

**SETTING ENVIRONMENTAL
TAXES FOR AIRCRAFT:
A CASE STUDY OF THE UK**

by

**Brian Pearce
and
David Pearce**

CSERGE Working Paper GEC 2000-26

**SETTING ENVIRONMENTAL
TAXES FOR AIRCRAFT:
A CASE STUDY OF THE UK**

by

**Brian Pearce ²
and
David Pearce ¹**

**¹ Centre for Social and Economic Research
on the Global Environment
University College London
and
University of East Anglia**

and

² Forum for the Future, London

Acknowledgements

The Centre for Social and Economic Research on the Global Environment (CSERGE) is a designated research centre of the UK Economic and Social Research Council (ESRC).

We are grateful for comments on an earlier version of this paper from the participants of a seminar at the Civil Aviation Authority, London; from Nic Ferriday of the Aviation Environment Federation, London; and from Michael Mann and Eric Weinstein of the UK Department of the Environment, London. However, we alone are responsible for the interpretation in the paper and for any remaining errors.

ISSN 0967-8875

Abstract

There is growing interest in the environmental regulation of the aviation sector since it is growing rapidly and is associated with significant air emissions, greenhouse gas emissions and airport noise. After reviewing the existing policy context, this paper estimates an externality tax for Heathrow airport, UK. The relevant externalities are carbon dioxide emissions, nitrogen oxide emissions as conventional pollutants and as precursor greenhouse gases, and noise nuisance. Taxes set equal to the marginal overall externality are estimated and applied to aircraft types to secure a per-aircraft-type tax.

1. Introduction

1.1 The UK and market based instruments for environmental policy

The UK government is committed to the introduction of market-based instruments for the management of natural resources and the environment. The first clear signals of a change in policy came under the Conservative government in 1989 with the espousal of the central messages of *Blueprint for a Green Economy* (Pearce *et al.*, 1989). ‘*Blueprint*’ had been commissioned in 1988 by the then Secretary of State for the Environment, Nicholas Ridley, as a guide to inform the UK response to the World Commission on Environment and Development’s report on sustainable development (WCED, 1987). One of the central messages of *Blueprint* was that economic and environmental policy need to be integrated, and that there needed to be a switch of regulatory policy away from ‘command and control’ towards the use of market-based instruments such as environmental taxes and tradable permits. The 1990 White Paper on environmental policy cautiously embraced these principles (UK Government, 1990). The commitment to economic instruments has continued with the current Labour administration:

‘Over time, the Government will aim to reform the tax system in ways that will deliver a more dynamic economy and a cleaner environment: shifting taxes from ‘goods’ like employment, towards ‘bads’ such as pollution’ (DETR, 1999).

A number of environmental taxes are already in place, for example: a landfill tax, a forthcoming tax on the extraction of aggregates, a real price ‘escalator’ on gasoline and diesel¹, a differential road vehicle tax based on engine capacity, and a forthcoming climate change levy (effectively an energy tax). Some taxes have been linked to ‘negotiated agreements’ whereby polluters agree to take environmentally corrective action in return for some dispensation from the tax. In several cases, the setting of the taxes has been informed by measures of the economic value of the damage done by the activity or product in question (the aggregates tax and the landfill tax).

Nonetheless, the design of existing and proposed environmental taxes reflects a mixture of considerations, and the resulting instruments tend to be a long way from the ‘textbook’ prescriptions. Thus, the landfill tax was initially based on estimates of the environmental damage costs of landfill and incineration (CSERGE, EFTEC and Warren Spring Laboratory, 1993), but the tax itself has

¹ The escalator was abandoned as a regular annual event in November 1999, but retained as a budget option.

since been raised substantially to seek compliance with the European Union Landfill Directive. Raising taxes above the level of the (marginal) externality effectively implies that the stated target, in this case the target embodied in the Landfill Directive, cannot itself be justified on cost-benefit grounds. Government has therefore moved away from setting what the economist would regard as ‘optimal’ taxes, towards taxes designed to achieve environmental targets that are politically rather than economically determined². In the same way, the impending aggregates tax is a tax on tonnes of aggregate rather than on the externalities directly. The choice of a tax per tonne of material reflects the need for administrative simplicity, as with the landfill tax. However, such taxes are potentially inefficient in contexts where the demand for the taxed product is inelastic, which means that the tax will raise significant revenues but do little to reduce the tonnage of materials used. If the tonnage is not significantly affected, then the externalities are similarly not significantly affected. The environmental purpose of the tax is therefore largely lost³. Only by taxing the externalities directly – e.g. noise, dust, visual intrusion, road vehicle emissions – is there an incentive for the industry to ‘delink’ the tonnages from their environmental effects (EFTEC, 1999). Finally, the proposed climate levy is a tax on energy used by industrial users. It contains serious inefficiencies since (a) it ignores household energy use because of the feared affects on low income households (and political opposition), and (b) it is not a tax on carbon dioxide, emissions of which vary by type of fuel. Once again, the tax is linked to the UK’s greenhouse gas reduction targets agreed under the Kyoto Protocol and the European ‘burden sharing’ agreement on European greenhouse gas emissions reduction.

Overall, then, whilst Conservative and Labour governments alike have, in our view correctly, espoused the cause of market-based instruments, the instruments themselves lack many of the features of ideal externality tax design. Nonetheless, designing taxes that target the externality directly is difficult. In this paper we consider a potential tax that can be calibrated fairly precisely on the externalities.

1.2 Market-based instruments and the aviation sector

To date, some sectors have not been regarded as focal points for potential taxes, but there has been a growing concern to investigate the aviation sector in this respect. Aviation is a rapidly growing industry and there is a concern over greenhouse gas emissions in particular (IPCC, 1999). Carbon dioxide emissions by

² An optimal economic tax is one that would equal the incremental (‘marginal’) external damage at the point where this incremental damage equals the incremental cost of achieving that level of damage.

³ The government argument for retaining such taxes is that they have a ‘signalling’ function, acting as a threat in the event that industry does not introduce satisfactory ‘self-regulation’ through negotiated agreements.

aviation were around 550 mtCO₂ in 1995 (around 150 mtC) (Michaelis, 1997). Air travel is energy intensive, so that carbon-per-passenger kilometre in passenger air travel is comparable to that for cars and light trucks, short-haul being more carbon intensive than long haul.

In 1995 the International Civil Aviation Organisation (ICAO) initiated a study on the costs and benefits of environmental policy measures for aircraft noise and emissions (ICAO-EASG, 1996). At the meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) in 1998, recommendations were made to study the role of market-based options for the control of aviation externalities⁴. This work should be completed by 2001. In the meantime, CAEP received a report in 1998 suggesting that the preferred target for taxes should be fuel and en route charges (ICAO, 1998). But taxes appear to not to be welcomed by much of the industry. Suggestions have been made for a tradable permits scheme such that emission 'caps' are applied to aircraft to meet an overall emissions target. New aircraft could then only be added to the world's (or a nation's) fleet if permits were purchased or redeemed by scrapping old aircraft (Cooper, 1999). However, as noted above, the target of any tax matters because the 'wrong' target may produce inefficiencies. Accordingly, the exercise reported in this paper seeks to estimate taxes that are directly related to externalities. If needs be, such taxes can be converted to 'per tonne fuel' or 'per route' taxes but further work is needed to see the degree to which such measures deviate from the design of an 'optimal' tax.

The European Union has also intimated its interest in an aviation environmental tax. In December 1999, the European Commission issued a Communication arguing that aviation should not be exempt from such taxation (European Commission, 1999). The Communication considered three types of tax: a tax on take-off and landing, an en route tax, and a fuel tax. The fuel tax was rejected because of the need to secure international agreement. The Communication also suggests the tax revenues could be used to offset carbon dioxide emissions through funds to finance carbon sinks (such as afforestation) and to compensate house dwellers for noise nuisance. There is some suggestion that the European Commission is frustrated at alleged slow progress by ICAO in terms of reducing aircraft noise levels (ENDS, 1999). Within Europe, some countries have environmental taxes. Thus Zurich airport has an emissions tax and a noise tax added to the landing charge. Sweden has emissions charges at ten of its airports (since

⁴ Market based instruments include taxes, charges, joint implementation and emissions trading. ICAO distinguishes taxes and charges, the former being aimed at revenue raising, the latter at correcting the externality or pricing a service. In this paper we do not distinguish between charges and taxes, but the instrument we propose is a 'charge' under the ICAO definition and not a 'tax'.

1998). Germany has indicated an interest in investigating the feasibility of charges.

The view of the European Commission is that, because of its inherently international character, any taxes on aviation will require international action. This view is widely shared, although rationales vary.

Some argue that aviation charges are not permitted under the Convention on International Civil Aviation (the 'Chicago Convention') of 1947, which regulates international civil aviation. Article 15 of the Convention forbids discrimination against any aircraft for rights of transit into, out of, or across any Member State territory. But the Delft Centre for Energy Conservation and Environmental Technology (CE, 1998) notes that the non-discrimination clause relates solely to rights of transit. An environmental tax is not solely for rights of transit, although it is arguable that it places conditions on that right. The extent to which a tax for environmental purposes runs counter to the letter of the Chicago Convention is therefore open to debate. It seems more likely that the zero taxation of aviation fuel is sustained by bilateral Air Transport Agreements between individual countries (Michaelis, 1997). Others argue that, any aviation tax would be anti-competitive and hence, unless the tax is introduced globally, it will also fall foul of the Chicago Convention which explicitly requires that charging practices be reported to ICAO.

CE (1998) concludes that taxes could be introduced in the context of the Chicago Convention provides they are specifically environmental charges, i.e. are not related to the permission to use a country's air space, and are non-discriminatory. It is interesting to note that the same conclusion had been reached much earlier by OECD in 1978 as regards aircraft noise charges (OECD, 1978).

1.3 Purpose of this paper

In this paper we investigate the design of an aviation tax that could be applied unilaterally by any one country if it can be shown to be consistent with the Chicago Convention, or that could be applied globally. A global or regional tax would, of course, face formidable problems of inter-country negotiation that we abstract from here. We use the United Kingdom as an example simply to show how the tax can be computed and what its probable size would be. Because environmental damage varies with aircraft type and airport location, we seek a tax that is differentiated by aircraft type and airport characteristics. We also require that the tax should reflect the (marginal) damages from noise nuisance and from air pollution. In the case of air pollution we distinguish localised, regional and global impacts. The requirement to reflect damage done means that charges also need to vary by location, since population density varies at different

airports, and by the contribution that individual aircraft make to overall pollution and noise from aircraft. Clearly, any tax on aviation for environmental purposes needs to account for the multi-pollutant nature of air travel and for the localised conditions in which some of the externalities occur.

2. Environmental Charges For Aviation: Historical Perspective

Discussion of environmental charges for aircraft dates back some twenty-five years, mainly in the context of work at the OECD in Paris (OECD, 1978, 1980, 1986, 1991; Pearce, 1976). Alexandre and Barde (1974) (both at the OECD at that time) made a proposal for a tax on aircraft related to their noise profiles. Their suggested tax took the form:

$$\text{Charge per aircraft type} = v = t \cdot \sum_i I_i \cdot F_i$$

where t is the tax *rate* applicable to all aircraft, I is the percentage of people in a noise zone (measured in dBA) who are highly annoyed, and F is the noise footprint for each noise zone I , measured in square kilometres. The expression $\sum_i I_i \cdot F_i$ is termed the ANOI index. The rate of tax, t , is

$$t = C / [\sum_j \sum_i L_j \cdot F_i \cdot I_i]$$

where C is mitigation cost, and L_j is the number of landings for aircraft type j .

The basic principles underlying the Alexandre-Barde tax are correct in so far as the number of landings made by an aircraft type and the noise footprint help determine the tax. But there is no particular rationale for selecting the ‘highly annoyed’ fraction of the population only. All annoyance has an economic cost. Similarly, the monetary value is derived by relating annoyance to the cost of mitigating measures. The tax would be optimal in these circumstances only if the total pre-determined expenditure was itself optimal, i.e. came about through the equating of marginal mitigation costs and marginal social benefits. This is unlikely to be the case since the formulae relate to benefits only very indirectly through the size of the footprint and number highly annoyed. (The Alexandre-Barde formula can be generalised to include population density). Thus, there is still a requirement to devise a tax that is related to marginal economic damage.

CE (1998) have suggested a charge related to air emissions only. Their charge for any given aircraft type j is given by

$$T_j = \sum_i e_{ij} \cdot p_i$$

where e is the emissions of pollutant i , and p is the shadow price of the pollutant. Emission factors will vary with aircraft type, passenger/freight load factor and distance. This approach is directly related to damage done and is therefore superior to the Alexandre-Barde approach. CE nonetheless consider some second-best approaches such as fuel charges and charges per ticket. Also

attractive in the CE approach is the attempt to calculate damages from high level NO_x emissions since NO_x emitted at high levels is a precursor gas for global warming. Missing in the CE approach is any charge for noise. The other main weakness is the use of shadow prices which do not come from robust research sources. A direct comparison of emission factors in the two studies is not possible because CE quote emission factors only for 'average' rather than specific aircraft.

The OECD and CE proposals have not been enacted. Most charge schemes in place have had little or no linkage to annoyance or damage measures. France introduced an aircraft tax in 1973 to part-finance soundproofing of dwellings round airports in Paris, but the tax was unrelated to noise nuisance and was not therefore differentiated by aircraft. The tax was abolished in 1987. Japan introduced a special noise-related levy in 1975. This charge was based on aircraft weight and noise levels. Germany introduced a rebate scheme in 1976 on landing charges for aircraft complying with ICAO standards, and Manchester airport had adopted this approach in 1975. Stansted, Gatwick and Heathrow followed suit in 1979. The Netherlands attempted the introduction of noise charges in 1983 through an amendment to the Aviation Act, but the system was considered too complicated to administer. Switzerland introduced aviation noise taxes in 1980. In general, all these tax measures had little or no incentive effect since the charge levels were very low relative to overall airline operating costs (OECD, 1991).

3. Devising an Environmental Charge for Aircraft

In the remaining sections we develop an environmental charge system that incorporates both noise and atmospheric pollutant emissions and which is differentiated by aircraft type. A spreadsheet analysis is available that permits changes in variables to be entered into the charge calculation so that it can be adapted to other airports according to their noise footprints, population density, and mix of aircraft. (Pearce, 1999).

3.1 Noise nuisance

The relevant tax for noise nuisance is equal to the marginal environmental damage from aircraft (ideally measured at the optimal level of the noise externality). The tax is derived below. To illustrate the procedure, each step is accompanied by the estimate for a Boeing 737-400 at Heathrow in 1997.

Let

N_i = total aircraft events (an event being an arrival and departure) of aircraft type i at a given airport per day. For a Boeing 737-400 the figure is 157.9 per day.

N = total events for all aircraft types. Heathrow on an average day in 1997:
 $N = 583.5$.

N_A = average (EPNdB) noise level on arrival = 89.1dB for a B737-400

N_D = average (EPNdB) noise level on departure⁵ = 100.2 dB for a B737-400

The acoustic energy, E , for aircraft type i per arrival is given by

$$E_{i,A} = 10^{(N_A-10)/10} \quad [1]^6$$

So that for a B737-400 we have $10^{(89.1-10)/10} = 1.047$ (the figure is divided through by 10^9 for convenience).

And, for departure, we have:

$$E_{i,D} = 10^{(N_D/10)} \quad [2]$$

So that for a B737-400 we have $10^{89.1/10} = 0.813$ (again, the figure is divided through by 10^9 for convenience).

⁵ This is in fact an average of take off and side-line noise.

⁶ The deduction of 10 dB reflects an adjustment for the different relationship between certified noise levels and noise footprints on arrival compared to departure – see Pearce, (1999).

The total acoustic energy generated by all aircraft of type i, is then

$$N_i \cdot E_{i,A} + N_i \cdot E_{i,D} \quad [3]$$

(= {157.9 x 1.047} + {157.9 x 0.813} = 165+128 = 293 x 10⁹ for a B737-400).

For all aircraft types on a typical 1997 day at Heathrow airport the total acoustic energy generated is:

$$E = \sum_i (N_i \cdot E_{i,A} + N_i \cdot E_{i,D}) = 2824.6 \times 10^9$$

This allows us to calculate the average daily Sound Exposure Level (SEL) at Heathrow:

$$\text{Average SEL} = 10 \log (E/N) = 96.85 \text{ dB (in EPNdB)}$$

$$\text{Now, by definition } Leq^7 = \text{average SEL} + 10 \log (N) - 47.6$$

So the marginal noise nuisance caused by the reduction in an event of aircraft type i is:

$$\begin{aligned} \partial Leq_i / \partial N &= \partial \text{average SEL} / \partial N + 10 / (N \cdot \log_e 10) \\ &= \text{average SEL} - 10 \log (E - (E_{i,A} + E_{i,D})) / (N-1) + 10 / (N \cdot 2.3) \\ &= 96.8491 - 96.8537 + 0.00745 \\ &= +0.0029 \text{ EPNdB} \end{aligned}$$

To convert EPNdB to dBA units:

$$\begin{aligned} &= +0.0029 / 1.35 \\ &= +0.0021 \text{ dBA.} \end{aligned}$$

This is the quantity of noise produced by an event or arrival and departure of a B737-400 on an average day at Heathrow. Note that this marginal quantity depends on the existing level of activity or noise; $\partial Leq_i / \partial N$ will be lower at a noisier airport, with a higher N, than at a quiet airport.

⁷ The 47.6 comes from 10 log (T), where T time is 57600 seconds; the 16-hour measurement period.

3.2 The noise externality

The noise externality due to one aircraft *event* (an arrival and departure) is:

$$tn_{i,M} = DHPD \times \partial Leq_i / \partial N \quad [7]$$

where DHPD is the daily price depreciation on houses due to noise. DHPD is the marginal willingness to pay for aircraft noise reduction as reflected in the differential house prices round airports. This is an application of the hedonic property price methodology for placing an economic value of environmental detriment (Freeman, 1993). This evidence is reviewed below.

We estimate that DHPD = £15,801 for Heathrow on average in 1997, so that for a B737-400 the externality, and hence the desirable tax (see above), is:

$$£15,801 \times 0.0021 \text{ dBA} = £34 \text{ per B737-400 aircraft event.}$$

Table 1 illustrates the calculation of the noise tax for London Heathrow aircraft movements, taking the main aircraft involved in movements, including Concorde because of its noise levels.

Table 1: Noise taxes for selected aircraft at London Heathrow

Aircraft	N _i in 1997 per day	N _A	N _D	∂Leq _i /∂N (dBA)	tn _{i,M}
A310	8.4	98.8	94.5	0.0041	£64
A340	8.8	97.2	95.8	0.0049	£77
Bae146	15.5	96	86.5	0.001	£15
B737-100	8.4	103.8	100.1	0.0143	£226
B737-400	157.9	100.2	89.1	0.0021	£34
B747-400	36.3	101.4	99	0.0106	£168
B757	88.6	98.1	92.6	0.0028	£44
B767-300ER	62.0	98.4	93.7	0.0034	£54
B777	17.2	97.6	91	0.0021	£33
F100	13	93	86.8	0.0008	£12
MD82	23.7	93.7	94	0.0031	£49
Concorde	2.1	117	115.8	0.5289	£8312

Source: Pearce, B (1999)

Note the substantial difference between taxes for the aircraft involved in most of the events at Heathrow (B737s, MD82s, etc), and Concorde. Despite the fact that Concorde accounts for only 2.1 events per day it attracts a tax of over £8000 per movement.

3.3 Estimating the marginal damage from noise

This section outlines briefly the rationale for using differential house prices to reflect the economic value of noise nuisance.

Peace and quiet is a local public good. This means that, if it is provided for any one person it is provided for all in the given vicinity where noise reduction occurs. Since individuals are, generally, free to move location, they can vary the quantity of any local public good they ‘consume’. This may be contrasted with, say, global warming which is a global public ‘bad’. Relocating will produce some variation in exposure to the risks of global warming (e.g. inland as opposed to coastal areas) but cannot eliminate risk. Peace and quiet may therefore be purchased across a continuum of both quantity (the amount of noise) and price (what it costs to achieve reductions in noise).

The price of a house is effectively a present discounted value of a future stream of services provided by the house. The value of each flow is a ‘rent’ and, in turn, the rents reflect the bundles of characteristics embodied in the house – number of rooms, proximity to transport, proximity to shops and other services, and environmental attributes such as noise. The difference in price between a noisy house and a less noisy house, other things being equal, is therefore the present value of the rental being paid for the difference in noise levels. This is the intuitive rationale for using house price differences to measure willingness to pay for peace and quiet. In practice, of course, few houses are exactly alike, so that regression analysis is used to isolate the effect of noise on house prices.

The underlying theory is not presented here – see Pearce, B (1999), Freeman (1993) or Garrod and Willis (1999).

Table 2 presents estimates of the ‘noise sensitivity depreciation index’ (the NSDI). NSDI is quasi-elasticity indicating the percentage change in house price associated with a unit change in noise dBA L_{eq} .

We use the model that Schipper (1998) estimates from a meta-analysis of 30 aircraft noise hedonic house price studies. This we use to estimate NSDI (the model is specified in terms of NEF EPNdB units) and from that the marginal willingness to pay (MWTP) for a reduction in noise at Heathrow:

$$\text{NSDI} = -1.54 + 0.3 * \text{Average house price/average income} - 0.4 \text{ (if log-linear form)} + 0.01 * \text{Last 2 digits of publication date}$$

The average house price-income ratio⁸ around Heathrow airport is 5.87. Taking the semi-log functional form, and 1999 as the publication date, then:

$$\text{NSDI} = 0.81 \text{ for } 1 \text{ NEF or } 0.6 \text{ for } 1 L_{\text{eq}}$$

Table 2: Estimates of NSDI for reduced noise

Study	Year	Location	NSDI	Noise measure
J F Gautrin	1975	London Heathrow	0.25-0.30 0.42-0.50	NNI L _{eq}
J P Nelson	1980	12 US/UK studies	0.50-0.60 0.37-0.44	NEF L _{eq}
Y Yamaguchi	1996	London airports	0.382 0.64	NNI L _{eq}
Y Schipper	1998	30 US/UK studies	0.83 0.61	NEF L _{eq}

Table 3 shows the various noise intervals, the area affected and total population in each noise interval for Heathrow.

Table 3: Population exposure to noise at Heathrow

Heathrow noise contours, 1997			Heathrow noise zones, 1997			
Noise level	Area	Population	Noise level	Area	Population	Households
DBA Leq	Square km	000s	DBA Leq	Square km	000s	000s
> 57 dBA	158.3	300	57-60	69.9	140.8	58.7
> 60 dBA	88.4	159.2	60-63	34.6	75	31.3
> 63 dBA	53.8	84.2	63-66	18.5	47	19.6
> 66 dBA	35.3	37.2	66-69	12.1	23.4	9.8
> 69 dBA	23.2	13.8	69-72	9.6	9.7	4.0
> 72 dBA	13.6	4.1	> 72	13.6	4.1	1.7

⁸ Based on the Halifax bank data for the average house price in 1997 in postcodes: W4, SW6,13-15,TW2-14,19,20, UB2,3,7,SL1,3,4,RG12.

Let

P = population within the 57 dBA noise contour, 000s. P = 300 for Heathrow.
H = households within the 57 dBA noise contour, 000s. H = 125 for Heathrow⁹
HPD = house price discount or marginal willingness to pay (MWTP)
PH = average house price. PH = £128,210 in 1997¹⁰
RA = annuity interest rate. We use the 6% real rate recommended by HM Treasury.

The house price discount is estimated using the NSDI from the Schipper meta-analysis:

$$\text{HPD} = \text{PH} \times (\text{NSDI}/100) = \text{£}769.$$

So the MWTP of an individual householder for a 1 dBA reduction in aircraft noise (average over the 16 hours period of the Leq measure) within the 57 dBA contour at Heathrow is £769.

The MWTP of all 125,000 householders within the 57 dBA contour for a 1 dBA reduction in aircraft noise = £96 million. These are one-off payments which are the present value of future daily welfare gains from such a noise reduction.

To obtain the daily MWTP or the marginal daily house price depreciation (DHPD) for a 1 dBA reduction in noise:

$$\text{DHPD} = (\text{HPD} \times \text{H} \times (\text{RA}/100))/365 = \text{£}15,801.$$

This estimate is then used above to calculate the value of the noise externality due to an aircraft arrival and departure of each aircraft type.

3.4 Estimating the total damage from noise

There are two ways to estimate the total damage from noise at Heathrow: one is to use the data on noise generated by all aircraft types; the other is to use the data on noise measured on the ground as represented by the noise contours.

The first method calculates the total quantity of noise (TQN) from all aircraft types on an average day:

⁹ We assume $H = P/2.4$, i.e. average household size if 2.4 persons.

¹⁰ Based on the Halifax bank data for the average house price in 1997 in postcodes: W4, SW6,13-15,TW2-14,19,20, UB2,3,7,SL1,3,4,RG12.

$$TQN = \sum_i (N_i \times \partial Leq_i / \partial N) = 3.3 \text{ dBA for Heathrow}$$

This quantity is then valued using the marginal willingness to pay or DHPD estimate:

$$T_n = \sum_i (N_i \times tn_{i,M}) = TQN \times DHPD = 3.3 \text{ dBA} \times \text{£}15,801 = \text{£}52,143 \text{ per day or } \text{£}19 \text{ million p.a.}$$

This would suggest that total noise nuisance per year at Heathrow airport is £19 million.

However, this assumes that the quantity of noise damage from the marginal aircraft event is the same at 10 events a day as 500. We have already pointed out above that the fewer the movements the larger will be the noise damage of the marginal aircraft event (because of the term $10/(N \cdot \log_e 10)$ in the $\partial Leq_i / \partial N$ equation. In other words the $\partial Leq_i / \partial N$ noise quantities measure each aircraft at 583.5 movements a day. Obviously the marginal quantity of noise will be higher at lower movement totals. It follows that the average quantity of noise damage per aircraft movement will be considerably higher than the marginal quantity. Therefore the £19 million total is likely to be a significant underestimate of the total noise damage at Heathrow airport each year.

The alternative method uses the noise contours and zones in table 3 to calculate the total quantity of noise from all aircraft on an average day:

Noise quantity in each zone j is calculated assuming the background noise level is 55 dBA:

$$QN_j = \text{average } Leq_j - 55$$

Total noise quantity is calculated by weighting each zone's QN_j by the proportion of households living within it:

$$TQN = \sum_j ((H_j/H) \times QN_j) = 6.5 \text{ dBA for Heathrow}$$

If however background noise is assumed to be 50 dBA then:

$$QN_j = \text{average } Leq_j - 50$$

and

$$TQN = 11.5 \text{ dBA for Heathrow.}$$

These quantities are then valued using the marginal willingness to pay or DHPD estimate:

$$T_n = TQN \times DHPD = 6.5-11.5 \text{ dBA} \times \text{£}15,801 = \text{£}37.4-66.2 \text{ million p.a.}$$

Thus the estimated range for the value of total noise nuisance at Heathrow is £37.4-66.2 million, based on ground noise measurements which, as expected, lies well above the £19 million estimate derived from summing the value of the marginal noise outputs.

4. Air Pollution

4.1 Air emissions

We now address the issue of local, regional and global air emissions from aircraft. The air pollutants of interest are¹¹:

Nitrogen oxides (NO_x)

Sulphur oxides (SO_x)

Volatile organic compounds (VOCs). Non-methane VOCs include non-methane hydrocarbons (NMHC)

Carbon dioxide (CO₂)

Carbon monoxide (CO)

The relevant emission factors for selected aircraft are shown in Table 4.

The effects of pollution can be localised, transboundary or global. In some cases, effects are dependent on the altitude at which emissions occur, e.g. NO_x. In others cases, e.g. CO₂, damage done is invariant with location or altitude. While low level emissions tend to be regulated, those at cruise level are currently not regulated. In this context local pollutants are non-methane VOCs and NO_x. NO_x is known to have direct environmental and health impacts, whilst benzene (a VOC) has direct health impacts. NO_x and VOCs combined with sunlight form low level ozone (O₃), which has ecosystem effects and possibly health effects. NO_x and SO_x also ‘travel’ across national boundaries and are subject to international regulation under the UN Long Range Transboundary Air Pollution Convention and its subsequent Protocols. NO_x emitted at high atmospheric level acts as a greenhouse gas. There is some uncertainty about the nature of the atmospheric chemistry involved (IPCC, 1994), but this uncertainty has diminished with recent research (IPCC, 1999). Aircraft release NO_x into the free troposphere, increasing ozone formation. In turn ozone at those levels is a greenhouse gas. CO₂ is the main greenhouse gas.

¹¹ We have not addressed the links between aircraft emissions and stratospheric ozone depletion since the science in question appears highly uncertain (see IPCC, 1999). In principle, however, if the relationships between subsonic and supersonic emissions and UV radiation is known, it should be possible to estimate an economic cost since changes in radiation can be used to estimate changes in skin cancer and cataract risks, and damage to materials, crops and fisheries. For a cost-benefit analysis of stratospheric ozone depletion see ARC Research Consultants (1998).

Table 4: Emission factors for various aircraft, kg

Aircraft	NMHC (VOCs)	CO	CO₂	NO_x	SO_x
	Landing/take-off				
A310	3	29	4836	20	2
A340	1	8	6340	40	2
BAe146	0	11	1788	4	1
B737-100	3	17	2887	8	1
B737-400	0	10	2591	9	1
B747-400	8	88	10680	55	3
B757	1	12	3933	19	1
B767-300	3	31	5076	21	2
B777	0	13	8045	53	3
F100	0	9	2337	5	1
MD82	1	6	3149	12	1
	Cruise 500 NM				
A310	-	-	13968	64	4
A340	-	-	20286	124	6
BAe146	-	-	8020	20	3
B737-100	-	-	8812	26	3
B737-400	-	-	8750	29	3
B747-400	-	-	31398	170	10
B757	-	-	11983	64	4
B767-300	-	-	15281	77	5
B777	-	-	23754	156	8
F100	-	-	7747	22	2
MD82	-	-	11178	50	4
	Cruise 3500 NM				
A310	-	-	101149	408	32
A340	-	-	137658	709	44
BAe146	-	-	-	-	-
B737-100	-	-	-	-	-
B737-400	-	-	-	-	-
B747-400	-	-	208700	917	66
B757	-	-	-	-	-
B767-300	-	-	105539	436	34
B777	-	-	149830	739	48
F100	-	-	-	-	-
MD82	-	-	-	-	-

Source: Pearce, B. (1999).

4.2 Shadow prices for air pollutants

Just as the shadow prices for noise nuisance were derived from a ‘consensus’ view of the available literature, so the prices for pollution are also derived by looking at the increasing number of studies on the economic value of air pollution damage. Table 6 reports the values used for the economic analysis.

Table 5: Unit shadow prices of pollution damage

Pollutant	Shadow price £ per kg	Range £ per kg
CO ₂	0.029	0.013-0.044
SO ₂	5.931	4.106-7.757
Nox low altitude	0.958	0.503-1.413
Nox high altitude	1.500	upper limit 1.885
VOCs*	1.119	Not estimated
CO	Not estimated	Not estimated

Source: Pearce, D.W *et al.*, 1999

Notes: * excludes benzene

The relevant values are based on in-house work and on literature sources. Carbon monoxide emitted by aircraft is not thought to cause significant damage and is not included in the analysis, but may be the subject of future work.

The value for high level NOx has been estimated as follows. The Intergovernmental Panel on Climate Change (IPCC, 1994) conjectured that:

‘the positive radiative forcing due to the release of NOx from aircraft could be of a similar magnitude, or smaller than the effect of CO₂ released by aircraft. These estimates are preliminary...’ (IPCC, 1994, p30).

This conjecture has been examined in more detail in IPCC (1999), which uses the concept of radiative forcing (RF)¹² to compare the climate change effects of each aircraft emission. Table 6 gives RF (in watts per square meter) estimates for aviation from IPCC (1999). This radiative imbalance will have a number of climate impacts, one of which is to raise the mean surface temperature of the Earth. This impact is calculated and also shown in Table 6.

¹² Radiative forcing is a measure of the importance of a potential climate change mechanism. It expresses the perturbation or change to the energy balance of the Earth-atmosphere system in watts per square meter (Wm⁻²). Positive values of radiative forcing imply a net warming, while negative values imply cooling. (IPCC, 1999).

Table 6: Radiative forcing due to aircraft air polluting emissions

	CO ₂	O ₃	CH ₄	H ₂ O	Con-trails	Sulphate aerosols	Carbon aerosols	Total
RF	+0.018	+0.023	-0.014	+0.0015	+0.02	-0.003	+0.003	+0.048
Δ°C	+0.011	+0.014	-0.008	+0.0009	+0.012	-0.0018	+0.0018	+0.029

Source: IPCC (1999). Note that mean surface temperature change is calculated as $\Delta^{\circ}\text{C} = 0.6 \cdot \text{RF}$ (see p199 of IPCC, 1999).

In total, IPCC (1999) calculate that the effect of civil aviation (in the 1992 base scenario NASA-1992) has a radiative forcing impact of approximately $+0.05 \text{ Wm}^{-2}$. In terms of mean temperature change alone this implies that, compared to a world without civil aviation (i.e. pre-1940s), the air polluting emissions of the world's current fleet of aircraft will raise temperatures by approximately 0.03°C . This represents some 3.5% of the total radiative forcing from anthropogenic sources in 1992 (p9, IPCC, 1999).

Nitrogen oxides (NO_x) are emitted as nitric oxide (NO) in the engine exhaust plume which is photochemically oxidised into nitrogen dioxide (NO₂) further downstream in the plume as described in Archer (1993). After CO₂ and H₂O, NO_x is the most abundant air polluting aircraft emission at 5-25 grams per kilogram of fuel burnt (depending on operational conditions). Its impact on climate change is not direct but through its effect on the greenhouse gas ozone (O₃), which is produced by subsonic aircraft cruising at 9-13km altitude through NO_x reacting with CO and HC in sunlight. IPCC (1999) estimates that NO_x emissions from subsonic aircraft in 1992 increased ozone concentrations at cruise altitudes (9-13 km) in northern mid-latitudes (30-60°N) by 6%, compared to a world without aviation (NO_x concentrations were raised 20%).

The key point is that NO_x emitted at altitude is much more efficient at producing ozone than a similar amount emitted at the Earth's surface. This is both because of different atmospheric chemistry and the much longer lifetime of NO_x emitted at cruise altitudes; lower temperatures mean a slower conversion to nitric acid and there is no land to act as a sink. Egli (1991) finds NO_x remains in the air as a precursor to the greenhouse gas ozone for 100 times longer than ground-level emissions. This means aircraft NO_x emissions do more damage than other anthropogenic sources, although high altitude NO_x emissions are nowhere near as long-lived and therefore well-mixed as CO₂. As a result the increased ozone concentrations are localised around busy air traffic routes i.e. northern mid-latitudes and regional climate effects can be expected. Averaged across the Earth

the RF of aircraft-NO_x-induced ozone is estimated by IPCC (1999) to be slightly larger than CO₂ as the table above shows.

Methane (CH₄), another greenhouse gas, is reduced by chemical reactions with aircraft NO_x emissions, partially offsetting the positive RF of aircraft-NO_x-induced ozone. IPCC (1999) estimates that the methane concentration in 1992 was 2% less than a world without aviation and this has a negative RF tending to cool the temperature at the Earth's surface. It can be seen from the table above that the net effect of aircraft NO_x on climate change by the increase in ozone and the decrease in methane is a RF equal to half the CO₂ RF.

Vedanthan and Oppenheimer (1998) estimate that, in 1990, aircraft were responsible for emitting 1.15 mt of NO_x above 9km altitude, and 0.15 Gigatonnes of CO₂ as carbon, i.e. some 150 mtC. If the IPCC conjecture is correct and these emissions do roughly half amount of damage (as an upper bound) then we can equate 1 tNO_x at high altitude with 65 tC. If each tonne of carbon emitted has a shadow price of £29 then 1 tonne of NO_x at altitude has a shadow price of £1885. As this is an upper limit, we take a guesstimate figure of £1500 here.

4.3 Air pollution damage from aircraft

The relevant tax for air pollution damage, like that for noise nuisance, is equal to the marginal environmental damage from aircraft (ideally measured at the optimum level of air pollution). The tax is derived below. To illustrate the procedure, we follow the noise example by showing each step accompanied by the estimate for a Boeing 737-400.

Let

$F_{i,LTO} =$ Fuel flow for aircraft type i during the landing and take-off flight stage (LTO). For the Boeing 737-400 the figure is 825kg.

$F_{i,C-SH} =$ Fuel flow for aircraft type i during the cruise stage of a short-haul flight (500nm) = 2787kg for the B737-400.

$F_{i,C-LH} =$ Fuel flow for aircraft type i during the cruise stage of a long-haul flight (3500nm).

$El_{i,NMHC,LTO} =$ Emissions index for aircraft type i for kg of NMHC per kg of fuel burnt during the LTO flight stage = 0.00063kg/kg for the B737-400.

$EI_{i,NOx,LTO}$ = Emissions index for aircraft type i for kg of NOx per kg of fuel burnt during the LTO flight stage = 0.0107kg/kg for the B737-400.

$EI_{i,NOx,C-SH}$ = Emissions index for aircraft type i for kg of NOx per kg of fuel burnt during the cruise stage of a short-haul flight (500nm) = 0.0103kg/kg for the B737-400.

EI_{i,SO_2} = Emissions index for aircraft type i for kg of SO₂ per kg of fuel burnt = 0.001kg/kg for all flight stages and aircraft types.

EI_{i,CO_2} = Emissions index for aircraft type i for kg of CO₂ per kg of fuel burnt = 3.139kg/kg for all flight stages and aircraft types.

SP_{NMHC} = Shadow price of NMHC.

$SP_{NOx,LTO}$ = Shadow price of low-altitude (LTO) NOx.

$SP_{NOx,C}$ = Shadow price of high-altitude (cruise) NOx.

SP_{SO_2} = Shadow price of SO₂.

SP_{CO_2} = Shadow price of CO₂.

The quantity of emission of NMHC by aircraft of type i during a short-haul flight is:

$$QE_{i,NMHC,SH} = F_{i,LTO} \cdot EI_{i,NMHC,LTO}$$

(= 825 x 0.00063 = 0.5kg for the B747-400).

The quantity of emission of low-altitude NOx by aircraft type i during a short-haul flight is:

$$QE_{i,NOx,LTO,SH} = F_{i,LTO} \cdot EI_{i,NOx,LTO}$$

(= 825 x 0.0107 = 8.8kg for the B747-400).

The quantity of emission of high-altitude NOx by aircraft type i during a short-haul flight is:

$$QE_{i,NOx,C-SH} = F_{i,C-SH} \cdot EI_{i,NOx,C-SH}$$

(=2787 x 0.0103 = 28.7kg for the B747-400).

The quantity of emission of SO₂ by aircraft type i during a short-haul flight is:

$$QE_{i,SO_2,SH} = (F_{i,LTO} + F_{i,C-SH}) \cdot EI_{i,SO_2}$$

$$= (825 + 2787) \times 0.001 = 3.6\text{kg for the B747-400}.$$

The quantity of emission of CO₂ by aircraft type i during a short-haul flight is:

$$QE_{i,CO_2,SH} = ((F_{i,LTO} + F_{i,C-SH}) \cdot EI_{i,CO_2})/3.67$$

$$= ((825 + 2787) \times 3.139)/3.67 = 3089\text{kg in C equivalent for the B737-400}.$$

The air pollution externality, $tp_{i,M}$, due to one aircraft *one-way* short-haul flight is given by:

$$tp_{i,M} = QE_{i,NMHC,SH} \cdot SP_{NMHC} + QE_{i,NO_x,LTO,SH} \cdot SP_{NO_x,LTO} + QE_{i,NO_x,C-SH} \cdot SP_{NO_x,C}$$

$$+ QE_{i,SO_2,SH} \cdot SP_{SO_2} + QE_{i,CO_2,SH} \cdot SP_{CO_2}$$

So for the B747-400:

$$tp_{i,M} = 0.5 \times 1.119 + 8.8 \times 0.958 + 28.7 \times 1.5 + 3.6 \times 5.931 + 3089 \times 0.029 =$$

$$\pounds 163$$

Table 7 illustrates the calculation of the air pollution tax for *one-way* short-haul flights, taking the main aircraft involved in movements, as before. The procedure for long haul flights is the same and the results are shown in the next section.

Table 7: Air pollution tax for selected aircraft on short-haul flights

	t-NMHC	t-NO_x,LTO,SH	t-NO_x,C-SH	t-SO₂	t-CO₂	tp_{i,M}
A310	4	19	97	35	148	£303
A340	1	38	187	50	210	£486
BAe146	0	4	30	18	77	£129
B737-100	3	7	40	22	92	£164
B737-400	1	8	43	22	89	£163
B747-400	9	52	256	79	333	£729
B757	1	18	96	30	126	£271
B767-300	4	20	115	39	161	£339
B777	0	51	233	60	252	£596
F100	0	5	33	19	80	£137
MD82	1	12	75	27	113	£228

5. The Overall Environmental Tax on Aircraft Noise and Air Pollution

The overall environmental tax on aircraft is simply the sum of the noise and the air pollution taxes:

$$t_{i,M} = tn_{i,M} + tp_{i,M}$$

Tables 8 and 9 show the environmental tax levied in alternative ways on selected aircraft types. Table 9 reports the per aircraft movement tax by type of aircraft and according to whether the flights are short or long-haul. Table 9 shows how the taxes can be re-expressed as taxes per passenger, per passenger/kilometre and per unit of fuel. The Table 9 figures are useful for illustrating the effects of the tax relative to a benchmark such as the current price of aviation fuel or the price of a passenger ticket.

Table 8: Environmental tax¹³ on selected aircraft types £

	Short-haul taxes			Long-haul taxes	
	(1)	(2)	(3)=(1)+(2)	(4)	(5)=(1)+ 4)
	Noise tax $Tn_{i,M}$	Pollution tax $tp_{i,M-SH}$	Total tax $t_{i,M-SH}$	Pollution tax $tp_{i,M-LH}$	Total tax $t_{i,M-LH}$
A310	64	303	368	1673	1737
A340	77	486	563	2512	2589
Bae146	15	129	145	Na	na
B737-100	226	164	390	Na	na
B737-400	34	163	196	Na	na
B747-400	168	729	897	3585	3753
B757	44	271	315	Na	na
B767-300	54	339	393	1761	1815
B777	33	596	629	2706	2739
F100	12	137	149	Na	na
MD82	49	228	277	Na	na

¹³ Short and long-haul are illustrative distances at 500 and 3500 nautical miles respectively.

Table 9: Short-haul taxes re-expressed per passenger, per passenger/km and per unit fuel

	Noise tax: $T_{n_{i,M}}$	Pollution tax $t_{p_{i,M}}$	Total tax $t_{i,M}$	Total tax per passenger $t_{i,M}$	Total tax per 1000pkm $t_{i,M}$	Total tax per kg fuel $t_{i,M}$
A310	64	303	368	2.65	2.90	0.06
A340	77	486	563	3.16	3.45	0.07
BAe146	15	129	145	1.88	2.06	0.05
B737-100	226	164	390	5.21	5.69	0.10
B737-400	34	163	196	2.00	2.19	0.05
B747-400	168	729	897	3.23	3.53	0.07
B757	44	271	315	2.31	2.52	0.06
B767-300	54	339	393	2.90	3.16	0.06
B777	33	596	629	2.99	3.27	0.06
F100	12	137	149	2.01	2.20	0.05
MD82	49	228	277	2.60	2.84	0.06

Note: Average passenger loads assumed.

The price of jet fuel is currently £0.13/kg¹⁴ so for some aircraft types, such as the B737-100 the tax represents almost a doubling of fuel costs. If we take a B747-400 as an example it represents a 54% increase in fuel and oil costs which in 1997 were 10.5% of total operating costs (CAA, 1999). So the tax will raise operating costs by around 6%.

If airlines pass all of the tax on to passengers then for the B747-400, as the table shows, a short-haul ticket price will increase £3.23. The BA economy fare to Berlin¹⁵ is £500 so the tax represents a 0.6% price increase. The BA economy fare on a long-haul flight to San Francisco is £717.30 and so the £13.54 tax is an increase of 1.9%. This is a similar sized tax to the existing UK departure tax of £20 a person. ICAO (1985) estimate the ticket price demand elasticity for short-haul leisure flights is -1.1 and for long-haul -0.8. It follows that the tax will reduce demand on short-haul routes by 0.7% and on long-haul routes by 1.5%.

Finally, Table 10 compares our estimates of environmental taxes with those produced in the CE (1998) study.

¹⁴ Source: FT 28/9/99 \$206/tonne converted @1.6.

¹⁵ Source: BA web page quote 29/9/99.

Table 10: A comparison of environmental taxes: this study and CE (1998)

Aircraft	This study's estimates			CE (1998) estimates		
	$t_{i,M}$	$t_{i,M}/$ passengers	$t_{i,M}/$ 1000pkm	$t_{i,M}$	$t_{i,M}/$ passengers	$t_{i,M}/$ 1000pkm
B737-400	196	2.0	2.19	482	3.5	3.8
B747-400	897	3.23	3.53	1650	3.0	3.2
B757	315	2.31	2.52	639	3.5	3.8
B767-300	393	2.90	3.16	811	4.4	4.8

Note: the CE (1998) estimates have been converted from \$ to £ at 1.6 and scaled from a 1079nm (500km) route distance to 500nm.

Although the tax or marginal damage estimates for air pollution are broadly comparable between this study and that carried out by CE(1998) there are number of factors that differentiate the two studies. In particular our estimates are between 61% and 67% of the size of those estimated by the CE study. This is despite the fact that we include noise damage at the originating airport whereas the CE study considers only air pollutants. However, the tax per passenger and per passenger/km estimates are much closer, suggesting some difference in load factor or seat capacity estimates. This study has also been able to use the latest estimates of cruise emissions (Falk, 1999) that may differ from those used by CE (Roos *et al.*, 1997). Moreover, estimates of MWTP or shadow prices have been taken from the latest available in the literature and these may also differ from those used by CE. In particular our estimate for high altitude NO_x marginal damage was able to take advantage of the latest research on radiative forcing published by the IPCC (1999). However, a rigorous comparison has not been possible in the absence of the CE source data.

6. Conclusions and Policy Implications

We have shown that the data and methodologies are available to estimate the monetary value of the environmental externalities associated with aircraft movements, and hence damage-based environmental taxes for aircraft. Estimates of damage are not, however, solely motivated by tax calculations. First, there is a ‘demonstration’ purpose, i.e. we can use the total value of monetary damage as an indicator of just how serious aviation externalities are. We show, for example, that noise nuisance at Heathrow costs £37-66 million p.a. in uncompensated losses of human wellbeing. Second, the damage estimates could be used as the basis for a tradable quota scheme such that airlines trade between each other for airport use according to the damage they do. Third, the damage estimates might be used as a regulatory device such that the regulatory agency (the Civil Aviation Authority in the case of the United Kingdom) could build the damage estimates into their considerations when allocating routes to airlines, or when resolving disputes over route allocation. This would provide a major incentive for airlines to improve emissions and noise impacts by changing aircraft fleets. Finally, this methodology could be used to investigate efficient airport capacity expansion by estimating total or marginal noise nuisance at the regional airports to supplement the private travel cost estimates used by the National Air Traffic Services (NATS) Second Passenger Allocation Model (SPAM).

If used for a tax, we estimate that ‘ideal’ taxes would add a little over 0.5% to the price of a short haul European flight, and just under 2% for a long haul flight, roughly akin to the existing UK departure tax per person. In some cases, fuel costs are effectively doubled by the tax. Given that some individual nations are introducing, or have introduced, domestic environmental taxes, this paper shows that those taxes could be based on a clear rationale based in environmental economics principles. Should there be internationally co-ordinated taxes, the methodology is essentially the same but the complex issue of how to set taxes that may need to be ‘harmonised’ arises. Essentially, the global externalities are common to aircraft types regardless of which country operates the airline. Hence this part of any tax could be common and equal between countries. But local externalities depend crucially on local conditions: airport location and population density, and house prices. Hence this part of the tax – basically that part reflecting noise nuisance and local pollution – should not be harmonised if the aim is to achieve some form of economic efficiency. Non-harmonised taxes may be difficult to agree upon because of fears of differential effects on competitiveness and relocation by airlines to ‘low tax’ countries.

Arguably, both regulators and the airlines have little room for manoeuvre in terms of behavioural change. Flight paths tend to be allocated in an effort to

minimise protests about noise nuisance so that re-routing in order to minimise noise impacts and avoid a noise tax is difficult. But other behavioural reactions are possible: airlines could change the location of airport choice, they can change aircraft type and, at the margin, they can choose not to fly at all. Airframe and engine manufacturers would face an incentive to promote technological development so as to reduce noise and the most damaging air pollutants; recent technological developments have reduced CO and non-methane VOCs, but at the cost of increasing NO_x emissions. Even if behavioural change is limited, aircraft taxes would raise revenues which can be used to compensate sufferers from localised externalities. As far as the tax component reflecting global impacts, revenues could be hypothecated to funds which are then used to finance the sequestering of carbon in forests, or to finance investment in carbon-reduced fuel technologies. There are precedents for this with the advent of 'green tariffs' whereby consumers are faced with several prices for the same product: an obligatory price and optional increments. The incremental price, if paid, is channelled into a fund to finance offsetting projects that reduce carbon emissions.

References

- Alexandre, A and Barde, J-P. (1974). Aircraft noise charges, *Noise Control Engineering*, September-October,
- Alexandre, A and Barde, J-P. (1978). Noise charges: an international assessment, *Noise Control Engineering*, March-April
- ARC Research Consultants, (1998). *Global Benefits and Costs of the Montreal Protocol on Substances that Deplete the Ozone Layer*, Environment Canada, Ottawa.
- Archer, L.J. (1993). *Aircraft Emissions and The Environment: COX, SOX, HOX, & NOX*, Oxford Institute for Energy Studies, Oxford.
- CAA (Civil Aviation Authority), (1999). *UK Airlines Annual Operating, Traffic and Financial Statistics 1998*, CAP 695, Civil Aviation Authority, London
- CE (Centre for Energy Conservation and Environmental Technology), (1998). *A European Environmental Aviation Charge: Feasibility Study*, EC, Delft. Report to DGXI of the European Commission, Brussels.
- Cooper, G (1999), CO2 permits prepare for take-off, *Environmental Finance*, December 1999/January 2000, 16-17.
- CSERGE, EFTEC and Warren Spring Laboratories, (1993). *Externalities from Landfill and Incineration*, HMSO, London.
- DETR (Department of the Environment, Transport and Regions), (1999). *A Better Quality of Life: Strategy for Sustainable Development for the UK*, Cm 4345, The Stationery Office, London.
- EFTEC Ltd, (1999). *The Economic Benefits of Environmental Awareness and Training Programmes in the Aggregates Industry*, Quarry Products Association, London.
- Egli, R.A. (1991). Air Traffic Emissions – Overview, quoted in Egli (1993).
- ENDS (1999). Commission proposes green levy on aviation, *ENDS Report 299*, December, 48-49
- European Commission (1999). *Communication COM(99)640*.
- Falk, R.S. (1999). *Estimating the Fuel Used and NOx Produced from Civil Passenger Aircraft from ANCAT/EC2 Inventory Data*, DTI/EID3c/199803/01. Department of Trade and Industry: London.
- Freeman, A.M., (1993). *The Measurement of Environmental and Resource Values: Theory and Methods*, Washington DC: Resources for the Future

- Gautrin, J-F. (1975). An evaluation of the impact of aircraft noise on property values with a simple model of urban land rent, *Land Economics*, **51**, 80-86
- Garrod, G and Willis, K. (1999). *Economic Valuation of the Environment*, Cheltenham: Edward Elgar.
- ICAO (International Civil Aviation Authority), (1985). *Manual on Air Traffic Forecasting*, ICAO Doc 8991-HT/772/2
- ICAO-EASG (International Civil Aviation Authority, (1996). *Final Report of the Economic Analysis Sub-Group Regarding Economic Analysis of CAEP/3 Noise and Emissions*, Working Paper 4.4, Economic Analysis Sub-Group of the Committee on Aviation Environmental Protection Co-ordination Working Group (WG4), ICAO, Bonn.
- ICAO, (International Civil Aviation Authority), (1998). *Report of the Committee on Aviation Environmental Protection Working Group 4*, Montreal, April. Document 9720.
- IPCC (Intergovernmental Panel on Climate Change), (1994). *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios*, Cambridge: Cambridge University Press.
- IPCC (Intergovernmental Panel on Climate Change), (1999). *Aviation and the Global Atmosphere*, Cambridge: Cambridge University Press.
- Michaelis, L, (1997). *Special Issues in Carbon/Energy Taxation: Carbon Charges on Aviation Fuels*, Annex 1 Expert Group on the UN Framework Convention on Climate Change, Paris: OECD.
- Nelson, J.P. (1980). Airports and property values: a survey of evidence. *Journal of Transport Economics and Policy*, **14**, 1, 37-52
- OECD, (1978). *Reducing Noise in OECD Countries*, OECD, Paris.
- OECD, (1980). *Pollution Charges in Practice*, OECD, Paris.
- OECD, (1986). *Fighting Noise: Strengthening Noise Abatement Policies*, OECD, Paris.
- OECD, (1991). *Fighting Noise in the 1990s*, OECD, Paris
- Pearce, B.D. (1999). *A Tax on Aircraft Noise and Air Pollution*, Master of Science Thesis, Environmental and Resource Economics, Department of Economics, University College: London
- Pearce, D.W. (1976). *Charging for Noise*, OECD:Paris
- Pearce, D.W., Barbier, E and Markandya, A. (1989). *Blueprint for a Green Economy*, Earthscan: London.

- Pearce, D.W., Hett, T., Howarth, A., Ozdemiroglu, O, Powell, J.C. (1999). *Life Cycle Research Programme for Waste Management: Damage Cost Estimation for Impact Assessment*, Economics for the Environment Consultancy (EFTEC), London. For the Environment Agency.
- Roos, J., Bleijenberg, A. and Dijkstra, W. (1997). *Energy and Emission Profiles of Aircraft and Other Modes of Passenger Transport over European Distances*, CE, Delft.
- Schipper, Y. (1998). Why do aircraft noise value estimates differ? A meta-analysis, *Journal of Air Transport Management*, **4** (1998) 117-124.
- Vedanthan, A and Oppenheimer, M. (1998). Long term scenarios for aviation: demand and emissions of CO₂ and NO_x, *Energy Policy*, **26**, 8, 625-641
- WCED (World Commission on Environment and Development), (1989). *Our Common Future*, Oxford University Press: Oxford.
- Yamaguchi, Y. (1996). *Estimating the Cost of Aircraft Noise Round Airports in London*, Master of Science Thesis, Environmental and Resource Economics, Department of Economics, University College London: London.