# Life satisfaction and air quality in London

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**Abstract**

A growing body of research in economics concerns self-reported happiness, or life satisfaction (LS), and its relationship to a wide range of other variables. The findings of this research tend to highlight the importance of non-income aspects of individuals' life conditions.

These findings are strongly complementary to themes within the sustainable development discourse. Firstly, they suggest ways in which we might consume less without compromising on our current levels of LS. And secondly, they help demonstrate the immediate LS benefits that could be gained from higher levels of environmental quality (EQ). However, the empirical evidence for the link between EQ and LS is, to date, surprisingly weak, due in part to a lack of EQ data at a level of detail to match the individual-by-individual resolution of LS measures.

This study seeks to contribute to the empirical literature by exploring and quantifying the link between LS and air quality in London. It collects original survey data for over 400 Londoners, and uses geographical information system (GIS) software to calculate pollutant concentrations in the immediate vicinity of their homes. It uses this data to estimate maximum likelihood regression models explaining LS ratings in terms of a range of individual, household and local variables.

This study finds that both perceived and measured air pollution levels are significantly negatively associated with the LS of Londoners, even when controlling for a wide range of other effects. An increase of 10 $\mu$g/m$^3$ in annual mean nitrogen dioxide concentration appears to correspond on average to a drop of nearly half a point of LS on an 11-point rating scale.

These findings, which may be generalisable to other cities in the UK and developed world, appear to strengthen and extend existing arguments in favour of policies to reduce urban air pollution, framed both in terms of conventional economic efficiency analyses, and in wider political and ethical (and potentially legal) terms.

*Key words:*
Life satisfaction, subjective well-being, environmental quality, air pollution, Geographical Information Systems, London

## 1 Introduction

A growing body of research in economics is now concerned with happiness, not just as an approximate synonym for income or wealth, but as directly and subjectively expressed by individuals (e.g. Veenhoven, 1997; Frey and Stutzer, 2002; Helliwell, 2003; Blanchflower and Oswald, 2004). The methods and findings of this work are a subject of increasing interest both within the discipline—where the status of happiness research in relation to the mainstream remains at best ambiguous—and in the public sphere.

Happiness research, in broad terms, argues that the apparently innocuous starting point for much of neo-classical economic theory—that, all other things being equal, more is always better—may be problematic. The issue is not so much the connection between *more* and *better*, if *all other things* genuinely could remain the same. It is that the policies that promote *more*—more production and more consumption, more goods and more services—inevitably have consequences for *all other things*. Moreover, the positive effect on our happiness of consuming goods and services, once we have enough to be comfortable, is often dwarfed by these other things' combined effects (e.g. Easterlin, 2003; Layard, 2003).

Happiness research highlights such other things—influences on our happiness beyond absolute income—including: the incomes of others, because of rivalry, and our own lagged income, because of habituation (e.g. Layard, 2002), health, marriage, trust, religious belief (e.g. Helliwell, 2003), unemployment or the nature of employment (e.g. Layard, 2007), housing quality and tenure, local amenities (e.g. Brereton et al., 2007), commuting (Stutzer and Frey, 2003), TV viewing, social capital indicators and 'relational goods', such as membership of groups or clubs, and friendly relations with neighbours (e.g. Putnam, 1995; Bruni and Stanca, 2006), and environmental quality parameters including climate, noise, and air quality (e.g. Welsch, 2006; Rehdanz and Maddison, 2008).

The major implication of much happiness research—that, to improve our lot, quantitative expansion may be a lesser imperative than qualitative improvement—represents a close complement to the core themes of the sustainability discourse. Sustainable development requires us to consume less so as to remain within the ecological limits of the planet, and not compromise the well-being of future generations (e.g. Meadows et al., 2004; Porritt, 2005). Happiness research can help make this palatable, since it suggests a means by which we could consume less for the sake of our own immediate well-being. Similarly, strong sustainability obliges us to safeguard the quality of our environment, so as to remain on the right side of a critical level of natural capital. Happiness research, again, offers to make this pleasant as

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well as good for us, by presenting compelling evidence that environmental quality in the present makes us happy, while environmental degradation makes us sad.

Or rather, in the latter case, it presents a surprisingly small and fragile body of evidence to that effect. Only a handful of quantitative, empirical studies characterising and quantifying the links between environmental quality (EQ) and human well-being have been published to date. These studies, on climate, noise and air pollution, all find significant positive relationships. Even these few studies are not always especially robust, however, in part because of the scarcity of EQ data at a spatial scale that approaches the person-by-person resolution of happiness measurements.

This study therefore seeks to contribute to the empirical literature by exploring and quantifying links between self-reported happiness or life satisfaction (LS) and very highly localised environmental quality levels, focusing specifically on air quality.

The study area, London, is interesting in respect of both air quality and LS. The city consistently fails to meet annual objectives for nitrogen dioxide and particulate concentrations (Greater London Authority, 2005), over half of Londoners think air quality is a major problem (Ipsos MORI, 2007) and up to two thirds believe that it affects their quality of life (Greater London Authority, 2002). In addition, recent data suggest that LS scores in London could be by some distance the UK's lowest (European Social Survey, 2006), and the city is distinctive from the rest of the UK in many of the demographic and socio-economic parameters known to affect LS: for example, it has the highest inward and outward migration rates, the greatest number of households of unrelated adults and single people, and a disproportionate number of households in both the top and bottom quintiles of UK income after housing costs (Office for National Statistics, 2007).

### *1.1 Concepts and terminology*

'Happiness', 'well-being', and 'life satisfaction' are all referred to above. Elsewhere in the literature are encountered 'decision' and 'experienced' utility, 'quality of life', 'the good life', 'hedonism' and 'eudaimonia' [1], amongst others. It is common for various different terms to be treated explicitly as interchangeable: see Easterlin (2003), Rehdanz and Maddison (2005) and Johns and Ormerod (2007) as examples. In part, this semantic diversity simply reflects the interdisciplinarity of the field. Unfortunately, however, it seems unlikely that everyone interprets all the different terms in the same way: in fact, it seems unlikely that everyone interprets even individual terms alike. 'Happiness' itself seems particularly problematic, capable of expressing ideas from episodic "smiley-face feelings" through to "desire-satisfaction", "flourishing" or "achievement" (Annas, 2004, 45). Of course, there is no definitive or

[1] 'Eudaimonia' may be defined as "living a complete human life, or the realization of valued human potentials" (Ryan et al., 2006).

correct happiness concept: the term that is chosen and the way it is interpreted, by both researchers and their research subjects, are philosophical and political questions reflecting individual and societal views of what we should be seeking in life.

In this research the term life satisfaction (LS) is used, both in the text and in the question asked of survey respondents, although authors using different or mixed terminology are cited without further comment. Following Aslam and Corrado (2007), LS is here understood as associated with eudaimonia more than hedonism and with cognitive judgements more than affective states, and as concerned with the extent to which experiences match with expectations over the longer term.

## 2 Literature review

### *2.1 Life satisfaction and environmental quality in theory...*

As discussed above, LS research places less faith in economic growth than more orthodox economic analyses do. It suggests that some degree of 'down-shifting' could enable many people to consume less while simultaneously increasing their LS, and thus provides a means by which (more) sustainable consumption might achieve some political acceptability. LS research also highlights further benefits to conserving and enhancing natural capital, since there are a number of pathways by which improving environmental quality (EQ)—raising levels of environmental goods and reducing levels of environmental 'bads'—could in itself raise LS levels.

Linking LS and environmental goods, access to high quality natural environments may enhance LS through biophilia, an "innately emotional affiliation of human beings to other living organisms" (Wilson, 1993, 31), and by providing open spaces both for social interaction and for recreation and exercise, which help reduce anxiety and depression levels and improve self-esteem and health (Morris, 2003). Since health is invariably found to be a major determinant of LS levels, it seems safe to assume that improving health also realises significant LS gains. Linking LS and environmental bads, including air pollution, health may again be an important pathway. As noted by Welsch (2006), this pathway does not require that individuals are conscious of the cause-effect relationship between their own health or LS and the environmental problem. However, awareness of environmental bads such as air pollution, and of their negative impacts on humans and ecosystems, may act to reduce individuals' LS levels directly and independently of health effects.

In relation to air pollution specifically, health effects and local awareness are both well documented. The wide-ranging health impacts of air pollution are summarised in Table 1; particularly susceptible groups include those with respiratory or cardiac diseases or asthma, infants, children and the elderly, and those with low socio-economic status, low levels of education, poor nutrition and poor general health (Utell et al., 2005). Individuals' perceptions of air pollution are positively related to objective pollution measures, as well as to broader evaluations of their local environment (Day, 2007). Furthermore, individuals are generally aware of the sources of pollution (principally, main roads), of its fluctuation according to weather conditions, and of its negative health effects, especially for children (Bickerstaff and Walker, 2001).

### *2.2 ...and in the empirical literature*

Despite these theoretical connections, empirical LS research has until recently paid "little attention to the importance of local environmental factors in people's health and quality of life" (SDRN, 2005, 2). Only a handful of studies, summarised below, have attempted to verify and quantify the link between EQ and LS.

Van Praag and Baarsma (2005), investigating aircraft noise around Amsterdam Schiphol airport, find that perceived noise nuisance is negatively related to LS, but objective noise measures are not significant. Rehdanz and Maddison (2005), looking at climate parameters across 67 countries, find that higher mean LS is associated with higher mean temperature during cold months and lower mean temperature during hot months, while Brereton et al. (2007) find higher LS in Ireland to be related to lower wind speeds and higher temperature in summer and winter. Welsch (2002; 2003; 2006; 2007), examining average LS in relation to average air pollution values across countries, finds significant negative associations in each case. Ferreira et al. (2006), working with individual-level data on air pollution and other EQ parameters in Ireland, also find negative associations between air pollution and LS. And Rehdanz and Maddison (2008) find that perceived levels of air pollution are also negatively related to LS scores in Germany.

All of these studies, then, find a significant positive relationship between EQ and LS (although this could potentially be due to publication bias). The studies also all use income data, entered as a regressor alongside the EQ variables, to calculate a financial trade-off between EQ and income. This represents a novel method for environmental valuation, combining some of the strengths of both revealed and stated preference valuation techniques (Frey et al., 2004; Ferreira et al., 2006). However, the wider methodological robustness of most of these studies is open to question.

Welsch's studies compare mean LS and mean air pollutant values at the whole-country level, thus making a strong assumption of cardinality. The 2002 and 2007 papers conduct a simple cross-sectional analysis of 54 countries. The advantage here is that unobserved heterogeneity across individuals, especially with respect to personality traits, may be expected to even out (Welsch, 2006). The disadvantages, however, are that LS and pollution levels are assessed only on the most grossly aggregated scale—with no indication of equity or variability or of individuals' real pollution exposures—and that unobserved heterogeneity between *countries* must be controlled for. Welsch attempts to control for heterogeneity between 54 countries using only per capita income, 'rationality' (the number of scientists and engineers per thousand people) and, in the 2002 paper only, an indicator of 'freedom' on a 1–7 scale. Rehdanz and Maddison's climate paper (2005) works on a similar cross-country basis, but with a much fuller set of control variables. Welsch's 2003 and 2006 papers use panel data for ten European countries to address unobserved inter-national heterogeneity, but the level of data aggregation remains problematic for both LS and EQ.

The remaining papers use individual-level LS data, controlling for an appropriately wide range of demographic, socio-economic and attitudinal variables in addition to indicators of EQ (of course, unobserved heterogeneity will always be an issue to some degree in LS studies, because LS is presumably affected to some degree by almost everything a person is, has, knows, does, and experiences). With the exception of van Praag and Baarsma (2005), who obtain noise data at postcode level, and Rehdanz and Maddison (2008), who have only perception data, the major limitation of these studies remains the level of spatial aggregation of EQ measures. The Brereton et al. papers (2006 and 2007) use data disaggregated at regional or local authority level. Ferreira et al. (2006), meanwhile, disaggregate location-specific measures by respondents' electoral districts (area: 18 to 6,189 hectares), except in the case of air pollution, which is calculated by proximity to one or more of only 10 monitoring stations for the whole of Ireland.

## 3 Methods

Since no data set including both LS and air quality measures was available for London, original data was obtained by survey. GIS software (GRASS Development Team, 2007) was used to augment this with appropriate local EQ metrics from several spatial data sets, and parameters for a number of regression models were estimated from the combined data. Since the LS scale cannot be assumed to be cardinal, the ordered probit model was used, which is the usual model for analyses of this type (van Praag and Baarsma, 2005). Standard errors were adjusted for heteroscedasticity and for clustering at postcode level. The results were compared with those given by ordered logit and Ordinary Least Squares (OLS) models. Regression models were estimated using STATA (StataCorp, 2003), and other statistical analyses were conducted in R (R Development Core Team, 2007).

### 3.1 Survey

A survey was developed as a standards-compliant, accessible website, using open-source software tools. This provided maximum flexibility in presentation and in collecting and formatting data for analysis. The survey design complied with all 11 of Dillman's web survey principles (1998), except that users were presumed to be now familiar with the use of web form controls and scroll-bars, which were therefore not explained. The survey was tested on multiple platforms and web browsers, and piloted using a speak-aloud protocol with three volunteers. The final survey may be viewed at `http://www.londonsurvey.org.uk/`.

The web survey mode has several advantages: for example, it does not suffer from interviewer bias, and respondents may feel more comfortable answering sensitive questions and moving through a survey at their own pace (Bateman et al., 2002). It also has disadvantages: for example, unlike with face-to-face or telephone surveys, it is impossible to offer clarification of questions, and some respondents may not fully understand what is being asked. The sample was a simple convenience sample, which may be subject to both selection and non-response bias.

Wherever possible, survey items were sourced from existing large-scale surveys—to take advantage of their extensive piloting and field-testing, association with existing data sets and, in some cases, potential familiarity to respondents—and adapted to the web survey format where necessary. The LS item was adopted unchanged from the ESS 2 (2006), question B24. It has strong similarities with Cantril's early 'self-anchoring striving scale' (1965), and is listed as item *O-SLW/c/sq/n/11/cd* in the World Database of Happiness (Veenhoven, nd):

> All things considered, how satisfied are you with your life as a whole nowadays?
> 0 (extremely dissatisfied) / 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 (extremely satisfied)

This item was chosen because it is clear and concise, its 11-point scale permits a relatively precise response (see Johns and Ormerod (2007) for discussion of the limitations of shorter scales) and to enable direct comparison with the ESS results which, as discussed in the introduction, are different for London than for the rest of the UK.

The LS item was placed first, since such items are particularly vulnerable to context effects (e.g. Smith, 1979). For the same reason, the initial explanation of the purpose of the survey was kept reasonably general and did not allude to air quality or other environmental issues. The survey opened just as reports became public of an attempted bombing in London (BBC News, 2007). Since it is possible that this would have affected LS ratings—Frey et al. (2004) confirm the intuition that the threat of terrorism is associated with lowered LS—length of time since the attempted attack was included in regression models where applicable. Numerical scales were presented in ascending or descending order at random, on a per-respondent basis, to counter any ordering bias. A dummy variable was also created reflecting the ordering selected.

Fields in web forms are typically either mandatory, such that respondents cannot progress unless a response is recorded, or optional, in which case missing and recorded responses are treated exactly alike. Making all items mandatory antagonises respondents and increases the risks of break-off and inaccurate survey completion (Dillman et al., 1998). Where all items are optional, respondents occasionally overlook items, leading to avoidable missing data. For this survey a potentially novel solution was therefore developed. The scoping questions and LS item were mandatory. All other items were optional, but missing responses on a page were pointed out to respondents, who were then given an optional second opportunity to respond.

### *3.2 Spatial data*

The location of each respondent's postcode was obtained using Ordnance Survey (OS) Code-Point, which provides coordinates of a location within the building of the nearest delivery point to the calculated mean position of all delivery points for a postcode, to resolution of 1m (Ordnance Survey, 2006). In some cases these coordinates are approximate: in the present case, four postcode coordinates were listed only as within 50m of the true location and two as within 100m.

Air quality data were generously provided by Cambridge Environmental Research Consultants Ltd. (CERC). The data set comprises annual average concentrations, modelled for the years 2001 and 2010 (forecast), of nitrogen dioxide ($NO_2$) and particles smaller than 10 microns diameter (PM10). It covers an area of 3,260km$^2$, including the whole of the M25 motorway, in 50m $\times$ 50m grid squares (cells), and was produced using CERC's Air Dispersion Modelling System, ADMS-Urban. Blair et al. (2003) and Mattai (2006) provide further details on the modelling methodology and inputs.

Since this survey research was carried out in mid-2007, average concentrations for the twelve months up to the middle of that year were estimated by linear interpolation. An indicator of the annual trend in air pollution was also calculated. These methods assume a smooth and continuous change in pollutant concentrations across the whole of London; since this assumption is open to doubt, sensitivity analysis of the regression models was carried out using the figures for 2001 and 2010.

Pollution levels around each respondent's home were calculated as the mean pollutant concentrations in the 5 $\times$ 5 cells centred on the cell containing the respondent's Code-Point. Of course, annual average concentrations in the vicinity of respondents' homes are only one of many indicators of exposure to air pollution. Others include: exposure away from home—such as when commuting and in the workplace—and from indoor sources; height of the home above ground level; and the extent of variability within the annual average. Furthermore, pollution levels during the particular hour, day, week or month the survey was administered might all affect individuals' perceptions of exposure, and their evaluations of LS. Refinements to account for these factors could usefully be incorporated in future research.

The measures calculated here are nevertheless believed to be at a finer resolution, and thus to capture more of the variation between individuals' local environments, than those used in any previous LS research. As discussed above, even Ferreira et al., who estimate similar models of LS making use of local EQ data "at a very high level of disaggregation" (2006, 11), calculate air pollution data only by simple proximity to ten PM10 monitoring stations for the whole of Ireland.

Since traffic is a major source of urban air pollution, but has potentially confounding additional effects, including noise pollution, the OS Meridian 2 data set was used to calculate each respondent's proximity to their nearest major road (A-road or motorway). Meridian 2 data is supplied to a resolution of 1m, though the level of accuracy is not specified and may vary according to the source of data on each feature type (Ordnance Survey, 2007).

## 4 Results and analysis

Respondents appeared well distributed across the sample area, as illustrated in Figure 1. Key socio-demographic parameters of the sample are shown in Table 2. The sample appears biased towards the young, the relatively highly educated, and the wealthy. Comparable gross household income bracket data could not be located, but while average gross household income for London during 2003–2006 was £766 per week (Office for National Statistics, 2007), the same statistic for this sample—which, given the large number of young people, might be expected to be lower—is conservatively estimated as £1,306 [2] . Since only 16% of the sample have children, relative disposable incomes may be higher still.

### *4.1 Air quality*

Histograms of the air pollutant measures for all respondents are shown in Figure 2. The $NO_2$ and PM10 concentrations are strongly related, having a Pearson correlation coefficient of 0.92. This is as expected, since road traffic is the principal source of both PM10 and nitrogen oxides in London (Greater London Authority, 2005),

[2] Average gross household income was calculated as the mean of respondents' mid-points of the ten original income brackets. For the unbounded top bracket (£100,000+) a fairly conservative mid-point of £110,000 was assumed.

and nitrogen oxides can also contribute to PM10 formation (Meng et al., 1997). Table 3 shows the proportions of respondents for whom annual average pollutant concentrations exceed target values. The WHO guideline for PM10 is exceeded for almost all respondents, and that for $NO_2$ is also exceeded for approximately two-thirds.

Perceptions of air pollution were distributed across the response scale: approximately one in ten respondents felt that air pollution was no problem at all in their street or block, with the same proportion describing it as a major problem, and 20–30% responding within each of the three intermediate categories. Overall, 31% of respondents felt that air pollution negatively affected their LS. This figure rose from 7% amongst those who said air pollution was no problem at all to 65% amongst those who said it was a major problem.

Table 5 shows the estimated parameters of a model predicting perceived pollution levels on the basis of measured levels and other potentially relevant factors. Since the pollution measures are strongly correlated, entering them together in a model would give rise to problems of colinearity. Regression models were therefore run using each measure separately, alongside the other regressors. For every sampling method, the two measures produced qualitatively similar results, but the $NO_2$ measure resulted in a better fitting model than the PM10, as judged by McFadden's pseudo-$R^2$. Log and quadratic pollution terms were also tried, but did not produce better fitting models. The $NO_2$ measure is therefore used as the principal indicator of pollution concentrations. Note that this is only an indicator: it should not be inferred that $NO_2$ is alone responsible for the observed effects.

Only respondents who had lived at least a year in their current accommodation were included in this regression. Results with the full sample (not shown) were similar, but with a lower pseudo-$R^2$ value. Models including pollutant concentrations for 2001 and 2010 were also run (not shown) to check the validity of the interpolated data; results remained qualitatively the same.

As seen in the table, a significant positive relationship was found between perceived pollution and measured $NO_2$ concentrations, consistent with previous research emphasising the importance of "direct, personal experience" of pollution in shaping perceptions (Bickerstaff and Walker, 2001, 136).

Having asthma or heart or lung disease, and being older, help determine sensitivity to the health effects of air pollution (World Health Organisation, 2005). Age was not significant, which may well be an artifact of the lack of older respondents in the data set, but asthma and cardiovascular disease were strongly so: marginal effects analysis indicated that respondents with asthma showed shifts of 6–10% away from the lower two categories and towards the higher two, and those suffering cardiovascular disease showed similar, larger shifts, of 7–18%. Spending time outdoors was included as an indicator of increased ambient pollution exposure, although it is not guaranteed that this time is spent near the home, and it did not prove significant.

Having children was included since respondents' concern over health effects on the family could increase perceptions of a problem, as suggested by Bickerstaff and Walker (2001) and in comments by the survey respondents, but was not significant. Income and educational indicators were included because previous work indicates an inverse relationship between socio-economic status and concern for local air quality, independent of measured pollution (ibid.). Neither was a significant predictor of perceptions here, however, and this may partly relate to relatively high education and income levels across the sample.

Distance from central London was included because of broad perceptions of city centres as dirty and unhealthy places (Bickerstaff and Walker, 2001; Day, 2007). However, being further out was in fact associated with slightly greater probabilities of answering in the higher problem categories. It may be that respondents allowed for their proximity to the centre in their responses, making their responses at least partly relative to expectations ("given that I live right in the centre, pollution isn't *all* that big a problem" or "I shouldn't have to deal with air this dirty out in the suburbs"). This could benefit from further investigation. An indicator of rating scale presentation order was also included, finally, and revealed no significant ordering effects.

In principle, the sensitivity and exposure variables could also have been included in the regression as interaction effects with pollution concentrations: for example, one might expect asthmatics to rate a given level of pollution as more problematic by an amount related to that level, instead of, or as well as, perceiving pollution as more problematic by some fixed amount. However, such interaction variables were so highly correlated with the basic dummy variables—with coefficients greater than 0.99 in every case—that they could not be entered into the model together. It was therefore decided to retain the basic variables rather than the interaction terms, because their marginal effects have a more straightforward interpretation.

### *4.2 Life satisfaction*

The pattern of LS ratings is shown in Figure 3. For comparison, patterns for the ESS 2 LS data are shown in Figure 4, and mean LS ratings for the data sets (which, although not strictly appropriate to an ordinal variable, help give a broad indication of similarity) are given in Table 6. All the data sets show a characteristic peak at the higher end of the LS ratings, having 8 as the first and 7 as the second most common. This peak is somewhat more pronounced for this survey than for the comparison data, however. Since the corresponding reduction in the frequency of other ratings is more pronounced at the lower than the higher end of the scale, the survey respondents show a slightly higher mean LS than in the comparison data for

London.

This marginally raised LS may well be explained by the nature of the biases in the sample. However, it may also be partly produced by context effects in the comparator survey, in which the LS item comes quite late, and directly follows 23 items on politics and government. Since "the level of alienation felt towards politicians, the main political parties and the key institutions of the political system is extremely high and widespread" in Britain (The Power Inquiry, 2006, 16), it seems quite possible that the political context was at least partly responsible for low LS ratings.

A series of LS models of increasing complexity were estimated from the data, as shown in Table 7. Model 1 represents a simple, standard LS model, with basic socio-demographic and socio-economic variables as regressors. Model 2 expands this to include indicators of household tenure, beliefs and perceptions, social activity and social relations, and perceived levels of local air quality and noise. Model 3 reproduces Model 2, except that it replaces the local perceptions variables with objective measures of these EQ parameters. For comparison, Model 3 is also estimated using OLS. As found by other researchers (e.g. Ferreira et al., 2006), OLS here gives extremely similar results to the ordered probit. The coefficients on the OLS model are therefore used to assess the magnitude of the regressors' effects, since this is much more straightforward than marginal effects over a large number of categories.

The goodness of fit of the models is very much in the range of existing EQ-and-LS research. For example, Ferreira et al. (2006) obtain an OLS adjusted-$R^2$ of 25% (with 35 regressors), while Brereton et al. (2007) obtain ordered probit pseudo-$R^2$ values in the range 9–16% and OLS adjusted-$R^2$ values in the range 21–33% (with up to 67 regressors).

It was not possible to include all variables that ideally would have been entered in the models. Unemployment, which is usually highly significant in LS models, could not be used since only three respondents were unemployed. Other employment, marital status and educational status variables, and squared terms in income and age had to be dropped for similar reasons or because of colinearity. None of these variables, when they were included alone, had a statistically significant effect. The three variables intended to allow for potential confounding effects of terrorism, weather conditions, and the order of presentation of rating scales were not significant in any model.

**Model 1** The statistically significant impacts on LS in the basic model are poor health (highly negative), being married (positive), and logged estimated personal income (positive, though significant only at the 10% level). These findings persist across all the models, and are intuitive and in line with previous LS research. Simple or squared terms in income, tried in alternative models (not shown), were not significant, while the significance of the logged variable accords well with an expectation of diminishing marginal utility for income. The lack of significance of gender and education are fairly standard findings (see e.g. Veenhoven, 1997). The lack of significance of divorce and separation is reasonably unusual, however (e.g. Frey et al., 2004; Brereton et al., 2007).

**Model 2** Model 2 shows that perceived level of local air pollution is a significant depressor of LS, as also found by Rehdanz and Maddison (2008) in Germany. Of course, identifying causation is a particular hazard with such perception variables—perhaps it is simply that happier people perceive problems as less serious—so it is helpful to be able to compare this with the measurements in Model 3.

The only change in statistical significance of the Model 1 regressors in this model is that age becomes a negative predictor of LS. Age is commonly found to have a U-shaped relation to LS, with those in middle age having lower LS than the young and old (e.g. Blanchflower and Oswald, 2004). The finding here is probably in line with this, since the lack of respondents over retirement age would be expected to turn that U-shape into a downward slope.

In respect of accommodation, crowding is found to exert a significantly negative effect on LS, whilst the tenure variables, home ownership and social housing tenant status, are not significant. Trust and social capital (or 'relational good') coefficients are all positive and highly significant, as found by Bruni and Stanca (2006) and predicted by theorists such as Putnam (1995). The religious belief indicator has no significant impact in the sample, however, and having children or being a single parent do not either.

Distance from central London, introduced in this model as an important control in relation to pollution—which is much higher in the centre—is significantly negatively associated with LS. The reasons for this are not certain but it seems possible that, on average, those living nearer the centre: are wealthier (for homeowners in particular, living near the centre could indicate substantial asset wealth which is not picked up elsewhere in the survey); spend less time commuting, an activity that systematically lowers subjective well-being (Stutzer and Frey, 2003); and enjoy a wider variety of cultural opportunities and public facilities on their doorstep, a factor mentioned by some respondents in the survey comments.

**Model 3 and OLS** This last model replaces the perceptions in Model 2 with objectively measured EQ indicators. As was the case for perceptions of pollution in the model in section 4.1, $NO_2$ concentration is significant, with a negative impact on LS ratings—nearly half a point per 10 $\mu$g/m$^3$ in the OLS model—while the yearly trend appears to have no significant effect. The year-on-year changes in the pollution data are fairly modest, averaging $-0.9$ $\mu$g/m$^3$ between 2001 and 2010. However, the combination of the significance of the absolute pollutant concentration and the non-significance of the change in concentration—the same pattern seen with perceptions of pollution—could be taken to indicate that air pollution levels are not readily habituated to [3] . PM10 levels, when entered instead of $NO_2$ levels, were not significant (not shown). The results of the model were robust to the use of data for 2001 or 2010 in place of the interpolated 2007 figures, however.

**Valuation** If the log of $NO_2$ concentration is entered in the OLS model instead of the untransformed variable (not shown), it becomes possible to value marginal changes in $NO_2$ concentration by calculating an elasticity as the ratio of the coefficients on log income and log $NO_2$ (Welsch, 2006). The coefficients here on $NO_2$ and income are respectively $-1.933$ and 0.365 (both significant at the 5% level), giving an elasticity of 5.3%. In other words, a 1% increase in $NO_2$ levels is equivalent, in LS terms, to a 5.3% drop in income. Notwithstanding that the $NO_2$ variable here may indicate more general pollution levels, this figure is unrealistically high, both intuitively and in comparison with results from revealed and stated preference studies.

Although this result may be due in part to the high incomes of the survey sample, surprisingly high values seem to be a fairly common finding in LS research. For example, Frey et al. (2007) use LS data from 1975–1998 to calculate that an average Northern Ireland resident would be willing to pay 41% of her income to reduce terrorist activity to the level seen in the Republic of Ireland, while Frey and Stutzer (2005) find an average Paris resident hypothetically willing to pay 14% of his income to reduce terrorism to the level seen elsewhere in the country.

## 5 Discussion and conclusions

The principal finding of this study is that LS in London appears to be significantly negatively associated both with subjectively perceived levels of air pollution and with air pollutant measurements at a very high spatial resolution. Since respondents' perceptions of air pollution were themselves significantly related to the objective measurements, the relative importance of health and perceptions as pathways or mediating factors for pollution's influence on LS are not separately assessed, and the objective measurements are presumed relevant to both pathways.

The negative influences of measured $NO_2$ and perceived air pollution on LS are

[3] By contrast, if pollution was easily habituated to, then one might expect the absolute level of pollution to be insignificant (because individuals are broadly used to it) and the change in pollution level to be significant (since it is an indicator of the component of pollution that individuals have not yet had the time to become used to).

both significant at the standard 5% level[4]. Contrary to the findings of some of the research using more aggregated measures (e.g. Ferreira et al., 2006), PM10 concentrations are not statistically significant in any LS model, despite their strong correlation with $NO_2$. However, since there are aspects of this study that might be expected to weaken any association between LS and pollution, the association of LS and $NO_2$ seems fairly compelling. Firstly, pollution levels, though varied, were high for everyone (WHO guidelines for $NO_2$ were exceeded for over two-thirds of respondents, and PM10 guidelines for every respondent bar one). This lack of any relatively unpolluted comparator could make the influence of pollution more difficult to detect. Secondly, given such high levels of air pollution, and a city with an annual population turnover of approximately 3% (Office for National Statistics, 2007), there could be substantial self-selection in London for those who are relatively indifferent to EQ. And finally, the biased nature of the survey sample may have weakened the association between air pollution and LS—this is considered further below.

The size of the effect of $NO_2$ concentrations on LS appears large: the OLS model suggests an average reduction of almost half a point of LS (around 4% of the whole LS scale) per 10 $\mu g/m^3$ of $NO_2$, within a range of just over 30 (between 28 and 62 $\mu g/m^3$). However, as noted in section 4.1, it should not be presumed that $NO_2$ alone is responsible for this effect. PM10 levels, being closely correlated, are presumably contributing too and, as always in LS research, the possibility of endogeneity cannot be ruled out[5].

The wider significance of these findings depends on their validity both internally—their ability to be generalised from the sample to the London population—and externally—their ability to be generalised from the London population to the rest of the UK and beyond. In respect of the former, the sample is not demographically representative of the London population. However, its biases are such that one might expect the effects of pollution to be under- rather than over-estimated. Recall that, on average, Londoners are substantially poorer and less highly educated than the survey respondents. In terms of health,

> "Population groups with lower socioeconomic status have shown increased risk of mortality and morbidity following exposure [to air pollution]. Higher susceptibility is also found in the least educated sections of the population... In addition, people with lower socioeconomic status have more risk factors for the health effects of air pollution, for example airways diseases, active and passive smoking and type 2 diabetes" (Utell et al., 2005, 111).

In terms of perceptions, too, previous studies have shown an inverse relationship

[4] More precisely, $p < 2.5\%$ for $NO_2$ concentration in Model 3 and $p < 3.4\%$ for perceptions in Model 2.

[5] Endogeneity would imply that the size of the effect of air pollution as estimated here is too high because of correlations with missing variables: candidate correlates here could include, for example, housing quality or proximity to industry.

between socio-economic status and concern for air quality, with “stronger worries more widespread among people in the ‘low class’ area” (Bickerstaff and Walker, 2001, 139). These reasons to expect the effects of air pollution to be worse than seen here appear to be confirmed in the discrepancy between the 66% of Londoners who say that air quality affects their quality of life in the Annual London Survey, and the 31% here who agree that air pollution reduces their LS [6] . In summary, then, the LS effects of air pollution shown in this study might well represent a lower bound on the effects that would be seen for London as a whole. Self-selection bias—for example, if potential respondents who are more sensitive to pollution were more likely to feel motivated to participate—still suggests a degree of caution here, though.

In terms of generalisation to the wider world, the physical health effects of air pollution must be universal. Perceptions of air pollution and the knowledge of its potential for harm could conceivably vary according to education and media coverage in different areas of the world. However, this study confirms the conclusions of Day (2007) and Bickerstaff and Walker (2001) that primary experience is the main determinant of perceived levels of pollution, and it seems reasonable to assume that personal experience is also formative of most people’s understanding of its potential to harm. On the other hand, it remains possible that LS in other places could be affected so strongly by other factors—such as disease, malnourishment, or political oppression—that no impact of air pollution would be detectable there. Therefore, while it seems possible that these results could be generalised to other UK and developed world contexts having similar levels of pollutants and of the other major influences on LS (and this appears to be corroborated by the handful of earlier studies on the subject), further research would remain valuable.

### *5.1 Implications for policy*

Arguments at a number of levels in favour of measures to reduce London’s air pollution are, of course, already known to policy-makers. They include the requirements of EU and domestic law, the prospect of improved public health (and reduced health spending), and the potential co-benefits in relation to anthropogenic climate change (since emissions of the pollutants considered here, for example in vehicle exhaust fumes, are generally accompanied by emissions of $CO_2$). However, the findings of this study significantly strengthen and extend those arguments.

In the first place, these findings affect conventional market analyses. The impact of air pollution on LS suggests a previously largely unquantified means, which may be partially additional to health, by which a reduction in pollution could deliver greater social efficiency. Furthermore, habituation considerations suggest that standard economic valuation techniques might under-estimate the level of air

[6] Of course, it is not clear quite how far the term ‘quality of life’ is comparable to LS, particularly given the stark numerical expression of the latter in this survey.

pollution reduction that would be socially most efficient[7]. Since air pollution, which has been gradually decreasing across most of London over the last six years, still has a significant effect on LS, it seems that people do not fully habituate to it. It therefore seems likely that air quality is something in which people would tend to under-invest (by their actions in the housing market, for example).

LS research is silent, of course, on the framework of ethics or rules within which decisions are made. Allowing for these, the findings of this study have additional policy implications. Human rights are one part of such a framework. If air pollution measurably reduces individuals' LS, it can be argued that they have a basic right to be free of such an influence, and developing case law under the European Convention on Human Rights increasingly gives legal force to such an argument (European Court of Human Rights, 2003, 22). Equity is another part of the ethical framework and, as explored in the growing literature on environmental justice, this raises issues of both the distribution and production of pollution. Regarding distribution, the most polluted communities in Britain tend also to be the poorest (Mitchell and Dorling, 2003, 909), and thus suffer a double burden of reduced LS. And regarding production, "communities that have access to fewest cars tend to suffer from the highest levels of air pollution, whereas those in which car ownership is greatest enjoy the cleanest air" (ibid.). It would appear, therefore, that those who reap the LS benefits of polluting activities impose LS costs on those who are both least able to enjoy those same benefits and least able to avoid those costs.

These points, finally, raise two more. First, given that income inequality is commonly cited as a factor that depresses average LS within a society (e.g. Alesina et al., 2004) one might ask, by extension, whether inequalities in EQ—or even inequalities in LS itself—could have a similar impact. Either way, what constitute acceptable levels of inequality is a matter that only informed and ongoing democratic participation can legitimately decide. And second, how might some individuals gain from their own polluting activity? Of the activities that generate air pollution in London, driving is by far the most important, and there is recent evidence that "the autonomy and empowerment drivers feel can benefit health and wellbeing" (Gardner and Abraham, 2007, 197).

The present study indicates that exposure to urban air pollution has negative effects on LS. Further research to clarify the potentially complex links between life satisfaction and sustainability in relation both to individuals' exposure to and production of urban air pollution could offer further insights for achieving simultaneously happier, cleaner and more sustainable cities.

[7] LS research suggests that we almost completely habituate to having more material possessions, so that their long-term benefits are small, whilst we do not habituate to the same extent to other positive aspects of our lives, such as human relationships. It also suggests that, because we fail to anticipate our habituation to material possessions, we over-invest in these and under-invest in other things, relative to the balance that would make us happiest.

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Table 1
Health effects of air pollution

| *Effects attributed to short-term exposure* |
| --- |
| Daily mortality |
| Respiratory and cardiovascular hospital admissions |
| Respiratory and cardiovascular emergency department visits |
| Respiratory and cardiovascular primary care visits |
| Use of respiratory and cardiovascular medications |
| Days of restricted activity |
| Work absenteeism |
| School absenteeism |
| Acute symptoms (wheezing, coughing, phlegm production, respiratory infections) |
| Physiological changes (e.g. lung function) |
| *Effects attributed to long-term exposure* |
| Mortality due to cardiovascular and respiratory disease |
| Chronic respiratory disease incidence and prevalence (e.g. asthma) |
| Chronic changes in physiologic functions |
| Lung cancer |
| Chronic cardiovascular disease |
| Intrauterine growth restriction |

Source: World Health Organisation (2000) in Gouveia and Maisonet (2005)

Table 2
Socio-demographic characteristics of respondents, with comparator

| | *This survey* | *Office for National Statistics, 2007* |
|---|---|---|
| *Area* | 020 dialling code | Greater London |
| *Date* | 2007 | 2005/2006 |
| *Ages* | 16+ | 16+‡ |
| *Age* | $N = 387$† | |
| 16–24 | 7.2% | 12.3% |
| 25–44 | 83.9% | 36.6% |
| 45–64 | 8.3% | 20.0% |
| 65+ | 0.5% | 11.8% |
| *Gender* | $N = 387$ | |
| Female | 62.5% | 50.9% |
| *Qualifications* | $N = 388$ | |
| None | 1.3% | 13.0% |
| Below degree level | 11.3% | 59.0% |
| Degree level+ | 87.4% | 28.0% |
| *Gross household income* | $N = 363$ | |
| 0–£9,999 | 1.9% | |
| £10,000–£19,999 | 5.2% | |
| £20,000–£39,999 | 15.7% | – |
| £40,000–£59,999 | 19.8% | |
| £60,000–£99,999 | 33.9% | |
| £100,000+ | 23.4% | |

† The full sample size was 413. Since all demographic items were optional, $N$ gives the number of responses per item.

‡ The ONS qualifications data is for males aged up to 65 and females aged up to 59 only.

Table 3
Proportions of respondents for whom the 25-cell mean exceeds pollutant targets in 2007 ($N = 360$)

| *Target* | *Sources* | *Proportion exceeding target* |
|---|---|---|
| PM10 $\leq 20\ \mu g/m^3$ | WHO guideline<br>EU target, 2010<br>UK target, 2015 | 99.7% |
| PM10 $\leq 40\ \mu g/m^3$ | EU target, 2005<br>UK target, 2005 | 0% |
| $NO_2 \leq 40\ \mu g/m^3$ | WHO guideline<br>EU target, 2010<br>UK target, 2006 | 68.6% |

Targets are from WHO (World Health Organisation, 2005) and as set in the EU Air Quality Framework Directive and UK Air Quality Regulations 2000 and (Amendment) Regulations 2002 (Greater London Authority, 2002; UK Air Quality Archive, nd).

Table 4: Variable definitions

| *Variable* | *Definition* |
|---|---|
| NO2C2007 | $NO_2$ 25-cell mean concentration, 2007 ($\mu$g/m$^3$) |
| NO2TREND | $NO_2$ 25-cell mean concentration annual trend ($\mu$g/m$^3$) |
| ASTHMA | 1 if respondent has asthma, 0 otherwise |
| HEARTLUNG | 1 if respondent has a heart or lung disease, 0 otherwise |
| OUTMUCH | 1 if respondent spends more than one hour outdoors on an average weekday, 0 otherwise |
| 55PLUS | 1 if respondent is aged 55 or over, 0 otherwise |
| CHILDREN | 1 if respondent has one or more children, 0 otherwise |
| FEMALE | 1 if respondent is female, 0 otherwise |
| DEGREE | 1 if respondent is educated to degree level or higher, 0 otherwise |
| SUNNY | 1 if respondent reports weather as sunny or with sunny intervals during survey completion, 0 otherwise |
| REVSCALE | 1 if rating scales were presented to respondent in reverse order, 0 otherwise |
| SOHOKM | Distance of respondent's home postcode Code-Point from a point in Soho, Central London, as an approximation to the central business district, following Gibbons (2004) (km) |
| MAINROAD50M | 1 if respondent's home postcode Code-Point is within 50m of an A-road or motorway, 0 otherwise |
| AGE | The mid-point of the respondent's selected age category (72.5 is assumed for category 65+) |
| POORHEALTH | 1 if respondent rates their own health as 'fair', 'bad' or 'very bad', 0 otherwise |

Table 4: Variable definitions

| *Variable* | *Definition* |
|---|---|
| MARRIED | 1 if respondent is married and living with their spouse, 0 otherwise |
| DIVSEP | 1 if respondent is divorced, or separated from their spouse, 0 otherwise |
| INCOMEK | Respondent's gross individual income, in thousands of pounds, calculated as gross household income divided by a household size equivalence factor $(a + 0.7c)^{0.5}$, $a$ being the number of adults and $c$ the number of children in the household, following Joung et al. (1997). Gross household income was calculated as the mid-point of the selected income bracket (£120,000 is assumed for category £100,000+). |
| LOGINCOME | The natural log of the respondent's gross individual income, calculated as for INCOMEK (but not in thousands of pounds). |
| HOMEOWNER | 1 if a member of the respondent's household owns the household's accommodation, 0 otherwise |
| SOCIALTENANT | 1 if respondent's accommodation is rented from a person or body other than a private landlord or letting agent, 0 otherwise |
| CROWDED | 1 if respondent's household has fewer rooms (excluding bathrooms and toilets) than residents, 0 otherwise |
| RELIGIOUS | 1 if respondent chose "I believe in a God with whom I can have a personal relationship" as closest to their beliefs, 0 otherwise |
| TRUST | 1 if respondent agreed that "most people can be trusted", 0 otherwise |
| SINGLEPARENT | 1 if respondent has children and is the only adult in their household, 0 otherwise |

Table 4: Variable definitions

| *Variable* | *Definition* |
|---|---|
| TV | 1 if respondent watches television for more than 1 hour on an average weekday, 0 otherwise |
| RELATIVES | 1 if respondent meets or speaks to relatives outside the household at least once a week, 0 otherwise |
| NEIGHBOURS | 1 if respondent speaks to neighbours at least once a week, 0 otherwise |
| GROUPS | 1 if respondent participates in groups, clubs or organisations at least once a week, 0 otherwise |
| BOMBDAY | 1 if respondent completed survey on the day following an attempted car bomb attack in London, 0 otherwise |
| AIRBAD | 1 if respondent rated air pollution in their street or block as 2, 3 or 4 on a scale of 0–4, where 0 is no problem at all and 4 is a major problem, 0 otherwise |
| NOISEBAD | 1 if respondent rated noise in their street or block as 2, 3 or 4 on a scale of 0–4, where 0 is no problem at all and 4 is a major problem, 0 otherwise |

Table 5
Estimated parameters for pollution perception model (ordered probit)

| *Variable* | *Coefficient* ($\beta$) | *Robust std. err.* |
|---|---|---|
| NO2C2007 | 0.079 *** | 0.016 |
| NO2TREND | −0.237 | 0.286 |
| ASTHMA | 0.424 * | 0.175 |
| HEARTLUNG | 0.768 *** | 0.160 |
| 55PLUS | −0.278 | 0.295 |
| OUTMUCH | 0.247 † | 0.144 |
| CHILDREN | 0.281 | 0.207 |
| INCOMEK | −0.003 | 0.003 |
| DEGREE | −0.032 | 0.240 |
| SOHOKM | 0.068 ** | 0.025 |
| REVSCALE | 0.097 | 0.140 |
| $N$ | 234 | |
| Log pseudo-$L$ | −333.0 | |
| Wald $\chi^2$ (11) | 169.2 | |
| Pseudo-$R^2$ | 5.3% | |

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6
Comparison of mean LS ratings

| *Data set* | *Region* | *Mean LS rating* |
|---|---|---|
| This survey | London (020 area) | 7.00 |
| ESS 2 | London (unknown) | 6.47 |
| ESS 2 | UK | 7.12 |

Table 7
Estimated parameters for LS models: ordered probit and OLS

| | *Model 1* | *Model 2* | *Model 3* | *OLS* |
|---|---|---|---|---|
| *Variable* | | *Coefficients* | | |
| AGE | −0.011 | −0.016 † | −0.014 † | −0.023 † |
| FEMALE | 0.042 | 0.112 | 0.065 | 0.065 |
| DEGREE | −0.009 | −0.190 | −0.240 | −0.240 |
| POORHEALTH | −1.112 *** | −1.134 *** | −1.175 *** | −1.691 *** |
| MARRIED | 0.394 ** | 0.372 * | 0.383 * | 0.463 * |
| DIVSEP | 0.197 | 0.290 | 0.275 | 0.428 |
| LOGINCOME | 0.166 † | 0.209 * | 0.228 * | 0.363 * |
| HOMEOWNER | | 0.196 | 0.155 | 0.225 |
| SOCIALTENANT | | −0.400 | −0.388 | −0.646 |
| CROWDED | | −0.377 * | −0.330 † | −0.541 * |
| RELIGIOUS | | 0.165 | 0.118 | 0.163 |
| TRUST | | 0.304 * | 0.279 † | 0.412 * |
| CHILDREN | | −0.017 | −0.062 | 0.020 |
| SINGLEPARENT | | −0.373 | −0.293 | −0.235 |
| TV | | 0.029 | 0.017 | 0.047 |
| RELATIVES | | 0.238 † | 0.291 * | 0.423 * |
| NEIGHBOURS | | 0.482 *** | 0.454 ** | 0.645 ** |
| GROUPS | | 0.351 ** | 0.350 ** | 0.424 * |
| SOHOKM | | −0.042 * | −0.071 *** | −0.097 ** |
| AIRBAD | | −0.266 * | | |
| NOISEBAD | | 0.188 | | |
| NO2C2007 | | | −0.032 * | −0.042 * |
| NO2TREND | | | 0.182 | 0.132 |
| MAINROAD50M | | | 0.124 | 0.209 |
| BOMBDAY | 0.187 | 0.181 | 0.167 | 0.209 |
| SUNNY | −0.021 | −0.101 | −0.078 | −0.116 |
| REVSCALE | 0.116 | 0.102 | 0.082 | 0.092 |
| *Constant* | | | | 5.901 ** |
| *N* | 350 | 331 | 331 | 331 |
| Log pseudo-*L* | −594.5 | −536.2 | −536.1 | |
| Wald $\chi^2$ | 64.0 *** | 123.8 *** | 142.4 *** | |
| F | | | | 5.36 *** |
| Pseudo-$R^2$ | 4.6% | 9.1% | 9.1% | |
| Adjusted $R^2$ | | | | 24.9% |

† p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Fig. 1. Respondent postcode Code-Point locations, plotted over motorways and the River Thames (© Crown Copyright/database right 2007. An Ordnance Survey/EDINA supplied service.)

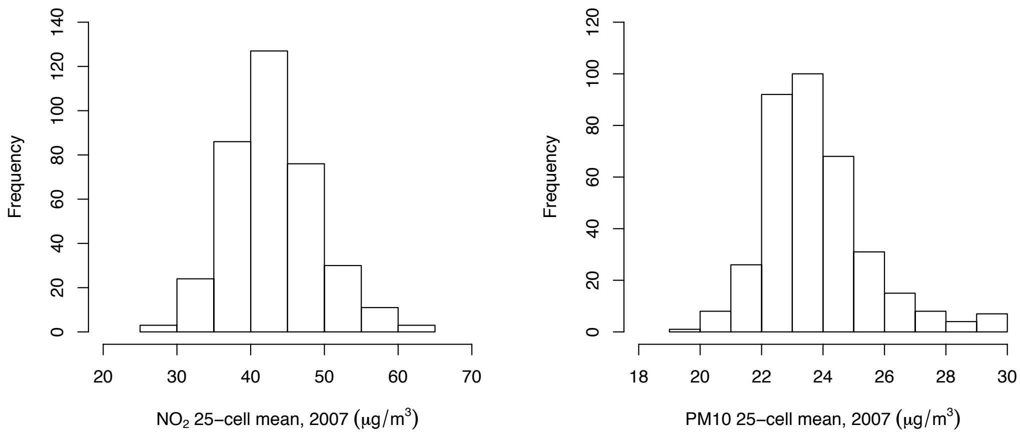


Fig. 2. Distributions of 25-cell mean pollutant concentrations in 2007 ($N = 360$)

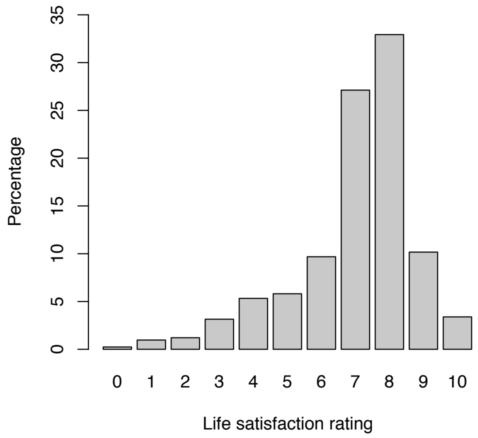


Fig. 3. Life satisfaction ratings ($N = 413$)

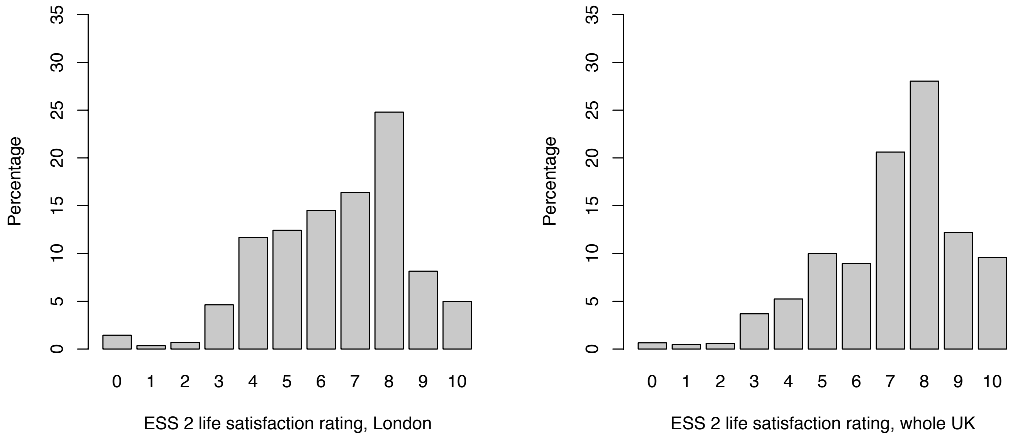


Fig. 4. ESS 2 life satisfaction ratings for London ($N = 144$) and the UK ($N = 1890$)