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VALUING NOISE NUISANCE

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Abstract
This paper presents an historical overview of the development and application of methods to value nuisance from transportation noise. The main focus is on the recent application of stated preference techniques and the additional insights they can offer relative to the more traditional revealed preference approaches. The paper draws on studies undertaken by the author and colleagues to value road traffic noise in Edinburgh and Lisbon; aircraft noise in Manchester, Lyon, Bucharest and Athens and the wider literature. Issues discussed include: the representation of changes in noise levels to respondents; the design of stated preference surveys; the derived values of noise; the determinants of variation in noise values; the potential and actual applications of the values and future opportunities to further develop and apply valuation methods.

Keywords: noise, valuation, stated preference.

1 Introduction

Noise nuisance has been recognised for hundreds if not thousands of years – as has the recognition that noise to some is not noise to others:

> *"Every body has their taste in noises as well as other matters; and sounds are quite innoxious, or most distressing, by their sort rather than their quantity. When Lady Russell, not long afterwards, was entering Bath on a wet afternoon, and driving through the long course of streets from the Old Bridge to Camden Place, amidst the dash of other carriages, the heavy rumble of carts and drays, the bawling of newsmen, muffin-men and milkmen, and the ceaseless clink of pattens, she made no complaint. No, these were noises which belonged to winter pleasures; her spirits rose under their influence". Jane Austen, 1818, page 149.*

The UK Royal Commission on The Distribution of the Industrial Population (1940) recognized health, efficiency, development and psychological effects of noise but not annoyance explicitly. With respect to the scale of the problem, the European Environment Agency estimated that over 30% (or about 120 million people) of the EU population were exposed to road traffic noise levels above 55 dB L_{dn} (1999). More recent data is now available for large cities (with a population above 250,000) in the EU; 67 million (or 55% of the population of these areas) are exposed to road traffic noise levels in excess of 55 dB L_{den} (EEA, 2009).

Interest in seeking to place a value on the nuisance imposed is of more recent origin, largely stemming from the development of cost benefit techniques in the appraisal of public projects – most notably work on the 3rd London Airport proposals and the Victoria underground line in the UK in the 1960s (Foster and Beesley 1963; Foster and Mackie 1970; Flowerdew 1972). Essentially do the benefits associated with the generation of the noise outweigh the costs imposed by the noise?

> *"In connection with another project involving large capital expenditure, the supersonic transport, we are told that this will cut three hours off the time of a journey from London to New York. Assuming that the value of the time of perhaps a hundred or so passengers on that journey is valued at this rate, this comes out at £75 a journey. One can set this alongside the fact that the noise and so on which will be created by these jets will affect, one might guess, 100,000 people who would perhaps be prepared to pay a penny a day to be rid of it. In this event it seems that unless one has more than 6 journeys a day by supersonic transport from London to New York the people who want to lead a quiet life will win."* Professor G.A. Barnard 12th December 1962 (in Foster and Beesley 1963).

The approach can then be applied to assessing the net benefit of noise mitigation measures:

> *"If even the cheapest method of reducing noise costs more than the amount at which people affected value the noise reduction, it is not worth taking that step to reduce noise."* (Page 124, Foster and Mackie 1970).

Essentially we are seeking to value noise to enable informed decisions to be made on transport and noise policy and mitigation measures. In this paper I aim to provide an overview of progress towards valuation of the costs imposed by noise on individuals. The paper aims to provide an update to the overview by Navrud (2002) and to complement Nelson's (2008) assessment of hedonic pricing studies of transportation noise. The main focus is on the recent application of stated choice techniques in this context; addressing insight obtained and progress made and identifying gaps in knowledge and challenges in methodology.

The paper is organised as follows. Section 2 examines the dominant method for valuing the costs of transport noise in the home. Section 3 outlines the stated preference approaches. Section 4 examines two major challenges in the design of valuation experiments namely the representation of noise and strategic bias. Influences on the value of noise nuisance are examined in section 5. Section 6 looks at some applications of noise values and section 7 contains conclusions.

2 Revealed Preference Approaches

As there is no market for quiet, the classic approach to valuing noise nuisance has been to seek a market within which noise is implicitly valued. Typically, use is made of the housing market where price is a function of a bundle of characteristics of the house and the neighbourhood including noise. This approach has seen the greatest development since the early attempts to value noise in the late 1960s for the Third London Airport study (Flowerdew, 1972; Walters 1975). The approach is termed “Hedonic Pricing” (HP) after Rosen’s (1974) definition of the “hedonic hypothesis that goods are valued for their utility bearing attributes or characteristics” (Rosen, page 34). Detailed exposition of the theory and method may be found in Baranzini *et al.,* (2008). The value of noise obtained is normally expressed in the form of a Noise Depreciation Index (NDI) or Noise Sensitivity Depreciation Index (NSDI) which indicates the percentage change in house prices that results from a 1 dB change in noise levels. Table 1 summarises results from some recent studies of road traffic noise in Europe.

Table 1 Results from HP studies of road traffic noise: percentage change in house prices with respect to a 1 dbA change in noise

Authors	Location	Threshold dB(A)	NSDI percentage change
Wilhelmsson (2000)	Stockholm	56 (implicit)	0.60
Lake et al (1998, 2000)	Glasgow	54 68	0.20 1.07
Rich and Nielson (2004)	Copenhagen: Houses Apartments	50	 0.54 0.47
Bjørner et al (2003)	Copenhagen	55	0.47
Bateman et al (2004)	Birmingham	55	0.21-0.53
Theebe (2004)	Western Netherlands	65	0.3 to 0.5
Baranzini and Ramirez (2005)	Geneva - rent	50	0.25
Andersson et al (2010)	Lerum	50 55	1.15-1.17 1.68-1.69

Developed from Nellthorp *et al.,* 2007

As can be seen from Table 1, even in a sample from a small number of Northern European countries there is considerable variation the estimated impact of noise on house prices. Comparison of studies is difficult due to differences: in functional form, the quality and scope of data, definitions of variables and the level of discrimination of the impact being valued.

Recent meta-analysis by Wadud (2010) utilising 53 estimates of house price depreciation from aircraft noise concludes that a 1 dB(A) change in aircraft noise levels leads to a fall in house prices of between 0.45% and 0.64%. This estimate is broadly consistent with earlier studies by Nelson (2004 and 1980) though somewhat lower than the estimates of Schipper *et al.,* (1998) of 0.9% to 1.3%. Bateman *et al.,* (2001) reviewed 18 studies of road traffic noise mostly North American finding an average NSDI of 0.55%.

The HP method is attractive because it has a basis in real decisions in the market place. However, the approach may be criticised in that purchasers may not have perfect knowledge of all the attributes of the different houses they choose between; the housing market is susceptible to other imperfections most notably transaction costs; explanatory variables suffer from correlation and it is difficult to measure some intangible influences and perceptions of them. HP is also limited in that it can only give a value of disturbance as experienced at home. Meta-analysis suggests that this cost may be capitalised through a house price discount of about 0.5% to 0.6% per dB (A). However, this cannot tell us what people might be willing to pay now for changes in the noise level experienced or how this might vary by time of day, day of week or season. These are interesting policy questions and for answers we must find another approach.

3 Stated Preference Approaches

These are essentially hypothetical questioning techniques. There are two main forms: Contingent Valuation Method (CVM) and Stated Choice (SC), each is discussed below.

3.1 Contingent valuation

In CVM the respondent is asked a direct question on willingness to pay for a beneficial change (or to avoid a deterioration) or willingness to accept compensation for a deterioration (or to forgo a benefit). Essentially, they are asked for a value that is contingent upon a hypothetical change (Garrod and Willis, 1999). The earliest studies, pre-date the common use of the term CVM and include studies in the UK of aircraft noise (Plowden 1970; Commission on the Third London Airport 1971; Ollerhead 1973; Ollerhead and Edwards, 1977) and road traffic noise (Langdon 1978), in the USA early examples tended to be with respect to outdoor recreation (Davis, 1963) and aesthetics (Randall et al, 1974; Brookshire et al, 1976).

An open-ended CVM question would simply ask, for example, "What increase in your monthly rent would you agree to pay in order to halve your housing noise level?" (Soguel, 1994). However, people find it difficult to provide a specific amount expressing a precise strength of preference. Offering a starting point for an iterative bidding process can lead to a final valuation that is dependent on the starting point (Mitchell and Carson, 1989) and higher valuations (Bateman *et al.,* 1995). This has led to more examples of dichotomous choice (or referendum) CVM where respondents are given an amount and asked whether they are willing to pay it or not. This approach has been found to yield higher values, which may be the result of "yea saying" rather than because the values are genuinely higher (Hanley et al, 2001). Most applications to noise valuation are straightforward open ended questions and so should avoid starting point bias (Pommerehne, 1988; Feitelson et al, 1996; Vainio 2001; Bjørner 2004; Wardman and Bristow 2004). However, other approaches have been adopted including: an open question with a starting point prompt for non-responders and follow up increments (Soguel, 1994); a similar approach but with increments or decrements (Ollerhead and Edwards, 1977) payment cards (Langdon, 1978; Lambert *et al.,* 2001; Baughan and Savill, 1994; Martin *et al.,* 2006); closed single amount question followed by an open ended question (Navrud, 2000); a single referendum (Kriström, 1997) a referendum double bound design (Faburel and Luchini, 2000); a one and a half bound design Barreiro et al (2005) and a dichotomous choice followed by a payment card (MVA et al, 2007). The designs also vary considerably in terms of description of the change being proposed in terms of noise or annoyance or traffic flow and the extent to which this would change.

3.2 Stated Choice

Stated choice experiments are similar to CVM in that they offer hypothetical scenarios, but in this case the choice is between two or more scenarios that differ with respect to a number of attributes. Figure 1 shows an example choice between scenarios A and B which have five attributes that may vary between scenarios, respondents are asked to indicate which scenario they prefer.

A.	B.
Car Journey times: As now	Car journey times: 33% faster
Bus journey times: As now	Bus journey times: As now
Noise levels: As now	Noise levels: Twice as good
Air quality: Twice as bad	Air quality: Twice as good
Council tax: £12.00 per week	Council tax: £22.00 per week

Figure 1: Stated Choice Example (Wardman and Bristow, 2004)

Wardman and Bristow (2004) rehearse the arguments on the relative strengths of CVM and SC approaches and these are briefly summarized here.

- SC examines several attributes simultaneously whilst CVM tends to look at attributes in isolation, therefore SC can
  - Reduce any incentive to strategic bias,
  - Reduce protest responses and
  - Examine interaction and package effects.
- SC examines different levels of attributes supporting detailed analysis of the functional relationship between the value of an attribute and its level as well as size and sign effects.
- SC asks for the order of preference whilst CVM asks for strength of preference – the former is both easier and more prevalent in everyday decision making. Bateman et al (2006) find some evidence to support this when comparing open ended CVM with contingent ranking.
- SC is a behavioural model from which values are derived, CVM is a direct valuation model and easier to analyse.
- CVM is easier to design and analyse.

The remainder of this paper will focus on SC because it can offer insights not available from hedonic pricing models including: evidence on variation in values by time of day, day of week and seasonal effects the ability to identify the influence of attitudinal and socio-economic factors on values, revelation of current preferences and the ability to explore preferences across a range of different policy options. The number of SC studies in this context is growing but still limited and includes the following:

- Aircraft noise: Thune-Larsen 1995; Carlsson *et al*. 2004; Bristow and Wardman 2006; MVA 2007; Thanos 2008; Wardman and Bristow 2008;
- Road traffic noise: Sælinsminde 1999; Daniels and Hensher 2000; Hunt 2001; Eliasson *et al*. 2002; Garrod *et al*. 2002; Wardman and Bristow 2004; Galilea and Ortúzar 2005; Arsenio *et al.* 2006, Parumog *et al.* 2006; Caulfield and O'Mahony 2007; Li *et al.* 2009; Dave *et al.,* 2009 and
- Rail traffic noise, Nunes and Travisi, 2007.

The following discussion focuses on aspects of experimental design in section 4 and identifying influences on noise values in section 5.

4 Experimental design

4.1 Representation of Noise

One of the main challenges facing the valuation of environmental attributes in general and noise in particular within a survey context is that of presenting the attribute in question in what respondents take to be a realistic and understandable fashion. Noise cannot be sensibly presented in the dB(A) units in which it is usually measured. Researchers have used a number of approaches.

A simple approach is to use categorical scales, such as 'very noisy', 'noisy', 'quite noisy' and so on (Wardman and Bristow, 2008). The main problem is to relate these scales to actual levels of the variables in question and in particular at the evaluation stage to be able to know when a change causes an individual to experience one level of the variable instead of another.

Specifying proportionate changes was a common approach, especially in early studies, for example, Pommerehne, 1988; Soguel, 1994; Thune-Larsen 1995; Sælinsminde, 1999; Bateman *et al.,* 2000; Navrud, 2000 and Wardman and Bristow, 2004. Two key disadvantages are respondents' difficulties in understanding percentage changes and, since the impact of a given percentage change will depend upon the base to which it applies, relating changes to an objective measure.

Respondents can experience the environmental impact at different levels under experimental 'laboratory controlled' conditions. However, noise simulation tends to be an expensive approach whilst respondents may be affected by the artificial and usually limited exposure. Evidence from sleep disturbance studies suggests that both levels of annoyance and actual disturbance are higher in laboratory tests than when surveys are conducted in the respondent's own home (Samel *et al.,* 2004). There are few applications in the context of noise valuation. An early study by Sinnot and Plowden (1977) looked at willingness to accept a noisy device into the home. Eliasson *et al.,* (2002) used videos as an aid to illustrate the differences that were being described in words.

Experienced variation is an attractive approach. It can take a spatial dimension, whereby the respondent is asked to compare different locations with different noise levels (Pommerehne, 1988; Arsenio *et al.*, 2006), or else a temporal dimension, where at the same location there is variation in exposure over time (Barreiro *et al.,* 2005; Thanos *et al.,* 2009). The method assumes the respondent has some familiarity with the different levels of the noise.

A proxy measure, such as traffic levels (Langdon, 1978) or aircraft movements (Bristow and Wardman 2006; Carlsson *et al.,* 2004; MVA, 2007), and variations in movements may be used to imply variations in traffic or aircraft noise. Noise measures are then taken or estimated for the different movements. Some CVM studies used the removal of noise annoyance instead of attempting to present noise. With proxy approaches there will always be some uncertainty as to how respondents translate changes in the proxy variable to changes in noise levels.

In a study of aircraft noise (Bristow and Wardman 2006; Wardman and Bristow 2008) two presentational approaches were used in one of the stated choice experiments, with around half the sample presented with categories from extremely noisy to not at all noisy and the other half changes in aircraft movements in the daytime and the evening. If we assume that not at all noisy is represented by the removal of all aircraft movements we can compare the two approaches as shown in Table 2. In the cases of Lyon and Manchester the findings are close from the two different approaches. Bucharest has a much greater difference; however, for a variety of reasons we have less confidence in the Bucharest results. Overall and bearing in mind that the movement valuations might be too high, because it might not be necessary to remove all movements in order to achieve a not at all noisy level, the valuations obtained from two different means of presenting aircraft noise exhibit an encouraging degree of similarity. The only other study of which we are aware that compares different means of presentation (Dave *et al.,* 2009) uses both scales and experienced variation using spatial location to examine road traffic noise in Lisbon – but does not report comparable values for the two methods.

Table 2 A comparison of results from different means of presentation values in €.

Location	Categorical	Aircraft movements	% difference
Manchester	24.54	26.55	+8.2
Lyon	24.35	29.68	+21.9
Bucharest	0.73	1.79	+145.2

To date there are insufficient examples of within study comparison of presentational approaches for any more detailed analysis of the potential impact of means of presentation on values derived.

4.2 Strategic Bias

There is always a concern with hypothetical questioning techniques that they may be subject to different forms of bias. In the context of transport noise and especially aircraft noise which may be particularly contentious, strategic bias is perhaps the most likely to occur. There is some empirical evidence from studies in the transport sector with unreasonably large willingness to pay valuations obtained where the purpose of the study is transparent and/or contentious and the likelihood of paying for the improvement is small (Wardman and Whelan 2001; Wardman and Shires 2003). Recent studies have “embedded” variations in noise amidst other quality of life factors listed below; all studies also included a payment mechanism.

- Edinburgh: road traffic noise, air pollution, bus travel time, car travel time (Wardman and Bristow 2004)
- Lisbon: road traffic noise, view and sun exposure (Arsenio et al., 2006)
- Lyon, Bucharest and Manchester: crime, education, congestion, cleanliness, road traffic noise, air quality, road maintenance, aircraft noise, recreation facilities and other local amenities (Wardman and Bristow, 2008)
- Athens: aircraft noise, public transport travel time, tram access, congestion, (use of airport land) (Thanos et al., 2008)

In the study of aviation noise in Lyon, Manchester and Bucharest two styles of SP were used, in one the "priority ranking" (PR) approach aircraft noise was embedded within a set of quality of life attributes, in the other aircraft noise was transparently the focus, with only aircraft movements and cost as the attributes (SC). Across the Lyon and Manchester values the SC study consistently give higher values with a ratio of 1.5 to 3. Our conclusion is that this is most likely due to strategic bias, though other differences in the experiments may also have an effect (Wardman and Bristow, 2008). The ANASE study found very high values per aircraft movement using a standard SP design (Le Masurier *et al.,* 2008). There is clearly still a need for more research into sources of bias within SP approaches.

5 What influences the value of noise nuisance?

Here we will examine a number of issues including income effects, other influential variables, variation by time of day, thresholds and other non-linearities, noise source and valuation method.

5.1 Income effects

In an early revealed preference application Walters (1975) concluded that if property value reflected "permanent income" then the elasticity of demand with respect to price was 1.7 to 2.0. As elasticity measures the proportionate change in demand with respect to a proportionate change in price or in this case income, this would mean that spending on "quiet" increases with income by about twice as much as the increase in income – making quiet a "luxury" good. This study was criticised by Pearce (1980) with respect to the ability of HP models to provide an income elasticity, the structure of the model and the assumption that property prices are an adequate proxy for income.

Recent meta-analysis of HP studies by Wadud (2010) based on GDP per capita adjusted for purchasing power parity (PPP) concludes that as incomes increase by $1000 the NDI increases by 0.017. Clearly there is a positive relationship between income and willingness to pay for quiet but no conclusions on the strength of the income elasticity may be drawn. HP studies are limited in this regard as it is necessary to make assumptions about household income as the incomes of those actually moving are not known. Stated preference experiments can ascertain the income levels of respondents and then attempt to identify an income effect.

Estimated income elasticities of willingness to pay from SC studies of noise values include, for aircraft noise 0.4 for Lyon and Manchester (Bristow et al 2009) and 0.2 for Athens (Thanos et al 2009) and for road traffic noise 0.7 for Edinburgh (Wardman and Bristow 2004) and 0.5 for Lisbon (Arsenio et al 2006). These estimates are consistent with those from CVM studies, for example, 0.9 for aircraft and road traffic noise in Basle (Pommerehne, 1988); 0.3 for road traffic noise in Greater London (Harris, 1978) 0.4 for road traffic noise in Helsinki (Vainio, 2001) and 0.72 to 0.78 for road traffic noise in Copenhagen (Björner, 2004). All the values reported in the SP literature are less than one suggesting that quiet is not a luxury. These results are consistent with results elsewhere in the environmental economics literature including: Jacobsen and Hanley's (2009) meta-analysis of 145 estimates of willingness to pay for biodiversity conservation finding an income elasticity of WTP to be 0.38; Hökby and Söderqvist's examination of income elasticities with respect to environmental services in Sweden; an earlier review largely of largely European evidence by Kriström and Riera (1996) and discussion of early evidence by Pearce (1980).

The weight of evidence suggests that quiet is not a luxury good. Expenditure on securing a quiet environment increases with income but at a less than proportionate rate. However, the question as to how income elasticity might vary over time remains as unanswered now as in 1975:

"Clearly it would be much more satisfactory if the elasticity obtained from cross-section data were also checked against time series data – but no such data are at present available." Walters 1975, page 10.

5.2 Socio-economic and attitudinal factors

It is useful first to assess the evidence on factors that influence annoyance from noise as we would expect to identify similar influences on the value placed on that annoyance. Miedema and Vos (1999) examined 34 studies of transport related annoyance mostly of air or road traffic noise. Assessing the influence socio-economic characteristics on annoyance, they found that sex was insignificant; the old and the young were less annoyed than those aged 30 to 50; higher levels of education were associated with higher levels of annoyance as were higher levels of occupational status and home ownership. Higher status is then associated with higher levels of annoyance – note that income was not included in their analysis. They also explored economic dependency on the noise source as an employee and find those who are so dependent are less annoyed as are those who make use of the noise source (airport or road) to travel. Higher levels of reported noise sensitivity and fear are associated with higher levels of annoyance. In terms of scale sensitivity and fear were found to be much more important than socio-economic factors.

There is little robust evidence to date from valuation studies on the influence of socio-economic and attitudinal factors on noise values. The exception to this is the influence of income – for which the evidence is clear as shown in section 5.1. This is partly due to the different sets of factors examined in different studies which do not allow for direct comparisons. Also there is a need to allow for taste heterogeneity in modeling and few existing studies do so.

Factors where the evidence albeit limited is consistent include the following socio-economic factors

- Higher education levels are linked to higher noise values (Faburel and Luchini 2000; Bjørner 2004);
- Presence of a garden is linked to higher values (Faburel and Luchini 2000; Bristow et al 2009);
- Users of an airport have lower values of aircraft noise nuisance (Feitelson *et al.,* 1996; Bristow *et al.,* 2009);

- Exposure to higher noise levels increases the value of noise (Faburel and Luchini 2000; Pommerehne, 1988; Thune-Larsen 1995 and Li *et al.,* 2009).
- Presence of children in the household increases the value of noise (Hunt, 2001; Bjørner, 2004; Wardman and Bristow 2004 and Pommerehne 1988).

For other factors evidence is too limited or there are differences in findings for example with respect to age. Evidence on values increasing with exposure may also be found in HP studies (Nellthorp *et al.,* 2007).

Evidence on attitudinal factors is fairly convincing with respect to noise values increasing with level of annoyance or dissatisfaction (Faburel and Luchini 2000; Lambert *et al.,* 2001; Bjørner 2004; Li *et al.*, 2009; Bristow *et al.,* 2009). On other aspects the evidence is less clear.

It is also worth noting that in one of the few papers that allows for random taste variation (Arsenio *et al.,* 2006) finds that once this is done all the systematic influence of the socio-economic variables dissipates and they are no longer significant.

5.3 Time of day variation

Evidence is available from a small number of SC studies of aircraft noise. Carlsson *et al*., (2004) examined weekdays and weekends separately and within each early morning, morning, afternoon and evening. The model has some anomalies. Nevertheless the authors conclude that the most sensitive time periods are early mornings and evenings. Bristow and Wardman (2006) report results from two SP experiments, one of which asks respondents to directly trade daytime and evening movements (between period) and another where the time period is specified and the variation in aircraft movements are within it (within period). The surveys were conducted at three airports (Lyon, Manchester and Bucharest) for eight time periods/days of week. There was a high degree of correlation between results from the two approaches. The highest values at all three locations were placed on night time movements followed by evenings and Sundays (Manchester); Sundays and Saturday evenings (Lyon) and weekday evenings and Saturday mornings in Bucharest.

Le Masurier *et al.* (2008) report relative annoyance by time period relative to daytime for the ANASE study of UK airports. Estimates are relative to daytime and all periods were more annoying than daytime noise. Nighttime movements especially between 2300 and 0300 were the most annoying, followed by evenings and late afternoon.

The limited evidence thus far suggests that there is significant variation in the costs of noise nuisance by time of day and day of week.

5.4 Level, size, direction of change and thresholds

Level effects were discussed in section 5.2 – as noise exposure increases so do values. However, there is also some evidence that areas with low levels of background noise have higher discount rates for property per dB(A) (Baranzini *et al.,* 2005). Studies examining the influence of the size of a change and the direction (gain or loss) are limited in number and have to date found no evidence to support the presence of such effects. However, there is some, limited evidence that cost reductions (when offered to offset deteriorations in the noise environment) may be discounted by respondents resulting in insignificant cost coefficients relative to those for cost increases (Wardman and Bristow 2008).

There is more evidence the presence (or not) of thresholds for the onset of annoyance and willingness to pay and the appropriate level of such thresholds.

The meta-analysis by Miedema and Oudshoorn (2001) of the relationship between transport noise and annoyance suggests the following threshold points: 32dB(A) to move from zero annoyed to having some people who are 'a little annoyed'; 37dB(A) as the threshold where some become 'annoyed' and 42dB(A) as the threshold where some will become 'highly annoyed'. These thresholds apply to Ldn and Lden, measures which – by definition – produce higher levels of dB(A) than a 24 hour Leq measure.

In hedonic pricing studies of road traffic noise the depreciation rate of property prices is sensitive to the cut off or threshold point used – the higher the threshold the higher the depreciation rate (Bjorner *et al.,* 2003; Rich and Nielsen 2002; Lake et al., 1998 and Bateman *et al.,* 2001). Bjorner *et al.,* (2003) find 55 dB(A) to be the best cut-off level in terms of goodness of fit although the model improvement was marginal. The author's caution that the 55 dB(A) cut-off identified was for a large urban area and that a lower level may be appropriate in a more rural environment. Bateman *et al.,* 2004 used a threshold of 55dB(A) but further analysis of this data set reported in Nellthorp *et al.,* (2007) suggested that noise values are positive down to at least a 45 dB(A) threshold.

Evidence from SP studies is sparse but suggests either a lower cut off at 40 dB(A) (Weinberger 1992) from a CVM study in Germany or no threshold at all. Bristow and Wardman (2006) found a deterioration in the fit of models if a threshold was imposed, using aircraft valuation SC data from Lyon and Manchester.

In summary, it is a widespread convention that 55dB(A) is the appropriate cut-off (Navrud, 2004), and some evidence from HP studies of road traffic noise supports this. However, evidence from recent HP studies and annoyance studies together with limited evidence from valuation studies suggest that such a cut-off should be treated with caution and lower levels may be more appropriate.

5.5 Mode of transport

The weight of evidence in annoyance studies indicates that a given measured level of noise is more of less annoying depending on the source. Aviation noise is most annoying, rail noise the least annoying and road lies somewhere in between (Miedema and Oudshorn, 2001). Few valuation studies have addressed more than one mode, their findings are shown below:

- **Road v air:** values for road traffic noise exceeded those for aircraft noise in both a CVM and an HP study of Basle (Pommerehne, 1988). However, the author suggests this may be due to low overall levels of aircraft noise. Whereas for Geneva, Baranzini et al (2005) find the opposite result in an HP study.
- **Road v rail:** values for road intrusion were found to exceed those for rail in a study of Stockholm applying both SP and HP methods (Eliasson *et al.,* 2002) and more recently Andersson *et al.,* (2010) found a higher rate of house price depreciation for road noise than for rail noise. Whereas Day *et al.,* 2007) found the opposite result in an HP study of Birmingham.

Where studies have examined values for noise from different modes of transport the results are not always consistent with each other or with evidence from studies of annoyance from different modes.

5.6 Values cross method

It is difficult to compare values across studies carried out at different times and places and using different methodologies. An additional problem is that many SP studies do not include measures of noise exposure or the changes in noise levels. However, it is also necessary if we are to draw conclusions on the robustness and validity of different methods. Firstly we will examine the very limited number of studies that have applied two methods in the same context and at the same time and report comparable values; these are shown in Table 3. The results are not wholly consistent. In the context of aircraft noise Thanos finds that SC values for WTP are lower than HP but for WTA cover the same range as the HP. Eliasson et al (2002 report that SC values exceed HP for both road and rail (their values are not in Table 3 as they cannot be easily converted to a per dB value). All three studies comparing CVM and HP with respect to road traffic noise find the HP values to be higher. However, Pommerehne (1988) finds the reverse result for aircraft noise.

When comparing SC and CVM again the evidence from road traffic noise studies is clear cut with the SC values exceeding the CVM values. For aircraft noise MVA et al 2007 also find that the SC exceed the CVM values while Bristow and Wardman find the SC values exceed the CVM values in Manchester but in Lyon they are broadly equivalent. Thune-Larsen also finds broad equivalence with the values depending on the noise level.

Higher CVM values for aircraft noise may be the result of strategically biased responses as aircraft noise tends to be more contentious than road noise. This may well be the case in Lyon where a second runway was under active consideration at the time of the survey. This would then suggest the SC values are on the whole above CVM values.

There is a distinct lack of within study comparison of the HP and CVM and SC approaches. It is therefore useful to look at studies in other area that have compared the results from revealed preference and stated choice methods. In the environmental economics literature values derived from CVM tend to be lower than values derived from actual behaviour (Hanley et al, 2001) whilst SC and RP have tended to yield comparable results. Studies of rail rolling stock (Wardman and Whelan 2001) and passenger transport elasticities (Wardman and Shires 2003) suggest that SC values exceed those from RP estimations. However, the authors suggest that is a result of the transparency of the SC designs leading to strategic bias. We believe that the technique we have developed of embedding noise attributes amongst other quality of life factors has to a large degree overcome such problems (Wardman and Bristow 2008 and section 4.2).

Table 3 Noise values from studies applying more than one valuation technique

Methods	Approach and location	Value per dB(A) per year
Thanos (2008) and Thanos et al, forthcoming **aircraft noise**		€2005
CE	Athens, South Suburbs, 2005, presence or absence of an airport	WTP 1.68 – 13.68 WTA 10.08 – 83.52
HP	South Suburbs 1995-2001	51.94 – 84.32
Bjørner et al 2003, **road traffic noise**		€2002
CVM	Copenhagen Dichotomous choice payment card followed by open question	55dB - 2.34 75dB – 10.59
HP	Copenhagen 1996-2002	55dB 12.33 – 24.66 75dB 19.70 – 39.39
Vainio, 2001, **road traffic noise**		€2001

CVM	Helsinki, 1993	>55 dB 101 - 149
HP	Helsinki, 1991 (n1522)	>55 dB 365
Pommerrehne, 1988, **road traffic noise**		1983 SFr
CVM	Basle, Open ended (n223)	74.9
HP	Basle, 1983, (n223)	81
Pommerehne, 1988 **aircraft noise**		1983 SFr
CVM	Basle, Open ended (n223)	32.2
HP	Basle, 1983, (n223)	22.3
Zhao et al, 2010, **road traffic noise**		¥ 2009[2]
CVM	Kunming, 2009 (n300)	46.83
SC	Kunming, 2009	810.62
MVA et al (2007) **aircraft noise**		£ 2006
CVM	UK airports, 2005-2006	3.80 – 11.50
SC	UK airports 2005-2006	£2 to £10 *per aircraft*[3]
Bristow et al (2003); Bristow and Wardman (2005) **aircraft noise**		€ 2001[1]
CVM	Lyon, 2002, open ended	57.98 – 64.16
CE	Lyon, 2002	40.17 – 67.25
Bristow et al (2003); Bristow and Wardman (2005) **aircraft noise**		
CVM	Manchester, 2002, open ended	12.74 – 12.94
CE	Manchester, 2002, open ended	21.80 – 84.15
Arsenio, 2002; Arsenio et al, 2006 **road traffic noise**		Escudos, 1999
CVM	Lisbon 1999	4406 – 3996.36
CE	Lisbon 1999	WTP 2364 - 4440 WTA 3324 - 5412
Wardman and Bristow, 2004 **road traffic noise**		£, 1996[1]
CVM	Edinburgh, 1996, open ended (n403)	9.62 – 16.58
CE	Edinburgh, 1996	20.61
Thune-Larsen, 1995 **aircraft noise**		NOK 1994[1]
CVM	Oslo 1994	50-55 dB 155.88 55-60dB 217.20 60-65dB 311.40 > 65dB 532.92
CE	Oslo 1994	50-55 dB 136.08 55-60dB 189.12 60-65dB 364.08 > 65dB 689.52

[1]values converted from that for a 50% change to dB by assuming a 50% change is equivalent to an 8dB reduction in noise levels as per Navrud 2004, then annualised.
[2]values for a move to very quiet – assumed to be a 10dB reduction as per Navrud 2004.
[3]not strictly comparable but clearly the SC value per dB would be much higher than the within study CVM value.

Table 4 brings together values for road traffic noise from a number of CVM and SC studies standardised to 20001 values. This evidence supports the contention that SC values exceed CVM values.

Table 4. Road traffic noise: willingness to pay per dB(A) per household per annum, 2001 €

Author	**Method**	**Location, study year and**	**Value**

		scenario	
Pommerehne, 1988	CVM	Basel, Switzerland, 1988, % change	99
Soguel, 1994	CVM	Neuchâtel, Switzerland, 1993, % change	60-71
Saelinsminde*, 1999	SP	Oslo and Akershus, Norway, 1993, % change	48-96
Vainio, 1995, 2001	CVM	Helsinki, Finland, 1993, elimination of annoyance	6 – 9
Thune-Larsen, 1995	CVM	Oslo and Ullensaker, Norway, 1994, % change	19
Wibe, 1995	CVM	Sweden (national study) Elimination of annoyance	28
Wardman and Bristow*, 2004	SP	Edinburgh, Scotland, 1996, % change	37-55
Navrud, 1997	CVM	Norway (national study) 1996, elimination of annoyance	2
Navrud, 2000	CVM	Oslo, Norway, 1999, elimination of annoyance	23 – 32
Barreiro *et al,* 2000	CVM	Pamplona, Spain, 1999, elimination of annoyance	2 – 3
Lambert *et al,* 2001	CVM	Rhones-Alpes Region, France, 1999, elimination of annoyance	7
Arsenio *et al,** 2006	SP	Lisbon, Portugal, 2001, change to level in a known location.	55

Source: Values from Navrud (2004) Table 1 except where indicated *.

6 Application of Values

Clearly there are many issues to resolve in the valuation of noise nuisance. Nevertheless, values are applied in decision making for investment and other policy decisions. About half of EU countries include noise in cost benefit analysis of transport schemes. In most cases these are derived from HP studies, exceptions being Germany where values are based on a CVM study by Weinberger (1992) and Austria where the value is based on HP and CVM evidence. Nellthorp *et al.,* (2007) standardised these values for comparison and these are shown here in Table 5. Again we see a great deal of variation especially with respect to the allowance made for level effects with most countries adopting a standard value for decibel or affected person. Only the UK and Sweden have values that increase with the level of noise and the Swedish values are extremely high at the top of the noise range (based on Wilhlemsson, 2000) whereas the UK values also based on HP (Bateman *et al.,* 2004) increase much more slowly.

Table 5. Noise values used in appraisal in seven European countries, € 2002 per person per dB(A) annum at factor cost

Country	Scope	45-50	50-55	55-60	60-65	65-70	70-75	75-80
Values in €/dB(A)								
Austria	road noise only	36.4	36.4	36.4	36.4	36.4	36.4	36.4

Germany	noise exposure in built-up areas	0	0	52.0	52.0	52.0	52.0	52.0
Hungary[1]	annoyance from road noise	68.2	68.2	68.2	68.2	68.2	68.2	68.2
Sweden	road noise only	0	3.7	58.8	127	219	492	1177
UK	road and rail noise	6.8	13.3	19.9	26.4	32.9	39.5	46.0
Values in € per person exposed to noise above 55dB(A)								
Finland	noise exposure in built-up areas	0	0	695				
Switzerland	annoyance in dwellings	0	0	362				

Adapted from Bickel *et al* (2006), Table 6.4; UK data added.
Notes: [1]Hungary has no lower threshold.

Source: Nellthorp et al., 2007

The values in Table 4 are applied in the cost benefit analysis of transport schemes.

Researchers have applied values to examine country wide surface transport noise mitigation programmes in the Netherlands (Nijland *et al.,* 2003) and Israel (Becker and Lavee, (2003). Although Nijland et al., find the noise mitigation measures assessed to yield a net benefit, they are cautious with respect to policy recommendations recognising the flaws in the valuation methodologies.

Lu and Morrell (2001) estimate noise costs per landing by aircraft type varying from €16 for a jetstream 31 to €1852 for a B747100F to 300. Further analysis by the authors investigates costs at individual airports in the UK and the Netherlands identifying Heathrow as the airport with the highest average noise costs per landing (Lu and Morrell, 2006). Retrospective analysis of policy cost and benefit include that by Morrison *et al.,* (1999) of the 1990 Airport Noise and Capacity Act in the USA that phased out stage 2 aircraft e.g. DC-9 and Boeing 727) by 1999. The authors find this to have had a net cost of $5 billion, whereas a tax based on the marginal costs per household per flight might have yielded a benefit of $0.2 billion. The authors only attributed benefits to houses with noise exposure in excess of 65 dB(A) and are therefore understating the benefits. However, this does not undermine the point about the relative efficiency of different instruments. Brueckner and Girvin (2008) suggest that cumulative noise regulation by airports is more efficient than aircraft regulation by allowing for the heterogeneous nature of airports and their surroundings. Exploration and evaluation of innovative policies for noise reduction including tradable permits or licences for aircraft noise emissions (Hullah *et al.,* 2007; Bréchet and Picard, 2008).

Recently, the benefits of moving to low noise tyres has been estimated at €4.95 to 12.65 billion per annum (FEHRL, 2006). Even at the lower end of the scale this is a very large number. The value used here is the recommendation of €25 per household per decibel per year from The Working Group in Health and Socio-economic Aspects (2003). This recommendation was based on the review by Navrud (2002) which arrived at a figure of €23.5 by averaging the results of CVM studies. The FEHRL report makes the assumption that every household in the EU (204 million) will receive this benefit. Hence the €4.95 billion benefit from a noise reduction of 0.9 dB(A). Here it is not perhaps the value that is problematic but the assumption that all households would benefit and that a 0.9 dB(A) reduction would yield a noticeable benefit.

The Impact Assessment for the third runway at Heathrow estimates the noise costs to be £0.32 to 0.37 billion depending on the option assessed (discounted over the 60 year assumed life). This values applied are the webtag values for road and rail noise nuisance (Department for Transport, 2010) and only applied to noise exposure in excess of 54 dB(A) – both assumptions are likely to lead to an underestimation of the cost of noise. Sensitivity tests that lower the threshold to 45 dB(A) produce numbers closer to £1.75 to £1.97 billion (Department for Transport, 2009). So simply reducing the noise threshold increases the value five fold.

7 Conclusions

Values of noise nuisance are being applied in cost benefit analysis and influencing policy decisions. Yet there are still many uncertainties relating to such values.

With respect to the representation of noise in valuation experiments further work is needed on the way respondents interpret different levels offered. Robust comparative experiments are needed to test different forms of representation, especially: categories, experienced temporal or spatial variation and proxies.

Embedding noise with quality of life issues seems to work well in the four studies that have used this approach to SC design. The approach yields lower values than transparent stated choice - probably by reducing the incentive to strategic bias in response. Whilst further work is needed to provide a rigorous comparison between transparent and embedded designs the values obtained are broadly consistent with HP. This suggests that such values could be used as “top” level values and transparent designs used to obtain relative weightings.

Evidence on what influences values is still limited. The exceptions being, firstly, the influence of income where the elasticity is less than one indicating that quiet is not a luxury. Secondly the evidence that values vary by time of day and day of week. Few socio-economic variables are found to have a significant influence, attitudinal variables may explain more. However models need to allow for taste heterogeneity.

Future directions for research within residential noise nuisance include:

- Robust comparison of transparent and embedded designs
- Robust comparison of different forms of representation
- Explore further use of experienced variations in noise levels – where respondents are more familiar and physical noise may be measured and / or modelled
- Use transparent SP to explore preferences and influential variables rather than to establish base values of noise
- Exploration of different policy options for noise reduction.

Research gaps include:

- Further work is required on the variation in noise nuisance between sources, notably road, rail and air.
- There is no evidence on the value of noise over time. Only cross-sectional studies have been carried out to date.
- Nuisance experienced outside the home – a small number of studies have looked at recreational environments largely in wilderness areas and noise exposure in vehicles

– but work, shopping and external urban and rural environments have not really been covered.
- Exploration of potential for revealed preference methods other than house sales.
- Health effects – increasing evidence base.

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