to the i'th individual of his consumption of good no. 1 of the k'th production activity, and $\Sigma v_{k2}{}^{oj}$ is the sum of all marginal external effects, positive and negative, from the production of by-product no. 2, considered potentially harmful, to all persons, s, in the community. The sum of these two terms of which the latter is negative in the case of prevailing negative effects should be equal to the marginal cost c_k of the joint production of the k'th activity of the good no. 1 and the "bad" no. 2.

Dolbear (1967) and Mishan (1971 *a*) have illustrated *external diseconomies in consumption* using different techniques.

In the Dolbear case of a two-person community both are consuming bread, and one is also consuming heat thereby inflicting a diseconomy in the form of smoke on the other person. The exposition is made by means of indifference curves (fig. 2).

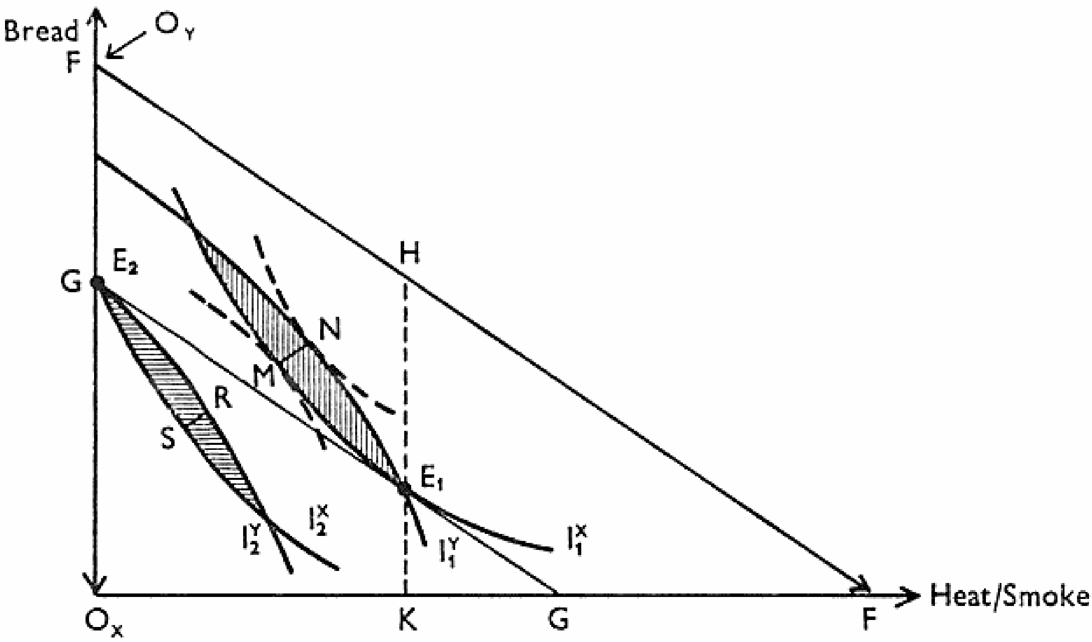

Fig. 2. Source: Dolbear 1967, p. 95, fig. 3.

FF represents the linear transformation function of society for bread into heat.

Individual *X* consumes bread and heat, the heat-consumption generating external diseconomies of smoke suffered by *Y*. The production of smoke is assumed to be proportional to the production of heat, and no other heat consumption processes are available. The consumption of *X* is measured from O_X.

Y consumes bread and has disutility of the smoke produced jointly with *X*'s heat-production. Any point in the Edgeworth triangle gives us the amounts of bread and heat allocated to *X* measured from O_X. *Y*'s consumption of bread is then what is left out of the total of bread production which is the distance through that point from the heat/smoke axis to the *FF*-transformation line. *Y*'s consumption of the negative good of smoke is measured in the same units as heat, and could be read off from the heat/smoke axis. The numerical slope of *Y*'s indifference curves increases as they fall from the bread axis towards the heat/smoke axis, indicating that *Y*'s marginal disutility of consuming increasing amounts of smoke is increasing in terms of bread.

Now an (arbitrary) income distribution is introduced, *GG* being the budget line of *X*. In terms of bread *X*'s real income is O_XG and that of *Y* is *GF*.

If *X* is *permitted* to generate the diseconomy of *smoke* without any compensation to *Y* he chooses E_1, thereby reaching the highest possible welfare as measured by the indifference curve I_1^X. He will consume O_XK of heat, and E_1K of bread; *Y* will always consume the same amount of bread, $FG(= HE_1)$, and his consumption of smoke will be that created by $O_X K$ – heat units (FH), his welfare level being $I_1{}^Y$.

The area enclosed by the intersections of $I_1{}^X$ and $I_1{}^Y$ gives the scope for bargain between the parties. It will pay Y to bribe X with some bread in order to reduce the amount of heat and smoke. MN is the locus of tangency for the two sets of indifference curves, where no further Pareto-improvement is possible.

If *smoke* production without compensation is *prohibited* the starting point is E_2, where both consume bread only. The individual indifference curves starting at E_2 again determine a bargaining area, where RS is the section of the contract curve, depicting Pareto-optimal bargains.

Whereas $I_1{}^Y$ must always intersect $I_1{}^X$ from above as long as Y has disutility from the smoke, and X's indifference map is well behaved, so that the bargain will result in some reduction in the amount of the diseconomy, there will be no bargaining possibilities from the E_2 position, if the marginal utility of X of the first unit of heat is less than the marginal disutility of X of the first unit of smoke. In this case E_2 will be a Pareto-optimal corner solution (fig. 3).

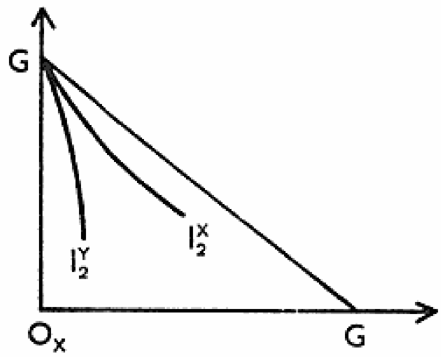

Fig. 3.

The results from this simple exercise of unilateral external diseconomies in consumption without corrective taxes or other measures but with bargaining allowed between the parties are the following:

(1) The allocation of resources between production of the goods without externality (bread) and the diseconomy-generating good (heat) depends on whether the law allows or prohibits the polluting activity without compensation[12].
(2) Obviously the amount of diseconomies and the allocation depends on the preferences of the parties involved.

12. In the case of the marginal rates of substitution between bread and heat/smoke being independent of the amount of bread consumed, the contract curve will be vertical, and the allocation will not depend on whether the law is permissive or prohibitive.

(3) The Pareto-optimal resource allocation and the corresponding amount of pollution depends on the initial distribution of real income.

(4) In the equilibrium, say N (X gets the whole of the improvement from E_1), the sum of the marginal rates of substitution of X and Y equals the common marginal rate of transformation[13], cfr. the Samuelson condition for optimal production of pure public goods: the marginal rate of transformation in production of the public good must equal the sum of all the individual marginal rates of substitution for the good.

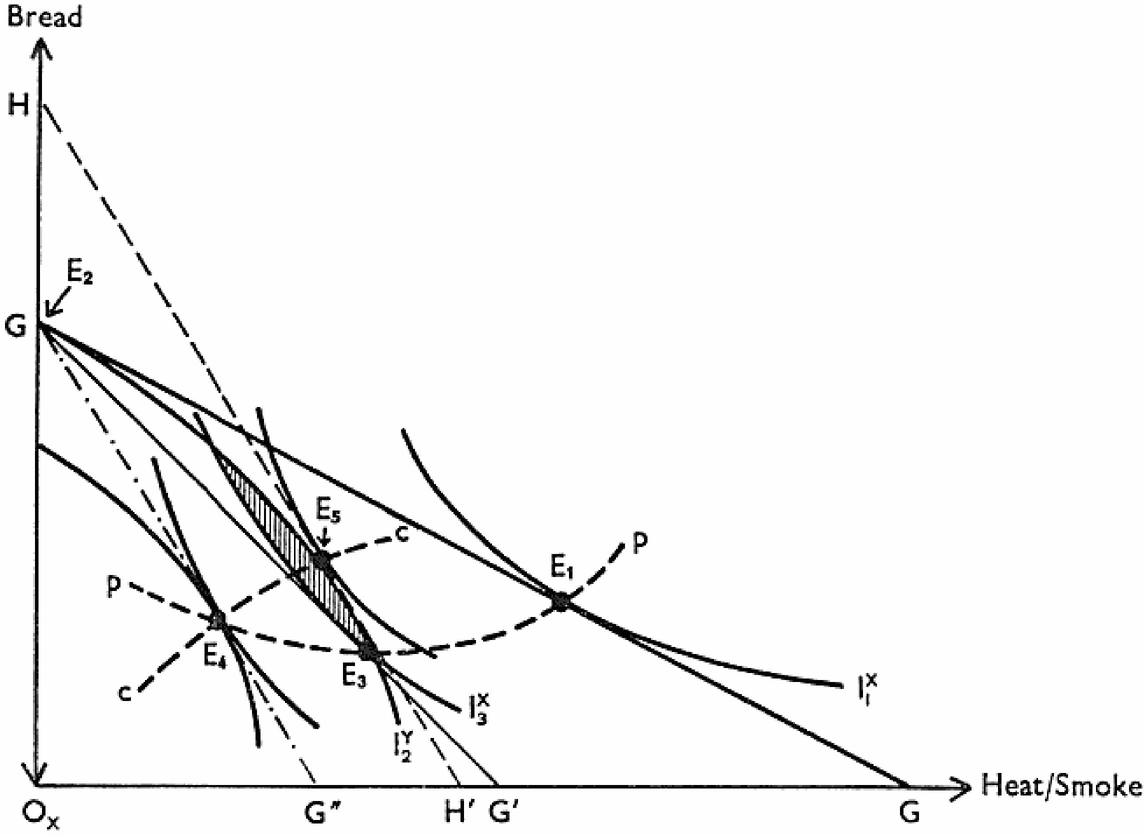

Fig. 4. Source: Dolbear 1967, pag. 98, fig. 4.

Taxation

One method of correcting the external diseconomy situation to get an optimal output is to use *taxation*. Dolbear assumes that the behaviour of the individuals is not modified by their knowledge of the tax, i.e. that they do not use

13. The slope of the common exchange rate at N is bigger than the slope of the transformation function FF, because it represents the marginal rate of substitution of bread for heat (negative), which must be numerically greater than the marginal rate of transformation (negative) in order to compensate for the (positive) marginal rate of substitution between bread and smoke. Let the marginal substitution rates for X and Y be (—5) and (+2), and the rate of transformation (—3). We then have Σ MRS = MRT or (—5) + (2) = (—3).

their quasimonopolistic position, but maximize utilities as if they were price-takers. This assumption is defended by reference to a later stage of the model with many X and Y type individuals, who must consider prices and taxes as given.

The starting point again is E_2, smoke being prohibited unless the damage is compensated for, but instead of a voluntary agreement a tax per unit of smoke to be paid in bread is considered. GG' is the budget line of X after the introduction of a heat/smoke tax that exactly compensates Y for the damage. (I_2^Y passes through E_2 – the welfare level of Y without smoke – and E_3, where X is in equilibrium under the compensating tax rate). But in E_3 there is still room for Pareto improvements inside the shaded area. So the tax will actually over-compensate Y, given the further negotiation possibilities.

In E_4, where the *pp* curve (X's chosen equilibrium consumption allocation for different tax rates) cuts the contract curve, *cc*, we are at a Pareto exchange optium, but now Y is over-compensated.

The combination of a Pareto optimum and exact compensation of Y is obtained in the Dolbear model by combining a tax rate corresponding to E_4 (Y is over-compensated with the tax revenue) with a lump sum transfer back from Y to X equal to GH. The budget line GG'' thereby becomes HH', which is the common tangency for I_2^Y and I_2^X. E_5 is the equilibrium point, realizing at the same time Pareto optimum and exact compensation of Y.

A similar argument could be developed for over-subsidizing X's bread consumption and transferring income back to Y, if we started out with a law that permitted X to generate smoke. Again the allocation of resources for the two productions, and the distribution of real income would be different in the tax-prohibitive and the subsidy-permissive situation.

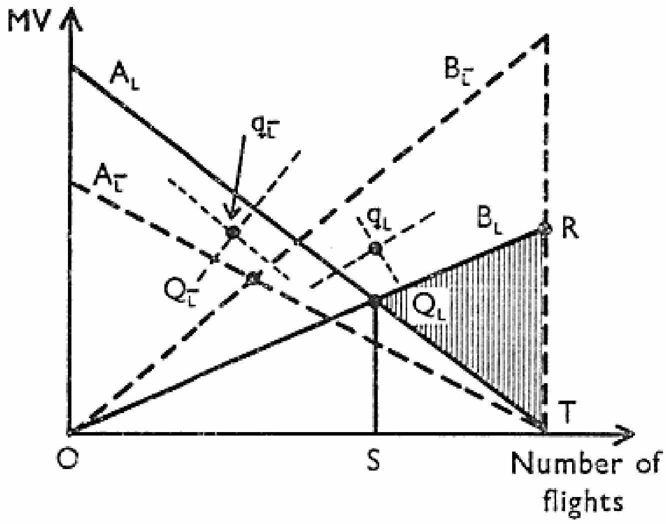

Fig. 5. Source: Mishan 1971*a*, pag. 20, fig. 2.

In a recent article *Mishan* (1971 *a*) argues along similar lines, using *marginal valuation curves.*

An air flight company, A, will under a law (L) that permits flights without compensation to the noise-plagued inhabitants around the airport, make OT flights per day, the marginal benefit at T being zero. A_L can therefore be interpreted as the minimum amount A will accept to forego the opportunity of marginal flights. Let B_L be the marginal noise damage caused to the people around the airport, which is also the maximum sum they will pay in order to avoid marginal flights.

In the case of no welfare (income) effects, it will pay B to bribe A to make $Q_L(OS)$ flights per day, but if the division of the area of common gain Q_LRT between the parties creates income effects for both, A_L and B_L will both increase and the final equilibrium point will be, say q_L.

Under *a prohibitive law* ($\bar{L}$) similar curves can be drawn, $A_{\bar{L}}$ now being interpreted as the maximum sum A will pay for successive flights, and $B_{\bar{L}}$ the minimum sum B will accept. $Q_{\bar{L}}$, or $q_{\bar{L}}$ in the case of normal income effects for both, will then give the number of flights. $OA_{\bar{L}}Q_{\bar{L}}$ is the area of gain to be divided between them.

Like Dolbear, Mishan concludes that there will be more flights and noise-pollution under the L-law than under the prohibitive law, and consequently the allocation of resources between air transport and other activities will be different[14].

General equilibrium models

As external diseconomies in production and consumption rather than the exception are increasingly the norm in the densely populated, highly industrialized modern societies, as implicitly understood in the writings of Pigou, the need for analyzing these effects in a general equilibrium context has become urgent. One of the weaknesses of the partial models is that even if correction is made for one type of externalities, say water-pollution, increased levels of other types of externalities, e.g. air-pollution may be the result of the correction.

Ayres and Kneese (1969) have worked out a general equilibrium model in order to be able to analyze all relevant interdependent externalities simultaneously. Their basic model is made in analogy with physical models of material balances, since the total weight of inputs in conversion processes must equal the total outputs of goods and residuals. As goods, whether consumer or investment goods, are sooner or later scrapped they become residuals some

14. Bohm has studied *external effects in production* in a partial equilibrium setting (Bohm 1964). Pollution and purification in relation to the theory of external effects are also dealt with by the same author (Bohm 1970).

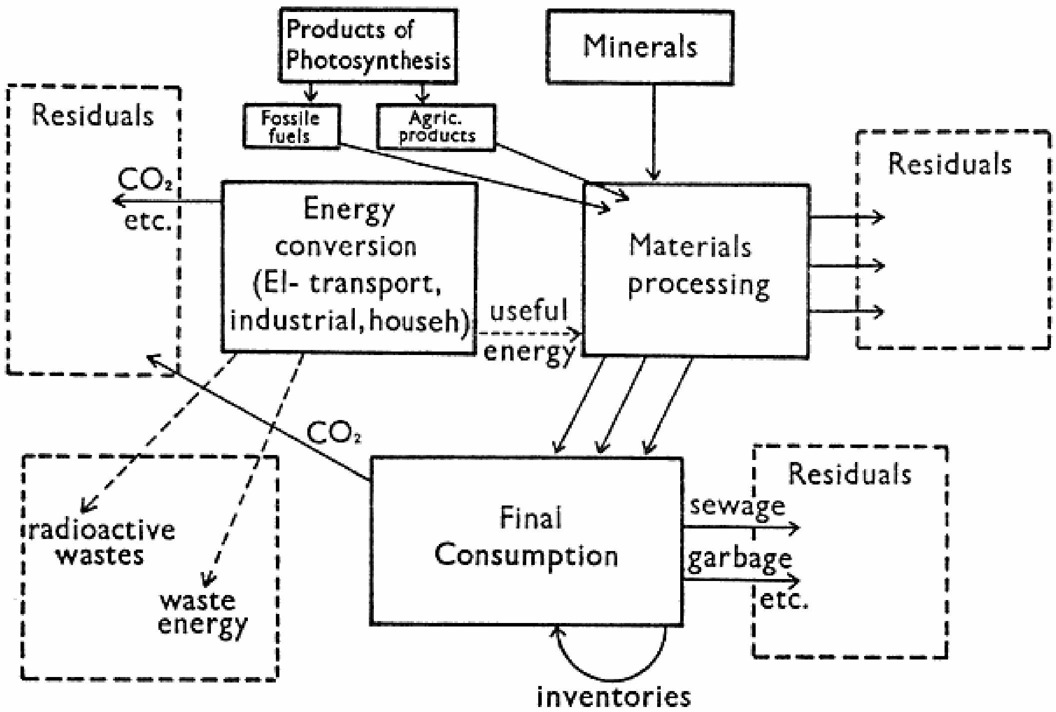

Fig. 6. Source: Ayres and Kneese 1969, pag. 285, fig. 1.

time after the inputs took place. A condensed model of the Ayres-Kneese material balance type is given in fig. 6.

This way of considering the pollution problem amounts to an emphasis on the fact that whatever is taken out from the environment and used as inputs in made-made processes (of energy conversion, materials processing and consumption activities) must always go back to the environment as residuals. Thus, attention is concentrated on the limited ability of the environment to absorb these residuals which transform the environment and change its quality. An alternative way of considering the problem is to emphasize the need of economizing with the exhaustible resources which we use in our processes.

In a general equilibrium model of the Walras-Cassel type and in input-output matrices (Leontief 1970) we would therefore want to introduce all relevant residuals created at different stages of input-conversion and attach (negative) shadow prices to all harmful residuals in order to be able to economize better with the resources, including common property resources like air, water, space, etc.

As the prices of these residuals have normally been zero, there has been little incentive to substitute existing processes with less residuals-incentive processes, to invest in purification plants and recycling processes, or to allocate resources to research in these fields.

The basic model used by Ayres and Kneese is described by the following equation[15].

$$\mathbf{R} = \mathbf{A}\,\mathbf{X} \tag{1}$$

$$\mathbf{X} = \mathbf{C}\,\mathbf{X} + \mathbf{Y} \tag{2}$$

$$\mathbf{R} = \mathbf{A}\,(\mathbf{I} - \mathbf{C})^{-1}\,\mathbf{Y} \tag{3}$$

$$\mathbf{p} = \mathbf{v}\,\mathbf{A}\,(\mathbf{I} - \mathbf{C})^{-1} \tag{4}$$

$$\mathbf{Y} = F\,(\mathbf{p}) \tag{5}$$

$$\mathbf{R} = G\,(\mathbf{v}) \tag{6}$$

Equation (1) describes the demand for non-reproducible basic resources, **R** being a $(M \times 1)$ column vector, **A** a $(M \times N)$ coefficient matrix (excluding substitution and joint production), and **X** a $(N \times 1)$ column vector of intermediate products. **X** is determined in a Leontief production model by the final demand vector **Y** in (2); (3) gives the derived demand for **R** directly on the basis of final demand **Y**. Perfect competition assumptions lead to the pricing **p** of final goods, **v** being the prices of resources (4). The model is closed by a vector-valued demand function for final goods (5), and a vector-valued supply function for resources (6).

In table 1[16] are shown the physical flows from the environment to the production sector, which equal the flows of residuals, waste and accumulation from the production sector and the final demand sector to the environment. Similarly the flows into and out of the production sector and the final demand sector, respectively, must be equal.

The flow of materials between sectors is partly accompanied by a flow of payments. These payments to and from environment are land rents and raw materials payments, but there are no money equivalent for use of (1) "common property" resources (air, water), (2) the capacity of the environment to absorb residuals, (3) and unwanted inputs to production processes (e.g. pollutants) (Ayres and Kneese 1969, p. 291). The authors therefore suggest the introduction of prices – positive or negative – to account for the scarcity of these economic resources, which are not normally priced due to the non-existence of proper institutions, permitting markets or other arrangements to

15. This condensed version of the original Ayres-Kneese model was suggested by Mr. E. Yndgaard, Institute of Economics, University of Aarhus, during a seminar on external diseconomies.
16. See note 15.

Table 1([b])

From \ To	Environment	Production sector	Final demand sector
Environment	o([a])	priced and non-priced basic resources	o([a])
Production sector	priced and non-priced residuals	o([a])	priced final products
Final demand sector	non-recycled products, i.e. waste plus accumulation	recycled products	o([a])

Notes: ([a]) Excluded by definition. ([b]) Horizontal sums equal vertical sums sectorwise.

allocate these resources properly. The scarcity of the environmental media must also lead to investments designed to improve the assimilative capacity of environment, besides investments in purification plants and recycling processes.

The practical difficulties of handling a big general equilibrium model can be partly overcome by operational systems of sub-models for regions and industries, so that the control with the environmental quality can be exercised by some degree of decentralization. Partial equilibrium models may still be useful for particular problems, but they must be complementary to more general models. An excellent bibliography finishes the article.

The only attempt to introduce the production of residuals into an input-output matrix seems to have been made by Leontief (1970).

Karl Göran Mähler[17] has applied modern general equilibrium theory to construct theoretical models which include the environment. Unpublished monographs by Kneese, Ayres and d'Arge[17] and by Russell and Spofford[17] treat environmental problems, developing the ideas outlined in the 1969-article by Ayres and Kneese.

An increasing flow of reports and articles on specific environmental problems are forthcoming. One of the most interesting is *Managing Water Quality* (Kneese and Bower 1968).

In *A Study of the Delaware Estuary* RFF[18] used a linear programming model to connect 30 sections, into which the river was subdivided, linking the outflow of residuals from each of these points with the receptor areas down-

17. Unpublished papers, 1970.
18. The environment research institution, Resources for the Future, Washington D.C.

stream. The model consisted of a system of linear simultaneous differential equations, where transfer coefficients a_{ij} related discharge from source j to receptor i. The quality of the water was measured in units of dissolved oxygen per unit of water. For each target of water quality the costs of obtaining the quality were minimized; the result was that the restrictions imposed upon the quality of the outflow of waste water from the different 30 zones were differentiated. The cost of obtaining a uniform level of water quality by means of imposing the same restrictions on all the zones would be many times greater than by the method actually suggested.

A study by Davis (1968; see also Davis 1969; Eckstein 1960) on the Potomac estuary showed that a former study by the Corps of Engineers had major weaknesses, as cost-benefit analysis was incorrectly applied, a narrow range of technical alternatives (only treatment and low-flow augmention) were considered, and a single objective of 4 ppm of dissolved oxygen used as a basis. The costs of their plan were U$ 140 million – but the same quality of water could be obtained much cheaper by the analysis applied by Davis along similar lines as those used in the Delaware project.

There are very few systematic treatments of the economics of air pollution (Ridker 1967). The difficulty of specifying the technological relationships for flows of polluted air is much more difficult than with respect to water streams, because the concentration of particles at some point depends very much on climatic conditions. Besides the extent of the damages caused by polluted air is incompletely known. A recent study on health and air pollution is Lave and Selskin (1971).

Pollution, public goods and joint production

As soon as one or more residuals follow as by-products from the production of a commodity the activity could be described as one of joint production. The price of the joint product is equal to the price of the good, as long as residuals are priced at zero, and the costs are those of producing the composite unit.

Buchanan (1966) and Mishan (1969 *b*) have tried to integrate the theory of joint supply or joint production with the theory of external effects[19]. Buchanan classifies external economies and diseconomies as a special category of joint supply, and believes this procedure has the advantage of concentrating on the optimal "externality mix" when the proportions between the single outputs of the joint product are variable within a certain area. Analogously, Oakland (1969) finds the same methodology useful in analyzing the optimal

19. Buchanan mentions (1966, p. 404, note 2) that J. G. Head (1962) has analyzed the connection between public goods, externality and joint supply, with the conclusion that externality and jointness do no belong to the same category. See also Shoup (1965).

provision of services from a public good. Thus, the location of a fire station will determine which combination of public services the inhabitants of the area are going to have.

Joint supply will be efficient, as soon as it is cheaper to produce the single elements of the product jointly rather than separately, and the conditions for an optimum are that the marginal cost of producing the joint product is equal to the sum of the prices, or better of the marginal valuations (Mishan 1969 *b*, p. 329), of the single items of the product.

Mishan examines the optimal social marginal conditions for production of jointly produced private and collective (public) goods – both optional and non-optional – with and without external economies and diseconomies. The results of the four cases he is dealing with are summarized in table 2.

Table 2

	No external effects	External effects
Jointly produced private goods	$\sum_{h=1}^{m} v_{kh}^{11} = C_k$	$\left(\sum_{h=1}^{g} v_{kh}^{11} + \sum_{h=g+1}^{m} v_{kh}^{oj}\right) = c_k$
Jointly produced collective goods	$\left(\sum_{h=1}^{g} v_{kh}^{11} + \sum_{h=g+1}^{m} v_{kh}^{01}\right)$	$\left(\sum_{h=1}^{g} v_{kh}^{11} + \sum_{g+1}^{m} v_{kh}^{01}\right)$

Source: Mishan 1969, p. 341.

If we look at *private goods* jointly produced *with externalities* the whole expression must equal c_k or the marginal cost of producing the joint good k. The expression can be read as the sum of the marginal valuations with respect to the g jointly produced goods for any individual plus the sum of the positive and negative marginal valuations with respect to the $m - g$ external economies and diseconomies produced jointly with the g genuine goods for *all* j individuals must equal marginal cost of producing the k'th complex of goods and externalities. The term o signifies that the response of any individual to an external effect is independent of the identity of the producing or consuming agent. This would not be the case, if e.g. we assumed that the identical amount of noise from the radios of two neighbours was valued differently by me. Written out in matrices we get the following picture.

The first row in the private goods matrix is to be added to the first submatrix of the externality matrix, where all submatrices are identical, which sum must equal marginal cost of producing the complex unit k.

Private goods matrix

$$\begin{vmatrix} v_{k1}^{11} & v_{k2}^{11} & \cdots\cdots & v_{kg}^{11} \\ \cdots & \cdots & \cdots\cdots & \cdots \\ v_{k1}^{ss} & v_{k2}^{ss} & \cdots\cdots & v_{kg}^{ss} \end{vmatrix}$$

Externality matrix

$$\begin{vmatrix} v_{k,g+1}^{o1} & \cdots\cdots & v_{k,m}^{o1} \\ v_{k,g+1}^{os} & \cdots\cdots & v_{k,m}^{os} \\ & \text{identical} & \\ & \text{identical} & \end{vmatrix}$$

Jointly produced collective goods with external effects

In this case the optimum condition is given by the second expression in the second row. The interpretation is that marginal cost of the k'th activity, c_k, must be equal to a sum of s expressions like that in the parenthesis which is given only for the first person. For the i'th person his marginal valuations of the j jointly produced optional collective goods are added to his marginal valuations of the $m - g$ non-optional collective goods, some of which may be unintended by-products or external effects arising from the k'th productive activity.

The left term in the second row gives the special case of no external effects, since all $m - g$ goods are interpreted as non-optional collective goods. The formal expressions are identical, whether there are external effects or not, so it might be useful for some purposes to use a more discriminatory notation than the one used by Mishan so that it would be possible to distinguish between external effects and non-optional collective goods.

Even if external economies and diseconomies could be looked upon as non-optional collective goods and "bads" (Mishan 1969, p. 340), there might be cases where the external effects were not completely non-optional, i.e. where they could be evaded or their impact reduced at no cost for the inflicted person, as well as cases where we want to make a distinction between "intended" and "unintended" collective goods (public goods and external effects).

Another distinction in the allocation of public goods is one made by Oakland (1969, p. 225). He compares the polar cases of pure public goods (Samuelson 1954) and pure private goods with the intermediate case of "joint goods", for which the degree of jointness in consumption is less than complete, as is the case of pure public goods, but on the other hand greater than zero, as for pure private goods.

In Fig. 7 A is the case of a pure public good of the Samuelson type. The (ordinal) utility of individual number 1 is OE, and that of number 2 is OD; the enjoyment of the good by individual 1 does not diminish the utility of the good experienced by number 2. DE is the utility frontier for a private good

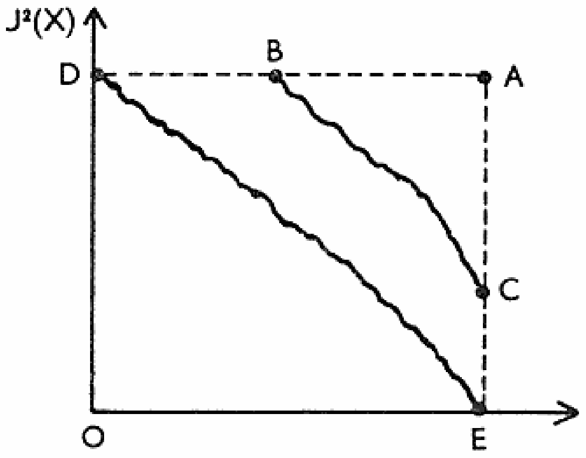

Fig. 7. Source: Oakland 1969, p. 225, fig. 1.

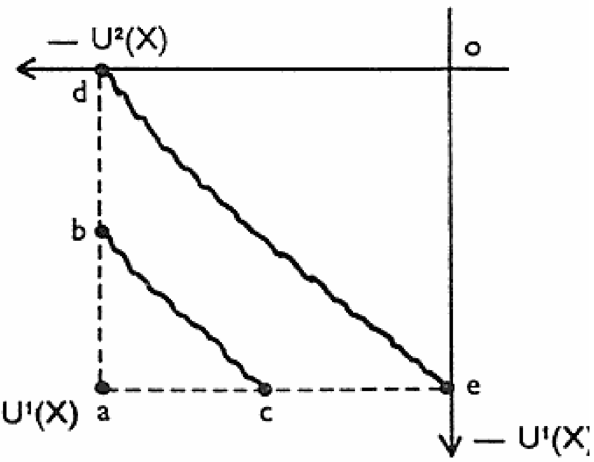

Fig. 8.

with complete rivalry in consumption: any increase in the amount of X allocated to one individual diminishes the utility enjoyed by the other. BC is the Oakland-joint-good case with some, but not complete rivalry in consumption. He uses the location of a fire station as an example of such a good. The same amount of fire extinguishing resources can be allocated in different ways geographically so that to each location a different mix of direct benefit of the collective good of fire extinction potential to some person and indirect benefits to all other persons will be the result. These indirect benefits could be labelled external effects (positive), but apparently they are not included in the Mishan formula, since in principle they are *intentional* indirect benefits from the public good in question.

The technique used by Oakland might also be used to illustrate negative external effects.

The point, a, will then be a pure public "bad", produced in some activity jointly with private or public goods, as the case may be. An example may be the decrease of the temperature of the oceans due to the spill-over of $1^1/_2$ million tons of oil every year which distributed thinly on the surface of the oceans reflect the rays of the sun so that the temperature of the oceans will gradually decrease[20]. This "bad" is enjoyed jointly be all individuals of the world. But many kinds of external diseconomies, e.g. smoke, will affect individuals differently depending on e.g. the location of the production unit so that we have a kind of *bc*-function.

A completely 'privatized' public "bad" may be sewage which could be led lawfully either to one stream or another thereby damaging different groups of persons differently. An increase of sewage to one stream would diminish

20. Example given by A. V. Kneese at a conference on Pollution and Externality Theory in Køge, Denmark, August 1970.

the amount going to the other outlet and thereby the damage to others. The utility function for such a private "bad" would be like de.

Apparently there is a need to examine how far the growing field of the theory of public goods could also be usefully applied in the theory of external diseconomies.

Recently a discussion has taken place on *optimal provision of public goods in a system of local government*. (Williams 1966; Brainard and Dolbear 1967; Williams 1967). If a local government provides public goods for its own citizens, and ignores the spillover benefits accruing to the citizens in other communities, it was earlier believed that the supply of public goods from the points of view of the nation would be smaller than the socially optimal supply, because the local unit would equate the marginal benefits to its own citizens to their marginal costs, thus neglecting the spillover marginal benefits (Williams 1966, p. 19). Williams concludes that it is not possible to predict, if undersupply or oversupply will result from such a system of autonomous public-good providing local governments, as long as the response functions of the governments to incoming spillover benefits are not carefully specified.

The same analysis would apply to a situation where regional decision units inside a nation were made responsible for regulation of the public "bads" of pollution and other environmental damages. We might end up in a situation with too little pollution ("under-supply" of pollution), analogous to the situation of over-supply of public goods. Apparently no literature exists as yet, where the analysis has been extended in this direction.

Welfare distribution, equity and the law

It is generally accepted that the characteristics of any Pareto-optimal solution depends on the existing distribution of income (Mishan, 1967 *a*, p. 225). The crucial role of the existing law in the attainment of optimal solutions in a situation with externalities has been emphasized by Coase (1960). Mishan (1967 *a*), and Burrows (1970), as briefly mentioned on page 182. The Coase article is reviewed by Mishan (1965, pp. 218-23).

Coase considered cases of external diseconomies in production, where firm *B* damages firm *A*, and emphasized the mutual inconvenience of the relationship, the crucial question being which of the firms should be allowed to impose a constraint on the other. Thus, if *B* was allowed to damage *A* the latter would have to accept this as an additional constraint on his behaviour, and conversely if *B* was not allowed to impose the burden of externalities on A without compensation this prohibition would constitute a constraint on the behaviour of *B*.

Other important points made by Coase are the following (Mishan 1965, 218-19):

1. apart from welfare (income)[21] effects the allocation and optimal output will not depend on who compensates whom;
2. the damage should be measured as the loss of rent to those factors that are less than perfectly mobile;
3. the compensation payment is the maximum social loss or amount to be paid, since the damage might be reduced somehow so that the sum of the smaller compensation amount, and the cost of diminishing the damage is less than the sum of full compensation;
4. the costs of government interference to correct the inoptimal situation or the costs of reaching and maintaining an agreement between the parties involved should be considered and added to social costs.

Whereas Coase criticizes Pigou's argument that the externality generating firm should be taxed to compensate for the damages inflicted of the reasons given in 1 and 4, Mishan defends Pigou's position on the ground "that the existence of alternative methods for reducing social diseconomies ..... (did not vitiate) .... the essential Pigovian doctrine that optimal outputs entail equality in all uses of the social value of the marginal net products of the factors, and that when the market solution did not yield this equality government intervention to promote optimal outputs by various devices, including taxes and subsidies, should be considered". (Mishan 1965, pp. 221-22).

The *interdependence between the law and optimal solutions* is explored further by Mishan (1967 *a*, pp. 225-61) and Burrows (1970). In the former article it is demonstrated that in the case of external effects (1) the optimal solution and (2) the costs involved in reaching an optimum both depends on the law. Further attention is drawn to the fact (3) that most Pareto-optimal solutions in situations of opposing interests are implicitly constrained by a requirement that the persons involved use the same time-space segment. If a beach is used by two groups of individuals of which one wants to listen to radio music, while the other doesn't[22], introduction of separate facilities or space-time segments may make solutions possible that are Pareto preferred to the non-separate-constrained solution. Smoker and non-smoker facilities are also examples of such separate areas. Zoning arrangements, whereby factories and traffic flows are separated from residential areas, are also examples of separate facilities diminishing the amount of external diseconomies in production suffered by consumers.

Mishan first considers the situation of four individuals under a law, L, permitting radio to be used without compensation. A numerical example is given in table 3.

21. The compensation payments will increase the income of the compensated party and therefore increase his marginal valuation of the damage suffered from the external diseconomies.
22. Mishan 1967, p. 231, table 1.

Table 3

Individuals	I Minimum sum required as compensation for giving up the right under *L* - law (to play his radio)	II Maximum sum the individual would pay to have successive radios turned off			III Total of I + II
W	—14	6	5	4	1
X	—33	9	7	3	—14
Y	—35	16	15	10	6
Z	—25	10	9	8	2

Source: Mishan 1967 *a*, p. 231, table 1.

The III-row which is the total of compensations proposed by each of the individuals is then the net value of reversing the permissive law (L) to a prohibitive law ($\bar{L}$).

Mishan appraises four different decision rules for whether and how a departure from the initial L-law situation with four radios playing could be brought about (Mishan 1967 *a*, pp. 232-37).

(1) *A single-outcome voting.* W, Y and Z with positive net valuations of prohibiting radios (1, 6 and 2) would vote for a $\bar{L}$-law, and only X would prefer the permissive law to prevail[23]. The law would then be replaced by a $\bar{L}$-law.

(2) *A single-outcome bargaining.* The voting is here weighted by the net benefits of each person involved, so the permissive law would have to be maintained, as the total net valuations of reversing the law is minus five (W, Y and Z with a total of 9 connot bribe X to stop his radio since he demands at least 14).

(3) *A Pareto-mixed outcome.* Under this regime one or more individuals can be exempted from the L law while the others are still subject to the law. If W were compensated by 14 (row I) out of the net benefits of the three others from having the first radio turned off, there would still be left a net benefit of $9 + 16 + 10 - 14 = 21$. Z could similarly be bribed out of net benefits from W, X, and Y, leaving $6 + 7 + 15 - 25 = 3$ in net benefits. Further improvements would not be possible, however, ($X = -33$; $W + Y + Z = 5 + 10 + 9 = 24$). The result would then be a $\bar{L}$-law for W and Z, and a L law for X and Y.

23. As Arrow has shown such a decision rule could lead to contradictory results, as the rule is not transitive.

(4) *A separate facilities outcome.* If the beach was divided into two beaches, W and Z could be placed on one of them under a $\bar{L}$-law, and X and Y on the other beach under a L law. Since W and Z do not have to be compensated by $-14-25+6+10=23$, as they are moved from a L-area to a $\bar{L}$-area, and as their row totals of 1 and 2 show that they together would pay 3 to be transferred to a $\bar{L}$-regime, the net benefits of arrangement (4) is 26 higher than those of scheme (3).

The results in terms of net benefits of the alternative arrangements compared with the status quo situation are summarized below.

1. —5 (L reversed to $\bar{L}$).
2. 0 (status quo).
3. 24 (L reversed to $\bar{L}$ for W and Z).
4. 50 (24 (situation 3.)+23+3 (improvement of 4. over 3.)).

If a prohibitive law ($\bar{L}$) was the initial position, symmetrical results would be produced, if the welfare (income) effects were zero, but this would not normally be the case with non-zero welfare effects, where in the example given only the first decision rule gives the same result as that produced under the assumptions of no welfare effects. The reason is that compensation payments are raised upwards for all those who prefer the $\bar{L}$-law to the L-law, and downwards for X, who wants a L-law regime. (Mishan 1967 *a*, pp. 239-41, and appendix 2, pp. 265-71).

The modifications in the social optimum made necessary by the existence of *bargaining costs* are discussed by Mishan (1967 *a*, pp. 241-44), and Burrows (1970, pp. 43-46).

Bargaining costs must be subtracted from net social benefits whenever an alternative arrangement is considered in a situation of external diseconomies inflicted upon others by the production or consumption activities of some agent. Mishan considers three classes of such costs (*a*) those of reaching an agreement to move from the situation created by the prevailing law (*b*) those of maintaining an agreement, (*c*) and capital costs of implementing the change considered.

Both authors agree that bargaining costs will make some bargains unprofitable which would be Pareto improvements in a costless situation. But Burrows criticizes Mishan's contention to the effect that *asymmetrical bargaining costs* (as between L and $\bar{L}$ situations) tend to favour the prohibitive law, $\bar{L}$, where bargaining costs are supposed to be smaller because of a relative small number of offenders compared to the number of offended individuals (or firms).

The existence of bargaining costs, G, even if they are symmetrical, means that O, S, or J is chosen depending on the size of G to the areas of AEO and

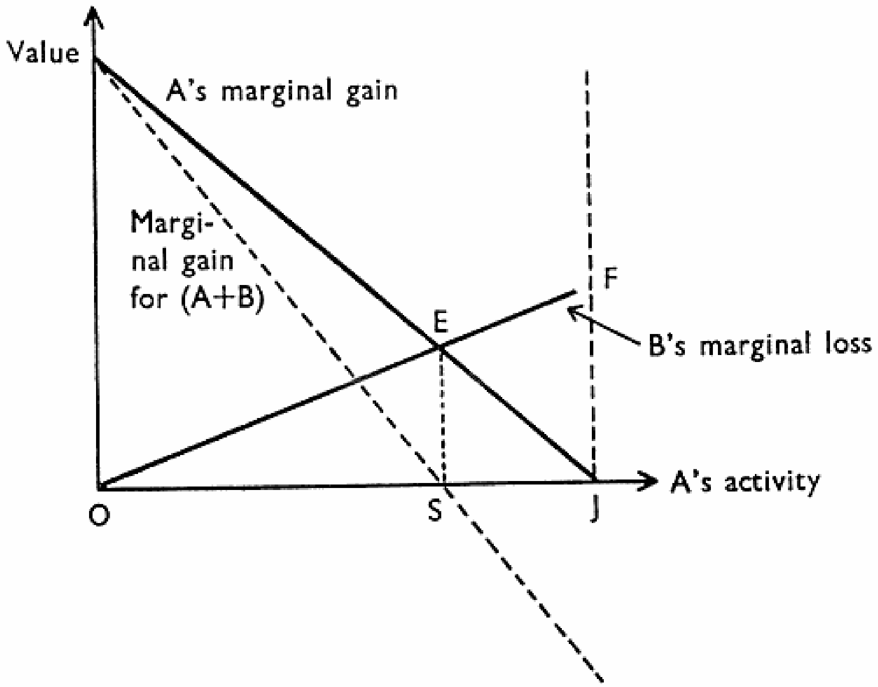

Fig. 9. Source: Burrows 1970, pag. 41, fig. 10.

EFJ in figure 9. If *G* is smaller than both potential gain areas, both the *L*- and the $\bar{L}$-law will take us to *S*. On the other hand, if *G* is greater than both, the initial situations of the *J* (*L*-law) and *O* ($\bar{L}$-law), respectively, will prevail.

But if $EFJ < G < AOF$, it will not be possible for *B* in the *J*-situation (*L*-law) to bribe *A* to go to *S*, whereas *A* out of *AOF* in the *O*-situation ($\bar{L}$-law) can pay the transaction costs and still be able to compensate *B* for permitting the activity level of *S*. If $AOF < G < EFJ$ we have a "symmetrical" result: *B* will be able to pay for the *S*-solution, whereas *A* will have to stay in *O*.

A further assumption of $G_L \neq G_{\bar{L}}$ (Mishan: $G_L > G_{\bar{L}}$) will produce the same type of results (*O*, *S* and *J*), the relative sizes of *AEO*, *EFJ*, G_L and $G_{\bar{L}}$ being decisive. As Burrows (1970, p. 44) correctly states there is no a priori reason for preferring a *L*-law to a $\bar{L}$-law on allocation grounds in a situation of asymmetrical bargaining costs.

Burrows (1970, p. 45) further questions the plausibility of the asymmetri assumption, maintaining that it would not be expected where small numbers are involved, and where large groups are involved the costs of reaching a bargain will not generally depend on whether the small group of offenders or the large offended group has to take the initiative to a settlement.

Where bargaining costs are substantial, however, no-bargain solutions (tax-subsidy arrangements, mergers, quantitative restrictions, etc.) may give more optimal solutions (Burrows 1970, p. 45; Mishan 1967 *b*, p. 64).

Burrows also argues (1970, p. 46-49) that if the law imposes restrictions on the distribution of rights (i.e. to inflict damage or to be compensated for damage) so that these are not fully negotiable between the parties involved, then conflicts are more likely to arise between economic criteria for optimal allocation (and distribution) on the one hand and legal equity objectives on the other. The problem of redistribution of rights is examined (1970, p. 49-55), and it is concluded that the juridical solution have merits which are absent in the bargaining and tax-subsidy solutions.

Growth and pollution. Recently a study has appeared on the relation between economic growth and environmental quality (d'Arge 1971). Another attempt to introduce pollution and environment into a growth model was made by Gomulka and Bolwig[24]. A production function with capital, labour and environment producing a joint output of one commodity and one pollutant is introduced. The environment deteriorates as a result of pollution, and improves because of natural and artificial (man-made) purification processes. Utility of society depends on the consumption of commodities and environmental services. The implications for a golden-age growth model are traced under alternative assumptions of environment as a public and as a privatized good. The allocation of labour and capital between the commodity producing sector and the purification sector is also determined. Finally, the paths through time of the actual state of environment and of the warranted state of environment are compared.

Income distribution. The consequences for the distribution of wealth and income of the different proposals of integrating the external diseconomies of pollution into the familiar models are largely disregarded or at any rate given little attension. Any optimal solution of an allocation problem is only defined for a certain initial distribution of income. With pollution the initial distribution of income or welfare must also include a distribution of nuisances or pollutants (diseconomies). All schemes of bargaining and compensation have implications for the distribution of incomes as have tax-subsidy schemes.

Mishan is one exception to this picture. One of his arguments for establishing prohibitive laws as a rule, wherever pollution or other harmful side-effects are present, is that "the $\bar{L}$ law would tend to produce a greater equality in the distribution of welfare as far as the commodities and services that generate the outstanding diseconomies – air and water pollution, noise, visual disturbance, destruction of natural beauty – are purchased by and earn incomes for the wealthier groups in the community". (Mishan 1967 *a*, pp. 256-60).

The environmental goods of fresh and noise-free air, clean water and na-

24. Unpublished paper (February 1971) given at a seminar June 1971 at the Department of Economics, University of York: Pollution, environment, and golden-age growth.

tural beauty, used to be rather equally distributed, because of their character of common property goods, but the burden of the decreasing quality of the environmental services may be progressively distributed, the poorest and less mobile sections of the society bearing more than a proportionate part of the quality deterioration.

These distributional aspects of pollution and other damages to the environment until now seem to have been little explored theoretically and empirically. Most arguments in this field have not been integrated into theoretical models or supported by empirical evidence.

The broad agreement on the necessity of reducing the level of pollution and increasing the quality of the environment in order to reach a kind of equilibrium level of the quality of environment seems to be shared by many sections of society, which in other economic policy matters have conflicting interests. Lack of specification of how the costs of improving different aspects of the environment should be distributed may have contributed to this apparent agreement.

Bibliographical note: Attention is drawn to the survey article on the Postwar Literature on Externalities (Mishan 1971), which contains references not mentioned here.

Further the *Swedish Journal of Economics* has concentrated on pollution and environment economics in a special issue, number 1, March 1971. All these articles are included in the following list of literature, but they appeared too late to be dealt with in the text.

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