# The economic and social value of aircraft noise effects: A critical review of the state of the art

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## ABSTRACT

The effects of Aircraft noise on health and quality of life are complex and require a comprehensive understanding of all intervening factors, apart from pure acoustical ones. Quantification and monetisation of the effects have taken on significance as a major field of study with important implications in policy making and business management.

A number of good quality studies have been conducted to quantify the monetary values of the effects of aircraft noise. The WHO report that calculated the burden of disease from environmental noise is one of the most important (WHO, 2011). In the UK, last year, the Civil Aviation Authority produced a report that proposes a methodology for estimating the monetary cost due to sleep disturbance from aircraft noise (Rohdes, et al., 2013). These studies have enriched the understanding of the magnitude and complexity of this matter. However, several gaps remain, challenging decision making on aircraft noise management at macro (public policy) and micro (airport operations) levels.

This article aims to provide a comprehensive review of the valuation of the effects of aircraft noise on human health and quality of life, and its implications within noise policy and sustainable airport operations.

We argue that aircraft noise management is a context dependent process: there is no “silver bullet” and it requires the interaction of academics, practitioners and policy-makers. Even if more high quality research is needed, we believe that it is possible to agree on some cross cutting principles, which could ensure comparability and accuracy and facilitate public and private decision making.

## INTRODUCTION

### Background

Across Europe, transport noise effects have become one of the major environmental health concerns for policy makers and communities. As part of the need for a better understanding and management policies, over the past 15 years there has been increasing attention to the economic valuation of the effects from this type of noise pollution.

The effects of transport noise on annoyance have long been a very active study area, with important developments in terms of methodologies, case studies, best practices and lessons learnt. In particular, the willingness to pay or accept (WTP/ WTA) approaches to valuing people’s preferences, have been the focus of the literature on the environmental and valuation economics since the 1960s. However, due to the subjective nature of noise and the complexity and variety on people’s responses, it has not been possible to establish standardised methods to monetise noise annoyance effects.

In contrast to that, the quantification of health effects from aircraft noise is a recent field of research, which has partly been driven by the need of adequate public policies that minimize the potential adverse effects from noise on health. Nevertheless, limitations on the scientific evidence base to establish causal relationship and thresholds (ENNAH, 2013)have prevented the calculation of accurate monetary values.

The disability–adjusted life year methodology DALY was developed in early 90's by the World Bank and soon was adopted by the World Health Organization to calculate the global burden of disease. Since then, it has been used to estimate the cost of environmental hazards on health, including noise pollution.

**Relevance of economic valuation**

Despite the complexities and limitations there is an increasing demand to quantify the extent of the impact of aircraft noise and its monetary cost to facilitate decisions making at macro and micro level.

From the public policy angle, monetisation is desirable so that the various cost of noise can be taken into account when making decisions and compared using the same metric. It will also allow noise implications be integrated into a cost – benefit analysis as part of a policy evaluation process. The UK Government appointed an independent Commission to examine and recommend how additional airport capacity can be met, for which it required to monetise noise impacts on annoyance, sleep disturbance and cardiovascular disease (Airports Commission, 2014).

**Purpose of the paper**

This paper aims to provide a comprehensive review about different methodologies for the economic valuation of aircraft noise effects on health and annoyance, and its implications within noise policy and sustainable airport operations.

This review intends to identify the most up to date and practical methodologies for valuing aircraft noise effects, which include the evidence base for its quantification and particular economic valuation methods.

We present what in our knowledge represents the "best" available evidence base for the quantification of health end points and annoyance, based on previous reviews from authors. Also, we analyse the particular methodologies that can be applied to valuate specific aircraft noise related impacts, bringing some examples of the monetary estimates. The identification of caveats and limitations forms a substantive part of our review. Finally, we provide an overview of current UK political debate on expanding airport capacity.

## AIRCRAFT NOISE EFFECTS – OVERVIEW

Human response to noise is very complex and varies between people and places. The extent of the response is influenced by many elements, besides the pure acoustical ones, such as personal, attitudinal and social factors.

The link between noise effects and potential impacts is neither simple, nor linear, as commonly presented. In fact, it depends on many aspects such as how one effect can modify another, the number of effects, the cumulative exposure and individual sensitivity to noise, the risk factors associated with health conditions and the influence of modifiers and cofounders factors (Porter, et al., 1998). This results in a complex web of pathways between noise and health and means that there is no simple cause-effect model between aircraft noise exposure and its potential health impacts.

Figure 1, below, shows that that noise exposure itself is only one of the multiple factors that feed the various paths on which people react when exposed to noise.

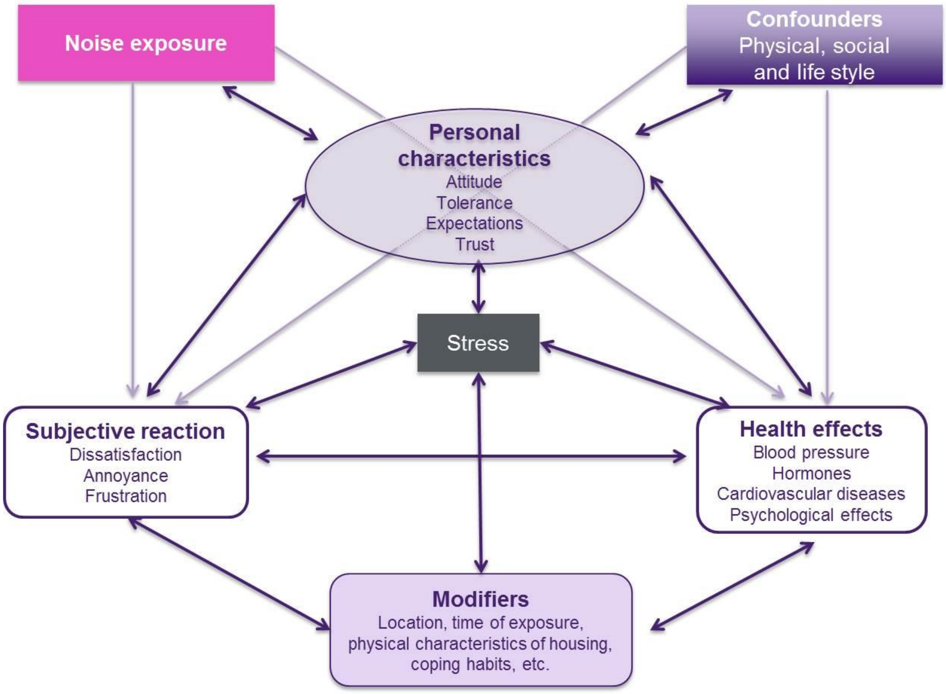


**Figure 1** Anderson Acoustics elaboration based on (Job, 1988) (HCN, 1999) (van Kempen, et al., 2005) (Babisch, 2002)

While the literature on non-auditory effects of aircraft noise exposure is extensive, the scientific evidence to establish a causal relationship and thresholds is limited. According to the European Network on Noise and Health (ENNAH, 2013), there are many gaps in the current knowledge related with the importance of noise sensitivity, the mechanism of co-exposures, habituation, the role of annoyance in health pathways, and the short and long term effects from noise exposure.

The evidence base that supports a link between each particular health outcome and noise exposure has developed independently.  Table 1 presents the strength of evidence of effects of noise on health, in terms of specific cause-effect pathways. This is based on recent reviews of the literature.

In general, the strength of evidence for cardiovascular disease, self–reported sleep disturbance, reading aged for cognitive development in children and annoyance tends to be sufficient to support an association.  However, no agreement exists on the robustness of dose – response and definition of thresholds.

In order to undertake quantitative monetisation, it is not enough to consider there is a sufficient evidence base that supports a link between noise and health effects; it is also necessary to have robust dose-response relationships that ideally should account for a causal relationship.

The uncertainties in these dose-responses relationships are a key component in the practical limitations of monetising health effects. The next section illustrates how those relationships can be applied in economic valuation.

**Table 1:** Summary of strength of evidence that supports an association

| **Health Effect** | | **Strength of evidence** | **Issues** |
|---|---|---|---|
| **Annoyance**(indirect - physiological) | | Sufficient | Complex interaction with other health effects and non-acoustic factors.<br>Debate on metrics and scope of analysis (sound vs movements) |
| **Sleep disturbance** (indirect - physiological) | Awakenings | Sufficient | A number of awakenings are normal. No agreement on threshold levels. |
| | Self-reported | Sufficient | Subject to bias |
| | Long term effects and performance | Inadequate / Lacking | Complex mechanisms underlying long-term effects.<br>No conclusive evidence of decrements in chronic objective long term effects, such as stress hormone level or immune system impacts, related with sleep disturbance. |
| **Cardiovascular** (indirect - physiological) | Acute Myocardial Infraction-AMI<br>Hypertension<br>Coronary Heart Disease-CHD | Sufficient | Even a causal link has not been conclusively proven, the strongly supported hypothesis is that exposure to aircraft noise may be a risk factor for cardiovascular disease<br>Scientific evidence for long term impact of stress hormone is inconclusive.<br>Concerns regarding validity of curves to derive threshold levels.<br>Importance of confounding and modifying factors |
| **Cognitive development** (indirect - physiological) | Adults | Inadequate / Lacking | Lack of data; no firm conclusions can be drawn |
| | Children | Sufficient | Evidence from primary school reading age and recognition memory in the short term. Less evidence for other cognitive effects. Uncertainties on the existence of long term effects.<br>The scale of effects is relatively small compared with other “life events” |
| **Mental health** (indirect - physiological) | | Lacking | Some evidence of symptoms, but not of severe clinical disorders |
| **Hearing impairment (**direct) | | None | No effects at environmental noise levels <75dB(A) |

## APPROACHES FOR THE ECONOMIC VALUATION FOR AIRCRAFT NOISE EFFECTS

The economic valuation of environmental effects on health and quality of life is a recent field of research which a burgeoning importance over the last years.

Monetisation of aircraft noise effects can be split between impacts on annoyance and health effects.

There are two generally accepted ways to monetise annoyance. One relates to an estimation of the “burden of annoyance”, through the calculation of DALYs as suggested by the WHO (WHO, 2011). The other relies on the traditional estimation of the willingness to pay to avoid (WTP) or to accept (WTA) a certain level of noise.

The economic valuation of health effects seems more complex and it is commonly undertaken by the estimation of DALYs or QALYs and it is based on dose-response relationships.

This section outlines the main approaches and gives a number of examples of typical monetisation calculations.

**Annoyance**

In the UK annoyance is currently one of the most debated issues regarding aircraft noise effects. Concerns around the metric used, the validity of noise contours in $L_{Aeq}$ to estimate people annoyed and potential increases in noise sensitivity, are key elements that add complexity to the debate.

According to the EU funded COSMA project, less than 20% of the variance in annoyance judgments can be explained by acoustical variables (Márki, 2013). US academics had pointed out that tolerance is of one of the main factors that determine annoyance prevalence rates, measured by the “community tolerance level” parameter (Fidell, et al., 2011). A study around Auckland Airport showed that “noise sensitivity has no relationship to auditory acuity, instead reflecting a judgmental, evaluative predisposition towards the perception of noise, and emphasised the importance of psychological and contextual factors (Shepherd, et al., 2010).

The economic valuation of annoyance can be undertaken using two approaches.

One is to estimate the “burden of annoyance” by combining exposure data with noise annoyance dose-response relationships.

In their report of 2011 the WHO used the percentage of “highly annoyed” persons (%HA) from the EU Position Paper to calculate DALYs. A disability weight-DW of 0.02 is proposed with a relatively large uncertainty interval (0.01 -0.12).

WHO estimated, for the European population living in urban areas, 654,000 DALYs lost due to all traffic noise induced annoyance, using a central value for DW (0.02). Aircraft noise accounts for about 16% (102,000 DALYs). Taking the extremes of the range of DWs, the DALYS lost from aircraft noise annoyance may be within 51,000 to 615,000

A major limitation of this approach relates to the difficulties to weight annoyance and relate it to existing weighted outcomes. This calculations show a difference of 12 times between the highest and the lowest value at the DALYs range, due to the range of DW. Also, a pivotal issue is whether or not annoyance significantly contributes to disability and it should be considered in the noise induced burden of disease. Policy makers must be aware of the implications and limitations of results.

In the second approach, annoyance is commonly monetised through the calculation of the WTP/WTA. This assumes that annoyance is the driver behind the pricing for avoiding or accepting certain level of noise and it does not require the link to be quantified.

The economic valuation can be undertaken using either revealed preference (e.g. hedonic pricing) or stated preference (e.g. contingent valuation) techniques.

Hedonic pricing uses house market prices as a proxy of the preference that consumers revealed for noise. Stated preference uses questionnaires in which people state their preferences based on hypothetical situations.

Hedonic pricing techniques have serious limitations. They ignore the complexity of people's preferences (that cannot be extrapolated), specific local conditions, the influence of multiple confounders and modifiers on decisions and cannot deal with asymmetry of information problems. All these factors, besides the lack of a quantitative link, make this an inappropriate way to monetise.

Stated preference solves some of the above limitations, but still has difficulties, such as the potential gap between making a choice from hypothetical and actual situation, which can lead to results may not reflect a real response. However, questionnaire design can overcome some of these issues. Also there are issues relating people's understanding on what a noise reduction means and the unfamiliarity with placing monetary values on intangibles such as noise.

**Sleep disturbance**

Sleep disturbance-related effects are a well-developed area of research but there is currently no agreement on a single dose – response relationship to inform an economic valuation methodology (Berry & Flindell, 2009)

The Civil Aviation Authority in the UK proposed in 2013 a methodology to evaluate the loss of productivity resulting from sleep disturbance and the health impacts resulting from the increased risk of hypertension that can lead to acute myocardial infarction, hypertensive strokes or dementia (Rohdes, et al., 2013). This work builds up on the work done by the Interdepartmental Group on Cost and Benefits, Noise subject IGCB(N) in the UK (IGCB(N), 2010).

The basic principle is to determine the additional cost or net benefit of a proposed policy measure compared with a baseline for these health outcomes using DALYs.

For the calculation of sleep disturbance effects, the methodology considers the percentage highly sleep disturbed function (%HSD for $L_{night)}$ from Miedema (2007), used by the WHO in the calculation of the Burden of Disease (WHO, 2011).

Impacts should be quantified separately for each policy measure. This starts with the number of people exposed to a particular noise level, from which the number of DALYs is estimated and ultimately a cost derived. The additional cost or benefit of the proposal is then the difference between the scenarios.

A major limitation of this methodology relies on the uncertainties derived by the quantification of the link between noise and sleep disturbance. As the %HSD is based on self-reported estimates, results possess a high degree of unexplained variance and are subject to bias. Acknowledging this, the IGCB(N) states that there is insufficient evidence to justify the use of any published dose-response relationship, over any other, to inform policy on adverse health effects (IGCB(N), 2010).

In addition, the disability weight (DW) plays a key role in the variance of the results. WHO chooses a central value of 0.07 as the DW of noise –related sleep disturbance, which takes into account the medians and means of DW observed in studies (WHO, 2009). It provides an uncertainty interval of DW, with a low estimate of 0.04 (median of the study with lowest DW) and a high estimate of 0.1 (primary DW for insomnia as defined by WHO). Also, the uncertainty in the dose-response relationship was not considered in the analysis of DW.

So, for instance, the results from the calculation of the burden of disease from aircraft noise in Europe provide a range of DALYs from 34,000 to 85,000, with central value of 60,000 (WHO, 2011). It is crucial that policy makers understand the variance in the answers to know the limitations of their decisions.

This methodology also proposes evaluation of acute health effects during night time exposure to aircraft noise, such as AMI and hypertension, using Babisch (2006) dose response function and Harding et al (2011) risk ratios, adjusted to night period metrics. We will present these estimations in the corresponding section of cardiovascular effects.

**Cardiovascular diseases: AMI and Hypertension**

The work done by IGCB (N), identified health as priority area for further research and the effects that can be part of valuation methodology. In particular, the Group recommends that (IGCB(N), 2010, pp. 3-4):

- Acute Myocardial Infarction (AMI) can be applied into monetary valuation of noise using the 2006 Babisch dose-response function. Policy makers using this methodology must be mindful of the uncertainties previously highlighted.
- The use of the IGCB(N)'s indicative quantification of hypertension and sleep disturbance impacts for sensitivity analysis in policy appraisal, but evidence is not sufficiently developed to monetise these quantified effects.
- Prioritising and monitoring policy-oriented research in areas where impacts are believed to be significant (hypertension and sleep disturbance), but quantification not sufficiently developed to enable inclusion in the IGCB(N)'s economic valuation methodology.
- Monitoring progress of academic research in areas where impacts are not sufficiently proven or large pieces of research are required in order for links to be quantified (cognitive development in schoolchildren, detriment to mental health and approaches to quantify amenity loses).

It is worth noting that to date new research has been developed in the UK and US, especially on cardiovascular diseases, which have contributed to both strength of evidence and definition of better and robust dose-responses. For instance, the study done by (Hansell, et al., 2013) which investigates the association of aircraft noise with the risk of stroke, coronary heart disease and cardiovascular disease in population living in near Heathrow Airport area; and also the updated version of the Health and Safety Laboratory report, which quantify and monetise the health outcomes related to hypertension due to noise exposure.

Also, the latest Babisch (2014) meta–analysis for the relationship between road traffic and coronary heart disease provides an important update in this matter. Even if pool estimates are similar to previous meta-analysis [OR: 1.08, 95% CI=1.04-1.13 per 10 dB increase in $L_{dn}$], this study extended the range of analysis (noise levels from <50 to 75 dB(A)), as well as brought a comprehensive quantitative overview of more epidemiological studies that have assessed the link between road traffic and CVD (14 studies and 17 individual estimates).

**Acute myocardial infarction**

Cardiovascular effects related with Acute Myocardial Infarction- AMI can be monetised by using the 2006 Babisch relationship, which establishes a NOAEL of 60 dB $L_{day}$, to assess the additional risk with raising road traffic noise levels (IGCB(N), 2010, p. 3). According to Babisch, apropos aircraft noise, no other alternative exists at present than to take the AMI risk curves derived from road traffic noise studies as an approximation for aircraft noise (Babisch, 2006).

However, the authors warn about the multiple uncertainties around this function, and the risk that noise management decisions based on this links might not have the expected results. Most of the uncertainties are related with the variability on responses across population due to differences in individual noise sensitivities, the role of habituation, effects from air pollution and other non-identified confounders, and applicability of the curve against other noise sources.

Moreover, recent research shows large number of technical and scientific uncertainties that prevents using this curve to establish threshold levels. According to Laszlo et al (2012) “there are limitations to the most widely used exposure-response relationships between transportation noise and myocardial infarction risk established in 2006 by Babisch and used in the 2011 WHO publication ‘Burden of disease from environmental noise’ and in the 2010 European Environment Agency ‘Good practice guide on noise exposure and potential health effects’. In particular this curve cannot be used to establish a NOAEL/LOAEL. A small number of good quality studies investigating the relationship between environmental noise and CVD risk have been published since then [2006] but more studies are needed examining the full range of exposures to better define the exposure-response relationship and investigate the possibility of threshold levels” (Laszlo, et al., 2012)

The Impact Pathway Methodology developed by the IGCB(N) can be used to comprehensively value the effects of noise on cardiovascular diseases, specifically on AMI outcomes. Monetisation was based on estimating the marginal health cost of AMI for noise level increase per household based on calculation of DALY and its recommended value for the UK.

The calculation encompasses estimations of changes in the risk if AMI and its subsequent monetisation. An overview of the main steps as well as the estimated results for the UK is:

i. Dose – response: Babisch (2006) function and odds ratios are used. For this purpose, it is assumed that $L_{day,\ 16\ hrs}$ is equivalent to $L_{Aeq,\ 18\ hrs.}$
ii. Estimate increase risk of AMI by multiplying change in the OR by prevailing probability and the level of exposure. According to UK data, the prevailing probability of AMI is of 0.084% per person, and the level of exposure is set as 2.4 persons per household.
iii. The cost of a single instance of AMI is estimated based on the calculation of years life lost and its value.
iv. According to evidence presented in research, 72% of AMI cases can lead to mortality. For both, mobility and mortality, it has been assumed that AMI reduces life expectancy by 11 years. The DW for individuals that have suffered an AMI has been set at 0.405 in line to the WHO.
v. The cost of an AMI is based on the IGCB(N) recommendation of a QALY value of £60,000

Estimates for the UK shows that the increase in cost due to changes in noise levels, is non-linear, so a raise in cost of 10% at low noise levels raises to a cost increase of 50% at high noise levels (IGCB(N), 2010, p. 17).

Notwithstanding, the IGCB(N) also warned about the multiple uncertainties and sensitivities surrounding the function and it assumptions. According to their Second Report (2010), most of them are related with:

- Dose-response function: (i) assumptions made to align multiple studies considered in meta –analysis, which provide the basis to derive curve; (ii) statistical link between noise and identified impact provides an association and not necessarily a direct causation; (iii) a single relationship may be inadequate to calculate noise impacts from different sources as they disperse noise differently; (iv) since dose-response is a static tool, potential dynamic effects may be ignored.

- Source of noise: different noise sources produce different types of effects
- Metric: calculations were done in $L_{Aeq}$ and are not applicable to alternative measures
- Noise sensitivity varies across population
- Specific instances where values cannot be applied

**Hypertension**

New research has been developed on the quantification of noise on hypertension effects. This has updated some of the recommendations that the IGCB(N) proposed on the possibility of monetising this health impact.

In 2010 the IGCB(N) considered that although Babisch & van Kamp (2009) pooled odds ratio for hypertension and aircraft noise [OR: 1.13, 95% CI: 1.00-1.28] could be used as best guess for quantitative risk assessment between aircraft noise and hypertension, they did not recommended to include it as part of a valuation methodology.

A report prepared by the Health and Safety Laboratory in 2011 (Harding, et al., 2011) identified the key health outcomes of hypertension (AMI, stroke and dementia) to quantify and estimate the monetary cost associated. Calculations of risk rates incorporated Babisch & van Kamp (2009) meta-analysis results.

However, the more recent publication from Harding et al (2013) updated the previous study by using more accurate dose-responses function between noise exposure and hypertension in monetising the link.

The study identified the key hypertension related outcomes (AMI, stroke and dementia) and quantified and monetised the impact on health attributable to environmental noise-related hypertension. This was based on the body of scientific evidence that links hypertension and those outcomes and their impact on society (Harding, et al., 2013)

van Kempen & Babisch (2012) pooled estimate [OR: 1.034, 95% CI: 1.011-1.56 for each 5dB $L_{Aeq\ 16hrs}$ increase in road traffic noise] were used as a first step in the quantification of the link. To quantify each hypertension outcome, the increased risk of hypertension due to noise exposure above the baseline, 50dB(A), was combined with risk of hypertension for AMI, stroke and dementia. The additional increase in risk was assumed to be zero for people aged less than 40 years for AMI and stroke, for dementia for people under 60 years.

Then, the methodology proposes to:

- Calculate the expected number of additional cases of hypertension per year, using estimates for additional risk and population exposed. Additional cases for one year in the UK are: 542 for AMI, 788 for stroke and 1,169 for dementia.
- Then, to estimate the QALYs lost resulting from additional cases, which values for the UK are: 4,895 QALYs for AMI, 5,287 for stroke and 7,914 for dementia. These values were based on DW produced in the Global Burden of Disease Report.
- Allocate a monetary value to each QALY of £60,000, which results in a total intangible cost of £1.09 million, with dementia accounting for 44%(£475 million), stroke for 30% (£317 million) and AMI for 26% (£294 million)

The difference in using alternatives dose – response functions is substantial. For example, the same study shows that when using Babisch & van Kamp (2009) estimates, the total impact of environmental noise on AMI, stroke and dementia increases to £2.53 billion. As explained in the document, this is considerably higher because those estimates used $L_{den}$ rather than $L_{Aeq16\ hrs}$, and the population exposed above the baseline is higher (67% $L_{den}$, and 54% $L_{Aeq16hr}$)

## CONCLUSIONS

Aircraft noise effects on health and quality of life are complex and require a comprehensive understanding about all intervening factors, apart from noise levels.

Monetising noise effects appear as a critical issue for noise policy makers and private airport operators to facilitate decision-making. However, the uncertainties and lack of agreement on thresholds levels over relationships, as well as the implications of confounding factors are major limitations for monetisation purposes.

So, in order to define whether or not is possible to include specific noise related effects as part of an economic valuation methodology it is fundamental to: (i) have sufficient strength of evidence that supports the link between each particular health outcome and noise exposure; (ii) have robust dose-response relationships to quantify the link; (iii) apply an appropriate monetisation methodology that considers elements above; and, last but not least, (iv) being aware of the multiple limitations and uncertainties that results may have in order to responsible orient noise management or policy decisions.

Aircraft noise management is a context dependent process: there is no “silver bullet” and it requires the interaction of academics, practitioners and policy-makers. Even if more high quality research is needed, we believe that it is possible to agree on some cross cutting principles, which could ensure comparability and accuracy and facilitate public and private decision making.

The UK context can provide a good example of how policy makers are approaching to these issues.

In 2012 the UK Government set up an Independent Commission tasked with identifying and recommending options for expanding UK airport’s capacity. Three shortlisted options were announced at the end of 2013, two at Heathrow and one at Gatwick Airports as possible locations for a new runway (Airports Commission, 2013).

Currently, the Commission is undertaking a Sustainability Appraisal for those three options, which in turn proposes incorporating the monetary values from the impacts of aircraft noise on annoyance, sleep disturbance and cardiovascular diseases.

The Commission proposes that monetisation of the costs of noise annoyance will be conducted using monetary estimates from hedonic pricing for road traffic (DfT WebTAG), based on daytime $L_{Aeq16hrs}$ noise exposure. For the economic cost of health effects, the Commission indicates they will adopt the CAA methodology (Rohdes, et al., 2013).

Several flaws arise from this approach. In particular for annoyance, the relationship used to quantify the link reflects responses due to non-aircraft noise, and its monetary values are based upon the impact on UK average house prices. So, it is unlikely not only that these estimates could reflect an accurate cost of aircraft noise induced annoyance, but also to address policy that responds to people preferences against noise.

Regarding health effects, the Commission should account for the latest research presented in this paper which have implications to preliminary estimates done by the Commission of noise impacts on health (Airports Commission, 2013)

Whilst there are significant issues and uncertainties associated with all of these methodologies, they are useful for comparing the options in a common currency over different periods of time. However, the results are indicative and should only be used to understand trends rather than being used to absolutely qualify the effects.

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