THE PRACTICAL DETERMINATION OF A CHARGE FOR NOISE POLLUTION

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INTRODUCTION

Typically, the neoclassical tradition in environmental economics has favoured the use of a “tax” or “charge” on polluters in order to correct for the misallocation of resources brought about by the existence of uncompensated externalities. Such a charge should, in theory, be set equal to the marginal damage cost incurred at the optimal level of pollution. In turn, the optimal level of pollution is determined by the equivalence of marginal abatement costs and marginal damage costs. Other writers, notably Baumol and Oates (1975), have stressed the fact that market imperfections, including the very existence of detrimental externalities themselves, may be such as to leave us with no indication as to which direction we should take in modifying the price structure for such alleged misallocations. They therefore opt for the more pragmatic approach of establishing environmental quality standards (or emission standards, which are taken to be functionally related to receiving environment quality levels) and using charges to secure those standards. Very simply, their model requires the charge to be set equal to marginal abatement costs for each firm so as to achieve the overall quality standard. This is held to be the least-cost approach to achieving the standard, since marginal abatement costs are equalised for each firm and are, in turn, equal to the tax rate of charge.

Approaches not based on estimates of marginal damage cost would reject, for example, estimates of marginal willingness to pay for reduction in pollution, derived from “hedonic” style models in which house prices are related to housing characteristics (including pollution as a negative characteristic) and non-housing expenditures. Favourable reviews of such models are given in Nelson (1978) and Freeman (1979), but the entire methodological basis for such benefit estimates is questioned in a number of papers—see Pearce and Edwards (1979) and Harris (1980). Thus, there is a dispute over the validity of benefit estimates and hence, by implication, a dispute on whether benefit estimates can be used to derive optimal pollution charges.

In at least one case, benefit estimates derived from hedonic models have been used to calculate a set of charges for aircraft noise (COWAPS, 1977). This approach is

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considered in more detail later. For the moment it is necessary to note that unless the marginal damage (benefit) function is constant—i.e., unless the damage function is linear—knowledge of the entire function, or a significant range of it, is necessary for hedonic estimates to be used for tax calculations, even if they can be shown to be correct. This simple but neglected point is illustrated in Figure 1, where $MAC$ is the marginal abatement cost function and $MDC$ is the marginal damage cost function. If $MDC$ appears constant, the tax rate is determined by the damage function alone, as long as one can feel assured of an existence property for optimality. If $MDC$ is not constant, we require knowledge of both $MDC$ and $MAC$. Claims have been made for the linearity of benefit functions as far as noise pollution is concerned (Walters, 1975), but detailed inspection of the various hedonic models used shows that this is a highly questionable implication of the models. The more conventional view that marginal damage is itself an increasing function of pollution levels would seem to be more correct on the basis of evidence about annoyance and other damage. It is known, for example, that "loudness", i.e. noise as subjectively perceived, doubles for each decibel increase—see below.\footnote{While not denying the possibility of marginal benefit functions that are \textit{inversely} related to pollution levels over some of their range (the so-called "non-convexity" problem—see Baumol and Oates, 1975), we reject this as an empirical hypothesis for noise.}

If, as we believe, benefit functions cannot be estimated with any degree of reliability, tax policy must be determined with respect to abatement cost levels and
externally, given environmental quality levels. A similar interpretation of the nature of a pollution tax has been given by the Commission of the European Communities in their Directive to member states on charging for pollution. Thus, the partial aim of internalising the abatement cost is to ensure that some amount of abatement actually takes place. A tax or charge is consistent with this objective, in the Baumol/Oates style.

One final introductory remark concerns the uses of revenues from taxes or charges. If the tax is set out per unit of pollution regardless of whether the desired standard has been reached, then there will be revenues generated from the tax level when it lies below the marginal cost of abatement. If the tax is set so as to achieve some desired quality standard and ceases once that standard is achieved, no revenues are generated: the tax merely exists as a “threat” to the polluter, who, if rational, abates pollution up to the point where his marginal abatement costs are equal to the tax. The latter policy option would, for example, be quite consistent with the “polluter pays” principle as enunciated by O.E.C.D. (O.E.C.D., 1975; see also O.E.C.D., 1976). But equally the O.E.C.D. principle permits revenues from taxes on “residual” pollution—i.e., pollution occurring below the “optimal” level—to be used for compensation (O.E.C.D., 1975, p. 6). In this respect the principle is very flexible. The situations are contrasted in Figure 2. Here, a tax of $t$ produces pollution level $P^*$, assumed “optimal” in some policy sense. The authorities have the option of taxing the polluter for each unit of pollution between $O$ and $P^*$, in which case a revenue is generated equal to $OtXP^*$. There can be a presumption that “residual” damage occurs in the range $OP^*$, although, if benefit functions are not known, this is not self-evident. Moreover, if the benefit function is not known, we require further rules of thumb for
the disposition of those revenues if, in part anyway, they are to be paid out in compensation. In short, the use of taxes based on abatement costs and exogenous quality standards alone requires a twofold policy decision: where to set the standard, and hence the tax; and whether to tax for so-called “residual damage” and, if so, what to do with tax revenues. The O.E.C.D. “polluter pays” principle leaves member states quite free to make both major policy decisions.

Baumol and Oates (1975) demonstrate that for “undeletable externalities” (essentially, externalities with public good (bad) attributes) the victims should not be compensated. For depletable externalities, compensation should be paid, because the damage has a positive marginal cost with regard to the number of “victims”. But, since actual externality situations tend to take on the characteristics of the undeletable case, we may take it that the Baumol/Oates policy prescription would, by and large, exclude payment of compensation on grounds of misallocation. This implies, in fact, that on efficiency grounds payment for residual damage has to be made by the polluter, but without actual compensation of the “victim”. If compensation has to be paid this will be only on equity grounds (Bard, 1977).

SOME PROPOSALS FOR A NOISE CHARGE

(a) Charges to induce noise abatement

We noted that most charging mechanisms have as at least one aim to induce abatement by the polluter. In the case of noise this may consist of “retrofitting” aircraft and vehicle engines, “muffling” noisy machinery, or early retirement of existing fleets and machinery in favour of replacement with new stock incorporating the abatement technology or with elements of redesign.

One immediate problem is that, for most noise contexts, retrofit is an indivisible technology. Noise is not reducible by marginal amounts. To ensure some continuity to the abatement cost function, then, requires us to consider applying retrofit to only some part of a vehicle fleet.

To illustrate the problem, consider a Boeing 707 with quiet nacelle retrofit costing $1.2m (1973 dollars). This would reduce approach noise levels by 14.6 dB. The noise charge, $t^*$, that could bring about this abatement is given by

$$ C = \sum_{t=0}^{t=R} t^* L d_t $$

or

$$ t^* = \frac{C}{\sum_{t=0}^{t=R} L d_t} $$

2 For formal proofs see Baumol and Oates (1975), ch. 4. Note that an undeletable externality has the joint consumption aspect of a public good or bad: it need not obey the general requirement, stated elsewhere in the literature on public goods, that it be non-excludable.
where \( C \) is the (indivisible) cost of abatement, \( L \) is the number of landings per annum (the tax is assumed to be integrated with landing charges), \( n \) is the economic life of the aircraft and \( d_t \) is the discount factor for year \( t \). Thus, for an economic life of 10 years, 500 landings per annum and a discount rate of 10%, our Boeing 707 should attract a charge of some $391 (1973 dollars) per landing (Pearce, 1976, p. 16).

The problems of relating charges to some level of retrofit are numerous. First, \( t^* \) will vary directly with the level of abatement costs. But, as Pearce (1976) shows, abatement costs are technologically determined by aircraft type and are not positive and continuous functions of the level of noise reduction. This violates the Baumol/Oates requirement that each firm (in this case, each aircraft type) bear the same tax. Second, the formula operates without reference to any externally given environmental standard. The link with actual noise reduction is tenuous, because aircraft noise abatement costs and noise-reduction levels are not necessarily functionally related. Finally, \( t^* \) varies inversely with \( L \), the number of landings, so that the charge can be held to be inversely related to noise impact (Opschoor and Jansen, 1976).

We conclude that cost indivisibility, and the fact that there is no direct functional relationship between abatement technology and noise reduction by aircraft type, makes simple "abatement inducing" charges of the kind discussed untenable. Note also that the model makes no reference to "residual" noise, the sole aim being to induce retrofit.

(b) Charges related to a standard

In the Netherlands the 1979 Noise Nuisance Law allows for noise charges for both road vehicles and other non-aircraft noise. An amendment of the Aviation Act permits charges to be placed on airlines for aircraft noise. Neither measure is yet implemented to the point where actual formulae for taxes are available.

For traffic noise, a ten-year programme of noise reduction is proposed for all areas exposed on a daily basis to more than 65 dBA (Leq.). Charges are to be related to emission levels but, as far as possible, also to potential impact in terms of annoyance. By and large, any charge is to be related to the area over which more than 50 dBA noise is caused by the offending source. This meets the requirement that the "sound power" of the source be taken account of. The duration of the noise has also to be considered. In the case of vehicles this seems likely to be related to their average kilometreage travelled each year. Finally, noise characteristics are allowed for by levying higher taxes on the more annoying noises (e.g. pure tones).

Although detailed formulae have not yet been developed, Suurland (1977) suggests that these requirements for non-aircraft noise taxes are consistent with a noise tax, \( t^* \), where

\[
 t^* = t_s E
\]

such that \( E \) is the number of "emission equivalents" per source (see below) and \( t_s \) is the tax per emission equivalent.

The notion of an "emission equivalent" is derived by normalising types of noise for duration, noise level, and noise characteristics. In general
where $T$ is the duration of noise
and $SL_{50} = r^2$
where $r$ = the distance at which source causes a sound pressure of 50 dBA
and $SL_{50}$ is the surface area in which noise levels exceed 50 dBA.

It will be seen that the proposed charge has a general form which relates the tax to noise impact and a specified standard. The Act relating to non-aircraft noise sources distinguishes the functions of any charge as

(a) to induce abatement, but only for "apparatuses"—i.e., excluding industrial establishments but including vehicles;
(b) to finance the resulting Noise Act. The costs of implementation are likely to be high, in view of the complexity of monitoring noise sources (especially mobile ones) and their geographical impact.

As Suurland (1977) notes, the distinction between the two types of charge is likely to be lost in practice.

The proposed non-aircraft noise taxes do, however, have a redistributive function in the sense used in this paper, since revenue will be used to finance abatement measures. They thus technically offend the Baumol/Oates efficiency criteria noted earlier for non-depleturable externalities, but are consistent with the objective of combining efficiency and equity.

The Dutch proposals for an aircraft noise tax include imposed standards. The difference between actual and acceptable noise determines the cost of a programme of insulation and (where necessary) demolition. This overall cost is then to be met by a charge on aircraft noise. This charge has the general form

$$ t = \frac{R}{\sum_i L_i W_i} $$

where $t$ is the charge
$R$ is the revenue requirement
$L_i$ is the number of aircraft landings
and $W_i$ is some weighting factor to allow for the different noise levels of different aircraft types.

Further,

$$ R = f(N - N^*) $$

where $N^*$ and $N$ are the desired and actual noise levels, respectively. Specific examples and illustrations of this kind of formula are given in Pearce (1976).

Again, the tax is related to specified environmental standards, and to impact in so far as $N - N^*$ is functionally related to annoyance and damage. As expressed here, however, it remains inversely related to landings, has no link with costs of abatement at source (it is of course linked to abatement costs in the receiving environment), and serves a strictly redistributive function. Given the indivisibilities associated with source abatement, its effect on the noisiness of aircraft is unknown.
(c) Charges related to benefit

The U.S. Council on Wage and Price Stability (COWAPS, 1977) has proposed an aircraft noise tax based on alleged measures of marginal benefit. Its argument is that aircraft noise damage functions are linear (COWAPS, 1977, p.20). As such, the marginal noise damage function is constant (see Figure 1) and alone determines the tax rate. The model may be formalised as follows:3

The "general" tax rate, t, is given by

$$ t = \frac{\hat{C}}{2D} $$

where $\hat{C}$ is the annuitised cost of noise in terms of property price depreciation;

D is number of departures of aircraft from the given airport, doubled to allow for landings as well.

The annuitised property loss is obtained by taking an average property value, V, a discount rate, r, and a depreciation factor per one unit of NEF (noise exposure forecast index), d, so that, for any noise zone i

$$ \hat{C}_i = \frac{1}{r} V_d $$

Daytime and night-time taxes differ owing to the weights given to the respective annoyance factors for noise in the NEF index. Effectively, the NEF index weights night-time noise twelve times more than daytime noise, so that

$$ t = N_n t_n + N_d t_d $$

where $N_n$ and $N_d$ are numbers of night and daytime flights, and $t_n$ and $t_d$ are the respective taxes. Similarly, the construction of the NEF index implies

$$ t_n = 12 t_d $$

so that (7) and (8) give

$$ t_d = 0.58 t $$

Although the model purports to embrace a linear damage function, the actual computed taxes are not based on such a function. Instead it is argued that the number of households affected decreases exponentially with NEF levels.4 To allow for this, the actual daytime tax, $t_d$, is related to the generalised form of the tax, $t_d$ (equation (9)) by

$$ t_d = \hat{t}_d 2^{0.24} $$

or

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3 The formulation here is that of the authors and is different from that in COWAPS (1977), where the full model is not clearly stated and where the notation is frequently confusing.

4 Actually, it is land area that decreases exponentially with NEF (see COWAPS, 1977, p.20, footnote 3), and that is quite a different thing. In any event, apart from being inconsistent with a linear damage function, the assumption also appears to be at odds with the data in COWAPS, appendix 1, note 3.
\[ \hat{t}_d = \frac{t_d}{2^{0.2A}} \]  

where \( A \) is the average number of NEF units to which households are exposed above NEF = 30. This average is found to be 5.9 units in the U.S.A., so that \( 2^{0.2A} = 2.3 \) and hence \( t_d = 0.43 t_d \).

By substitution, then, we have

\[ \hat{t}_d = \frac{0.58t}{0.2A} = (0.43)(0.58) t \]

\[ = \frac{0.25\hat{C}}{2D} \]  

For Logan airport (Boston) we have \( \hat{C} = \$23.4m \) (1977 dollars) and \( 2D = 194,610 \), so that

\[ \hat{t}_d = \$30.3 \]

The corresponding night-time tax is 12 \( t_d = \$363.6 \).

There are two overriding problems with the COWAPS formula. The first is specific to the particular formulation: the use of equation (10) introduces a non-linearity in the tax which is inconsistent with the assumed (and, for this model, necessary) linearity in the total damage cost function. In general, equation (10) appears to be an unnecessary complication to the model.

Secondly, and far more generally, the use of a per-unit noise depreciation factor for house prices is theoretically illegitimate. Hedonic models do not in fact permit us to say whether coefficients from linear or long-linear regressions of house prices on housing "characteristics" measure anything in particular. Detailed criticism is given in Harris (1980) and Pearce and Edwards (1979). Essentially, for regression coefficients to measure hedonic prices the underlying utility functions must be identical across all individuals. If they are not identical, the effect is to yield a set of observations each of which is representative of a different utility function, instead of what is actually required, many observations on a single function. What is actually secured is coefficients which are weighted averages of individuals' marginal valuations of noise at their particular levels of each attribute.

As it happens, the restrictions on utility functions are worse than this. In addition the identical functions must also be homogeneous, since, otherwise, marginal valuations depend on the levels of utility for each individual, and these cannot be assumed the same. Finally, all these identical, homogeneous utility functions must be separable in their characteristics—i.e. between household characteristics, and between those characteristics and non-household expenditures. This means that the price of any one attribute must not be dependent upon any other factor affecting house price (see Pearce and Edwards, 1979).

There are numerous other obstacles to the use of data of house price depreciation, but the theoretical basis of hedonic models is not sufficient for those models to be used in securing any marginal benefit function. Yet it is on the basis of these models, and the work of Nelson (1976), 1978 in particular, that the COWAPS estimates are based. Indeed, a further oddity is that a value of depreciation per unit NEF of 1% is
used, allegedly based on Nelson’s survey of hedonic models. As it happens, a 1% depreciation figure is obtained in only one study, and Pearce and Edwards (1978), extending the Nelson survey, show the range to be 0.45% to 2.25% per unit NEF for USA studies.5

A PROPOSAL FOR A CHARGE RELATED TO IMPACT

Given that their are extensive difficulties in both theory and practice attached to benefit-related charges, and in practice attached to abatement-inducing charges, it seems most sensible to construct charges which bear some relationship to "physical" impact where that impact is measured in terms of annoyance. Further, while we accept that the payment of "victims" may offend some efficiency considerations, we argue that equity considerations do dictate that noise taxes take on a redistributive function. In essence, it is impossible in practice to distinguish efficiency and equity considerations for policy purposes, and the fact that the redistributive function is generally accepted in those countries which have, or propose to have, noise taxes indicates that the equity function is politically important.

What we propose, then, is a tax based on a revenue requirement which is in turn determined by an assessment of a standard for the receiving environment. That is, a standard of noisiness is set and the cost of reaching that standard is determined. This cost then becomes the requirement for revenue from a noise tax which, in turn, should be related to impact. The missing "ingredient" in the tax structure is any statement about its effects in inducing abatement. Here again, however, we might allow for this by setting the revenue requirement in such a way that the implied taxes induce reduction of noise at source. It is difficult to tell just how far such a requirement would imply taxes above or below those which would be sufficient to meet what are currently regarded as "acceptable" levels of noise. Pearce (1976) calculated that taxes based on the model outlined below might require multiplication by a factor of three if they were to induce retrofit. However, as noted in the section on technology-inducing charges, there are problems with retrofit technology that make such charges difficult to justify. It therefore seems better to seek reduction at source through noise emission standards, and to adopt the noise charge for purposes of redistributing revenue to abatement in the receiving environment. It is fully accepted that this is a departure from the Baumol/Oates style tax discussed earlier. But the various difficulties discussed would seem to dictate that this is how a noise tax operates.

Following work by Alexandre and Barde (1974, 1976, 1978), we calculate a noise impact indicator that would serve as an assessment basis for noise from road traffic and aircraft.

With regard to the assessment basis the following points are stressed:

It should be a function of the potential impact of noise on populations.
It should, if possible, be the same for aircraft and for traffic noise.

5 The reported values in Pearce and Edwards (1978) are for NNI (Noise and Number Index), converted here to NEF, using INEF = 2.5 NNI. There appears to be some dispute as to the correct conversion factor from NEF to NNI.
Until recently, most of the knowledge concerning the relationship between noise and the amplitude of its impact (in terms of annoyance and proportion of people highly annoyed) had been obtained about aircraft noise, and very little was known (or at least there was no agreement) concerning the relationship between road traffic noise and the proportion of highly annoyed persons. The earlier work of the authors adopted the widely accepted assumption of a linear relationship between aircraft noise and the percentage of highly annoyed people.

The formula used was based on the premise that the percentage of highly annoyed = 2 times the noise index (minus a constant) and that loudness (i.e., noise intensity as subjectively perceived) doubles for each 10 dB increase.6

However, more recent research by Schultz (1977), based on an extensive synthesis of traffic and aircraft noise surveys, gives the following results:

(i) The relationship between traffic and aircraft noise and the percentage of highly annoyed is curvilinear (see Figure 3).

(ii) The formula proposed by Schultz is rather complex (see Figure 3). It appears, however, that the suggested curve follows simply (and almost perfectly) a “loudness” curve, so that we have approximated the relationship by7

\[
\text{% highly annoyed} = 6.7 \left(2^{(L_A - 50)/10} - 1 \right) \\
\text{with } 50 \leq L_{dn} \leq 90
\]

where \( L_{dn} \) is day-night equivalent noise level in decibels A(dBA)

6.7 is a coefficient to make the indicator vary between 0 and 100.8

This formula implies that there is no annoyance at 50 \( L_{dn} \) and that 100% of persons are annoyed at 90 \( L_{dn} \) (see Table 1). It is shown in Figure 3.

The formula can be applied both to traffic and to aircraft noise, and we now have the necessary elements to derive an assessment basis for noise charges which would be related to the potential impact of noise on people, and could be applied uniformly to all sources of noise. It is simple to calculate and to understand and would be internationally acceptable, as it would be based on most existing surveys and on potential nuisance.

Table 1 gives the variation of the impact indicator for a \( L_{dn} \) varying between 50 and 90.

Using this indicator, we can now calculate noise charges for the noise from road traffic and aircraft.

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6 The derived formula was:

\[
I = 2(L_t - L_a) + 2^{(L_t - L_a)/10}
\]

where \( I \) = impact indicator

\( L_t \) = noise level

\( L_a \) = noise level below which there is no annoyance.

7 The introduction of the term minus one in the formula is done in order that the formula equals zero when the index \( L_{dn} \) equals 50 dBA (\( 2^0 \) being equal to 1).

8 6.7 = 100/15 (100 to ensure that the indicator varies between 0 and 100 (%)) and 15 because \( 2^{(100-50)/10} = 16 \) which becomes 15 when the term minus 1 is introduced.
A CHARGE FOR NOISE POLLUTION

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**Table 1**

*Variation of the Impact Indicator*

<table>
<thead>
<tr>
<th>$L_{dn}$ in dBA</th>
<th>% of highly annoyed (Impact indicator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>7</td>
</tr>
<tr>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>80</td>
<td>47</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
</tr>
</tbody>
</table>

$$L_{dn} = 6.7 \left[ 2^{(L_{dn} - 50)/10} - 1 \right]$$

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**Figure 3**

Schultz formula:
$$\% \text{ HA} = 0.8553L_{dn} - 0.0401L_{dn}^2 + 0.00047L_{dn}^3$$

Alexandre/Borde approximation:
$$\% \text{ HA} = 6.7\left[ 2^{(L_{dn} - 50)/10} - 1 \right]$$

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(a) A proposed tax for traffic noise

For traffic noise we propose a "Traffic Noise Rating" (Alexandre and Barde, 1976):

\[ TNR = IMZ \]

where \( I \) is the impact indicator (as defined above)
\( M \) is the mileage per annum
\( Z \) is the zone rating

The zone rating is introduced on the assumption that, as a rule, the noise impact of vehicles owned by urban residents will be greater than that of vehicles owned by rural or semi-rural residents. Thus, for example, a rural area would attract a weight of 0.5, a semi-rural zone one of 1.0, and an urban 2.0. This assumption might be reasonable for numerous private car types, light vehicles, light small vans, mopeds and light motorbikes, of which the use will be tied to a great extent to the owner's residence, but becomes more questionable for heavy commercial vehicles and also for the heavier types of private cars that are used mainly for business purposes. This calls for a more sophisticated system of zone rating, perhaps taking the zone rating used by insurance companies for calculating premiums for motor vehicle insurance.

The application of a mileage coefficient is necessary to relate the charge to the actual use of the vehicle. This requires a periodic inspection of the vehicle and perhaps some additional measures to counter opportunities for fraud, but is, on the other hand, more equitable than a system whereby the use is estimated, for example, on the basis of statistics of average mileage per vehicle category. The actual choice should therefore be made in respect of both equity and costs of implementation of such a system.

Take, for example, a private car registered in an urban zone, with a relatively low noise level of 70 dBA and a recorded annual mileage of 10,000. We get a total noise rating of \( 20 \times 10,000 \times 2 = 400,000 \). For a truck registered in the same zone, with a noise level of 90 dBA, driven 30,000 miles a year, the number of taxable noise units would amount to \( 100 \times 30,000 \times 2 = 6 \) million, which is 15 times higher than for the car. If a truck were registered in a semi-rural zone the tax would be halved. The truck example shows that one has to be very careful in applying zoning factors, because it can hardly be expected that the use of a truck with an annual mileage of 30,000 will be confined mainly to one zone. If paid by manufacturers, an incentive rate must be high enough to induce them to produce quieter vehicles. Abatement technology will not be adopted by manufacturers unless the present value of charges for excess noise above a given level exceeds the present value of abatement costs (Pearce, 1976). Unfortunately, very little information is available that would enable us to calculate an incentive rate. (See METRA, 1979.)

But, as we have seen, the charge paid by users could also be related to abatement in the receiving environment (noise barriers, etc.). The rate would thus be equal to:

\[ r = K / \sum TNR \]

where \( K \) is annual cost of local action
\( \sum TNR \) is total number of estimated taxable units of \( TNR \) (Traffic Noise Rating) per year.
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(b) A proposed tax for aircraft noise

For aircraft noise the charge can be calculated more accurately, since the noise levels and noise "footprints"\(^9\) of each type of aircraft are well known. Data are also available on the number of aircraft movements for each type of aircraft on each airport.

Finally the number of people living around an airport noise footprint is also known. We can thus derive an "Aircraft Noise Overall Impact Index":

\[
\text{ANOI} = \sum_i F_i d_i I_i
\]

where \(F_i\) is aircraft noise footprint corresponding to a given noise, class \(i\) (in ha or Km\(^2\))

\(d_i\) is population density in \(F_i\)

\(I_i\) is impact indicator in \(F_i\)

The rate of the charge (\(r\)) could be calculated by dividing the cost of local action around this airport by the number of ANOI units produced at this airport. Each aircraft then pays a charge for each landing equal to \(r_i \text{ANOI}_i\).

In order to give an example of how such a formula would work in practice we consider the case of Amsterdam airport, where it has been estimated that 20,000 dwellings are qualified for sound insulation if one takes into account the increase of air traffic to 1985 and if one wishes to protect all dwellings which, at that time, will still be exposed to annoying noise levels (more than an \(L_{da}\) index value of 65)\(^10\).

The total cost (insulation costs + cost of demolishing 225 dwellings + administrative costs) amounts to 205 million Dutch guilders, i.e. around 80 million dollars, between now and the year 1985, if 100% compensation is given for the insulated dwellings.

In order to calculate the noise charge per aircraft (assuming that the total cost of insulation will be borne by such a charging system) one needs to know the types of aircraft (types which we differentiate according to the noise they produce) that are landing at Amsterdam and the number of flights for each type per year.

Table 2 shows the number of landings per type of aircraft, and the noise footprint of each type, for Amsterdam airport in 1976.

We can now calculate the number of ANOI units per aircraft. Thus, from Tables 1 and 2, for a non-certified 2-engine aircraft, we have:

\[
\sum F_i I_i = (19 \times 20) + (11 \times 47) + (2.5 \times 100) = 1147
\]

which, in order to facilitate the calculations, we transform into an index varying from 0 to 1 (1 for the highest value obtained).\(^11\) We can now derive the total number of

\(^9\) A "footprint" relates to the geographical contour traced out for any given level of noise.

\(^10\) The basic information concerning Amsterdam airport is taken from Suurland (1977).

\(^11\) We have not included the ranges 50–59 dBA and 60–69 dBA in our calculations because they would swamp any calculations. Anyway, this omission does not affect the differentiation which we make between noisy and quiet aircraft. Also in order to simplify the calculations, we did not take into account the variations in population density around the airport.
Table 2

Amsterdam Airport 1976

<table>
<thead>
<tr>
<th>Type of aircraft (movements/2)</th>
<th>Number of landings</th>
<th>Total noise footprint (F) in km² per aircraft type</th>
<th>ANOI units per aircraft</th>
<th>ANOI index per aircraft</th>
<th>ANOI index × number of landings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise class in dBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>70–79</td>
<td>80–89</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I = 20</td>
<td>I = 47</td>
<td>I = 100*</td>
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</table>

Non certified (noisy)          
2 engine                       | 36,000              | 19                                               | 11                      | 2.5                     | 1147                            | 0.26                            | 9,360                           |
3 engine                       | 6,000               | 34                                               | 21                      | 4                       | 2067                            | 0.48                            | 2,880                           |
4 engine                       | 12,000              | 70                                               | 39                      | 11                      | 4333                            | 1                               | 12,000                          |
Certified (quieter)            
2 engine                       | 2,100               | 7                                                | 4                       | 0.4                     | 368                             | 0.08                            | 168                             |
3 engine                       | 1,700               | 12                                               | 6                       | 0.7                     | 592                             | 0.14                            | 238                             |
4 engine                       | 2,100               | 30                                               | 15                      | 1.4                     | 1445                            | 0.33                            | 693                             |
Total                          | 59,900              |                                                   |                         |                         |                                  |                                  | 25,339                          |

* See Table 1.

ANOI units produced by all aircraft during the year 1976. Table 2 shows this to be 25,339, which we get after having multiplied, for each aircraft type, the ANOI index by the number of landings during the year. If we divide 25,339 by the total number of landings (all aircraft included), we get the average number of ANOI units per landing in 1976: 25,339/59,900 = 0.42. Between 1978 and 1985, it is estimated that there will be a total of 625,000 landings (total number of movements divided by two).

If we assume, for the sake of simplicity, that the share of each type of aircraft will remain almost the same until 1985, we can calculate the total number of ANOI units which will be produced up to 1985:

0.42 × 625,000 = 262,500

The rate of the noise charge (rₙ) per ANOI unit becomes:

80 million dollars/262,500 = 305 dollars.

The resulting amount of charge paid for each landing (depending on the type of aircraft) is shown in Table 3.

On the basis of an average 55 per cent load factor for each aircraft, the charge rate per passenger would be as follows (examples): on a DC9, $1.50; on a Boeing 707, $3; on a Boeing 747 (certified), $0.40; on a DC10, $0.20.

A lot of simplifications have been made in these calculations. In reality, a system of aircraft noise charges could be much more sophisticated. We could propose a more
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Table 3

<table>
<thead>
<tr>
<th></th>
<th>( r_{T, ANOI} ) (charge per landing in dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non certified</strong></td>
<td></td>
</tr>
<tr>
<td>2 engine</td>
<td>( 0.26 \times 305 = 79 )</td>
</tr>
<tr>
<td>3 engine</td>
<td>( 0.48 \times 305 = 146 )</td>
</tr>
<tr>
<td>4 engine</td>
<td>( 1 \times 305 = 305 )</td>
</tr>
<tr>
<td><strong>Certified</strong></td>
<td></td>
</tr>
<tr>
<td>2 engine</td>
<td>( 0.08 \times 305 = 24 )</td>
</tr>
<tr>
<td>3 engine</td>
<td>( 0.14 \times 305 = 43 )</td>
</tr>
<tr>
<td>4 engine</td>
<td>( 0.33 \times 305 = 100 )</td>
</tr>
</tbody>
</table>

detailed classification of aircraft; we could devise a special night charge;\(^{12}\) we could relate the charge to the net annual cost of noise abatement; and we could adapt the local rates not only to the local situation. This is the subject of future work.

Note also that if the charge induces abatement at source the revenue requirement will itself not be met. While this may affect the compensation payment made for residual noise, it is entirely consistent with the observance of the efficiency criterion.

CONCLUSION

This paper has surveyed the practical problems of calculating pollution taxes in the context of noise. We noted that taxes could be set to induce the optimal level of pollution if this is known, or to secure least-cost attainment of an environmental quality standard. In practice, noise damage functions are not known. The paper also demonstrates the particular difficulty that noise abatement technology is indivisible to a considerable degree. To some extent this can be overcome by abating noise in parts of aircraft fleets or in some road vehicles. The problems of practically operating such a scheme are complex, however, especially where ownership of vehicles and aircraft is not common. That is, it is difficult to see how the amount of abatement would be distributed across owners.

It was noted that, while efficiency considerations do not require pollution taxes to be used to compensate victims, actual legislation, existing and proposed, tends to operate with a "revenue requirement" for this purpose. That is, it seems likely that legislation will operate in two parts: the setting of standards for the reduction of noise at source, and the use of taxes to generate revenues for the reduction of noise in the receiving environment. If this is true it seems valuable to devise taxes which relate to the noise impact. The paper concludes with one formulation which does so, and we claim that it is quite general for traffic and aircraft noise.

\(^{12}\) This would simply entail recalculating the index I per aircraft by adding 10 decibels to the noise produced at night. This is based on empirical studies showing that the subjective "value" of noise at night is perceived as 10 dB more noisy than the same noise made during the day.
REFERENCES