Valuing Air Pollution in Britain

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Abstract

This study explores the relationship between happiness and air pollution in Britain using data from the British Household Panel Survey (BHPS). The effects of air pollution on individuals' happiness are estimated and their monetary value is calculated. In particular, three air pollutants are examined in this paper; the sulphur dioxide (SO_2), the ground-level ozone (O_3) and the nitrogen dioxides (NO_X). Moreover, two different approaches are followed. The first approach refers to panel fixed and random effects regressions. The second model considers fixed effects with lagged dependent variable. The results show that the SO_2 presents the strongest negative effects on well-being happiness followed by O_3 and NO_X. However, ozone's and nitrogen oxides' monetary costs are very low in comparison with sulphur dioxide.The monetary values for sulphur dioxide range between £12-£18, while the respective values for ground level ozone and nitrogen oxides range between £3-£6 and £2 respectively.

JEL: C23, Q51, Q53

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1. Introduction

Economists have long worried about valuing the environment (see Leontief, 1970 for an early example). The difficulty steams from the absence of markets pricing the environment/pollution. More specifically, environmental externalities are usually negative and because of the absence of the markets and market prices the economic agents have no concept of their actions on the environment. To value the environment, two popular methods exist: revealed preference and stated preference. The first method relies on hedonic price analysis or the travel cost approach while the stated preference approach, based on contingent valuation surveys, directly educidate the environmental value from question. Both methods have been widely used in practice (Carson *et al*. 2003). Both methods have weaknesses. Revealed preference approaches are based on stringent assumptions concerning the rationality of agents and the functioning of markets. More specifically, the results yielded following this approach can be biased, if the housing markets are not in equilibrium, maybe because individuals are not fully informed.

Moreover, using the hedonic method the results can be underestimations of the clean air benefits (Bayer et *al*. 2006). More specifically, decisions in markets for private goods may not accurately reveal people's hedonic experience from the consumption of public goods (Rabin, 1998).

1. The European Carbon market is an exception, European Commission Climate Action, 2005

In the stated preference approach, hypothetical scenarios are used, which may entail unreliable results. In particular, the hypothetical nature of the surveys allow for strategic behaviour and superficial answers (Kahneman *et al*., 1999). Overall, the problem of both approaches is that they only value the environmental goods of which individuals are aware of.

Instead this paper relies on life satisfaction evaluation (LSE). One advantage of this method is that it does not rely on asking people how they value environmental conditions. More specifically, individuals are not asked to value the environmental good directly, but to evaluate their general life satisfaction. Therefore, the LSE approach does not require awareness of cause-effects relationships but simply assumes that pollution leads to change in life satisfaction. These changes can be driven by observed or unobserved pollution. For example, if unobserved pollution leads to a health deterioration which triggers a reduction in life satisfaction. LSE is thus closely related to hedonic pricing but relies on life satisfaction rather than house price to evaluate how individuals value their environment. As such, it is not subject to market distortion and can be used even in area with shallow housing markets[2]

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Additionally, with life satisfaction approach the individual's demand can be captured, while using other approaches the individuals have limited incentive to disclose their true demand (Luechinger, 2009; Frey *et al*., 2009; MacKerron and Mourato, 2009). Furthermore, this approach does not rely on an equilibrium assumption (Frey *et al*., 2009). More precisely, LSE does not rely on the ability of the respondents to account and consider all the relevant consequences of a change in the provision of a public good. For example, the respondents might not notice that there is a relationship between environmental conditions and their subjective well-being. Additionally, the strategic behaviour might be avoided because the relationship between life satisfaction and the environmental good is made ex post by the researcher. On the other hand, there is the argument that a respondent exposed to a negative externality, he or she might strategically report an overly low life satisfaction. However, this can be a minor problem in LSE for the reason that life satisfaction data are usually collected for many and various purposes. Therefore, the same data can be used for a wide array of environmental goods evaluation, leading to the prevention of strategic behaviour and biases.

The contribution of this study is the exploration of the association between air pollution and happiness using panel micro-data in Britain, while other studies use panel macro-level data or cross section micro-level data. Moreover, other studies examine micro-level panel data taking into consideration the clustering on individual or household level, while the clustering on location or district is been ignored.

The paper explores the relationship between air pollution and well-being happiness using data from the British Household Panel Survey. The paper is organized as follows. Section 2 presents a short literature review. Section 3 describes the methodological framework. In section 4 the data and the research sample design are provided. In section 5 the results of estimating several versions of a happiness function, with air pollution included, are reported, as well as, the effects of air pollution on happiness and their monetary value are presented and discussed. In section 6 the concluding remarks are presented.

3. Literature Review

Research studies on happiness have identified various personal, demographic and socio-economic factors of happiness that explain observed happiness patterns. Some of the most important personal and demographic characteristics which affect happiness are age, sex, marital status, the size of the household and the education level. Sandvik *et al.* 1993 have shown that respondents who are satisfied with their lives are also rated as satisfied by family members and friends. Blanchflower and Oswald (2007) found that satisfied individuals are less likely to suffer from hypertension. Furthermore, life satisfaction predicts future marriage and future marital break-up (Gardner and Oswald 2006; Stutzer and Frey, 2006). There is the general belief that data on subjective well-being are valid and can be used for formal analyses (Di Tella *et al*., 2003; Pischke, 2011).

Empirical work has demonstrated that economic conditions like income, unemployment and inflation have a strong impact on people's subjective well-being (Clark and Oswald, 1994; Di Tella *et al*., 2001; Easterlin, 2001). The life satisfaction evaluation (LSE) computes the monetary equivalent of any determinant of satisfaction by dividing the estimated coefficient for this variable of interest on the estimated coefficient for income.

More specifically, the estimated coefficients can be interpreted as marginal utilities of the public goods or the marginal dis-utilities of the public bads. Together with estimates for the marginal utility of income, the marginal rate of substitution between income and the public good can be calculated. Thus, reported subjective well-being can serve as an empirically adequate and valid approximation for individually experienced welfare. Hence, it is a straightforward strategy for the direct evaluation of a public goods or bad expressed in utility terms (Clark and Oswald, 1996).

The LSE has been used by Welsh (2002; 2006; 2007) to evaluate environmental factors. More precisely, Welsch (2002; 2006; 2007), examines average life satisfaction in relation to average air pollution values across countries and he finds significant negative associations in each case. Ferreira *et al*. (2006), using individual-level data on air pollution and other environmental quality parameters in Ireland, find negative associations between air pollution and life satisfaction. Rehdanz and Maddison (2008) find that perceived levels of air pollution are also negatively related to life satisfaction scores in Germany using information about how strongly the respondent feels affected by air and noise pollution in their place of residence. One drawback of this study is that the analysis is based on subjective measures rather than objective measures.

Welsh notes that LSE does not require the awareness of individuals about the cause-effect relationship between their own health or happiness and the environmental conditions. However, the awareness of air pollution may reduce individuals' happiness directly and independent of the possible health effects. Moreover, based on Bickerstaff and Walker's (2001) study individuals are generally aware of pollutions sources, mainly the road traffic, the fluctuations on pollutions emissions, because of the meteorological and weather conditions, and their effects on health.

One major limitation of these studies is the individual identification at the same level. Roback (1982, 1988) circumvent at this limitation by assuming that households with identical wage-earning capacities are at the same welfare level. More over, this is based on the assumption that households present identical utility functions, as well as, this approach is based on the assumption of perfect mobility.

Welsh (2002) examined the water pollution in 54 countries during early and mid of 1990s and he found that marginal-willingness-to-pay (MWTP) is \$113 for nitrogen dioxides (NO_2). Similarly, Welsh (2006) using repeated cross-section for 10 European countries during period 1990-1997 found that MWTP is valued at about \$184 per capita per year in the case of lead. Based on Di Tella and MacCulloch's study (2007), the MWTP is valued at \$171 for sulphur dioxides (SO_X). Luechinger (2009) examined 13 European countries during period 1979-1994 and the MWTP is \$157 for sulphur dioxide (SO_2), while it becomes larger at \$324 when instrumental variable estimates are considered. Similarly, Luechinger (2010) using data from the German Socio-Economic Panel (GSOEP) for about 450 German counties during period 1985-2003 finds that MWTP is valued at \$200 for sulphur dioxide (SO_2). However, using IV estimates the MWTP becomes \$340.

4. Methodology

Happiness and life satisfaction can serve as an empirically valid and adequate approximation of individual welfare, in a way to evaluate directly the public goods. Additionally, by measuring the marginal disutility of a public bad or air pollution in that case, the trade-off ratio between income and the air pollution can be calculated. Therefore, the individual's reported happiness or life satisfaction levels can be treated as proxy utility data. More specifically, the life satisfaction approach assumes that interpersonal comparisons of utility are meaningful (Clark and Oswald, 1996).

$$LS_{i,j,t} = \beta_0 + \beta_1 e_{j,t} + \beta_2 \log(y_{i,t}) + \beta' z_{i,j,t} + \gamma W_{k,t} + \mu_i + l_j + \theta_t + \varepsilon_{i,j,t} \qquad (1)$$

The set $e_{j,t}$ is the measured air pollution in location *j* and in time *t*. $\log(y_{i,t})$ denotes the logarithm of personal or household income and *z* is a vector of all the other possible household and demographic factors, discussed in the next section. *W* is a vector of meteorological variables, as mean temperature and wind speed in location-city *k* and in time *t*[3].

3. Both calendar effects and weather affect life satisfaction; see for example Brereton et al. (2007) for the effect of wind speeds and temperature and pollution. Wind and temperature may also have a direct effect on the prevalence of pollution

Set μ_i denotes the individual-fixed effects, l_j is a set of location (local authority) fixed effects and θ_t is a time-specific vector of indicators for the day and month the interview took place and the survey wave. Finally, $\varepsilon_{i,j,t}$ expresses the error term which we assume to be *iid*. Standard errors are clustered at the local authority level.

For a marginal change of *e*, the marginal willingness-to-pay (MWTP) can be derived from differentiating (1) and setting dLS=0. This is the income drop that would lead to the same reduction in life satisfaction than an increase in pollution. Thus, relation (1) becomes:

$$MWTP = -\frac{dLS}{de} = \frac{\partial f}{\partial e} / \frac{\partial f}{\partial LS} \qquad (2)$$

Such a model is identified from changes in the pollution level within individuals (i.e. between interviews) rather than between individuals. To capture unobservable characteristics of the neighbourhood that may be correlated with pollution and life satisfaction, the model is estimated for a population of non-movers since the decision to move may well be correlated with pollution level. The identification is thus crucially dependent on variation in the pollution level between interviews. We argue that this is possibly exogenous and driven by differences in the time of the year that the interviews take place, as well as variation in the level of pollution between years due to variations in economic activity, weather conditions, and general reduction of pollution over time. Evidence of these exogenous changes is provided in the data section. Of course, time of interview and weather may have a direct effect on self-reported life satisfaction, it is thus important to directly control for these variables.

In its current form the model can be estimated by ordered probit or logit. Therefore, the dependent ordinal variable is converted in such a form where ordinary least squares can be applied. This procedure was introduced by van Praag and Ferrer-i-Carbonell (2004). More specifically, when the dependent variable is categorical, the ordinary least squares (OLS) method can no longer produce the best linear unbiased estimator (BLUE); that is, the OLS is biased and inefficient (van Praag and Ferrer-i-Carbonell, 2004).

More precisely, the categorical dependent variable is rescaled by deriving *Z*-values of the standard normal distribution that correspond to cumulative frequencies of the original categories. The calculation of the dependent ordinal variable can be stated as:

$$LS_{i,j,t} = E(Z \mid \mu_1 < Z < \mu_2) = [\phi(\mu_1) - \phi(\mu_2)]/[\Phi(\mu_2) - \Phi(\mu_1)] \qquad (3)$$

, where Z is a standard normal random variable, φ is the standard normal probability density function, and Φ is the standard normal cumulative density function.

Finally, the regressions are estimated for each air pollutant separately. The reason is that the data are available in different dates for each pollutant.

Concerning the samples used, the movers might tend to be more individualistic and less loyal to where they live. However, the total sample is considered to account for all respondents. On the other hand by restricting the sample to non-movers some bias associated with unobserved characteristics might be removed. A location fixed effect may derive, for example living to rural or urban areas, or living close to natural attractions as rivers. Furthermore, recent research has shown that the collective self is more central to identity and well-being among non-movers individuals than among movers (Oishi *et al*., 2007). Therefore, the relation between national happiness or life satisfaction and air pollution might be stronger among non-movers than movers.

4. Data

We use the British Household Panel Survey (BHPS) an annual survey of each adult member of a nationally representative sample of more than 5,000 households which started in 1991 and stopped in 2009. Individuals moving out or into the original household are also followed (Taylor *et al*., 2010). The data period used in the current study covers the waves 1-18, i.e. years 1991-2009.

Based on the happiness literature the demographic and household variables used in this study are income, gender, age, age squared, family size or household size, job status, house tenure, marital status, the education level and qualification, health status and local authority districts. Additionally, the regressions control for the day of the week, month of the year and the wave of the survey. Moreover, the minimum, maximum and average temperature, precipitation and wind speed are considered as additional variables.

Regarding the dependent variable, the general happiness is taken. More specifically there are two questions in the survey: one about their overall life satisfaction and one about their general happiness at the moment the question is asked. The second question is used to identify the effect of contemporaneous local pollution. General happiness is an ordinal variable measured on a 4-point scale representing respectively “much less happy”, “less happy”, “same as usual” and "happier than usual". The specific question is "what is your level of general happiness".

We focus on three air pollutant: ground-level ozone (O3), sulphur dioxide (SO2), and nitrogen dioxides (NOx) can be found at the website of the Department for Environment Food and Rural Affairs (DEFRA, http://uk-air.defra.gov.uk). The air pollutants are based on daily frequency and measured in μg/m^3. There are 96 monitoring stations for SO_2, 109 for O_3 and 156 for NO_X. The respondents' authority district located within 10 miles radius is considered in regression analysis.

Sulphur dioxide (SO_2) is a colourless gas, released from burning fossil fuels like coal and oil. It is one of the main chemicals that cause acid rain. Usually, power stations and oil refineries are the main sources of sulphur dioxide. Additionally, SO_2 has long been recognised as a pollutant because of its role in forming winter-time smogs. High concentrations of SO_2 can result in breathing problems with asthmatic children and adults who are active outdoors. Furthermore, short-term exposure has been linked to wheezing, chest tightness and shortness of breath, while long-term exposure is associated with respiratory illness and cardiovascular diseases (Harrison, 2001). The daily limit value for the protection of human health is 125 μg/m^3. More specifically, sulphur dioxide emission should not be exceeded 125 μg/m^3 more than 3 times a calendar year.

In maps 1-4 the sulphur dioxide total annual concentrations during 1987, 2004, 2006 and 2009 respectively are presented. It becomes clear that the air pollution has been significantly decreased. The reason is that since the 1960s, the burning of cleaner fuels, especially natural gas, the decline in heavy industry and the location of power stations with high stacks outside cities has led to an over 90% decrease in national average SO_2 levels.

Ozone (O_3) is a gas composed of three oxygen atoms. O_3 is a colourless, odourless gas at ambient concentrations and is the primary constituent and component of smog. Because smog can be seen, O_3 is a pollutant which can be observed by the individuals too. Furthermore, O_3 is known as summer-time air pollutant, because of the peak and highest values recorded during the high average temperatures. Thus, hot weather cause ground-level ozone to form in harmful concentrations in the air. Additionally, motor vehicle exhaust and industrial emissions, gasoline vapours, and chemical solvents as well as natural sources emit NOx and Volatile Organic Compounds (VOC) that help form ozone. The effects of ground-level ozone on health include chest pain, coughing, throat irritation, and congestion, while it can worsen bronchitis, emphysema, and asthma, as it can reduce lung function and inflame the linings of the lungs (Harrison, 2001). The UK objective for protection of human health for O_3 is 100 $\mu g/m^3$ with no more than 10 exceedences per year. The annual ground –level ozone levels are reported in map 5 during the years 1995, 2003 and 2005.

Nitrogen oxides (NO_x) are formed in the atmosphere mainly from the breakdown of nitrogen gas (NO_2). Nitrogen oxides are produced in combustion processes, partly from nitrogen compounds in the fuel, but mostly by direct combination of atmospheric oxygen and nitrogen. More specifically, NO_2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides and forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. The effects on health are the same as ozone's (Harrison, 2001). The threshold for human protection health is 40 $\mu g/m^3$.

Additionally, the reduction of air pollution is UK was a result of the Large Combustion Plants Directive 2001/80/EC (LCPD). The Directive's target is to reduce the effect of air pollutants throughout Europe. The LPCD came into effect in the UK through the Large Combustion Plants (England & Wales) Regulations 2002, the Large Combustion Plants (Scotland) 2002 and the Large Combustion Plants Regulations (Northern Ireland) 2003. The annual nitrogen oxides concentrations during 2004, 2006 and 2009 are presented respectively in the maps 6-8.

In order to minimise measurement error, we take the average air pollution for the last 30 days[4]; this also has the advantage of increasing the data coverage since pollution data is not always available for a given day.

Weather data are taken as additional controls into the estimations. The weather and meteorological data come directly from MetOffice (www.metoffice.gov.uk) and National Climatic Data Centre (http://www.ncdc.noaa.gov). More specifically, the data used is the average, minimum and maximum temperature, precipitation and the wind speed per city. Moreover weather data are averaged using the same interval as air pollutants. Temperature is important for ground-level ozone, while the wind speed can be important for all air pollutants examined (Jacob and Winner, 2009).

Moreover, it should be noticed that the sample of non-movers is 84.00 per cent of the total sample, while the sample of the movers within GB is 8.50 per cent. The remaining percentage refers to movers from abroad to GB, to movers where the location is unknown, to died, to individuals with unknown mover status and to new entrants in the current wave.

The summary statistics are reported in tables 1 and 2. In table 3 the individual fixed effects logistic regressions are reported. More precisely, the dependent variable takes value 1 if the respondent is non-mover and 0 if is a mover across Great Britain.

4.As a robustness check we also conduct the analysis using a 7 days average

Furthermore, the monthly air pollution average levels with one lag are included into the model, in order to examine the possible effects of air pollutants to individual's or household's decision about moving to different place. The results in table 3 show that the lagged air pollution levels do not affect individual's choice about moving in to a different place. Additionally, the weekly air pollution concentration averages, as well as, the daily pollution levels have been examined leading to the same conclusions.

The correlation coefficients between the air pollutants are reported in table 4. It can be observed that the association between NO_X and SO_2 is positive, while the relationship between NO_X and O_3, as well as, SO_2 and O_3 is positive and significant. In table 5 the individual fixed effects estimates of air pollution variation during the month where the interview took place are reported. It is clear that the air pollutants are varied. More specifically, sulphur dioxide presents significant and positive levels during March-May, while significant and negative emissions are reported during August-December. On the other hand, ground-level ozone presents positive and higher emissions during August, because of the higher temperature levels. Finally, nitrogen oxides present negative levels, with the exception of February, November and December, where significant positive emissions are presented.

5. Empirical Results and Discussions

5.1 Regression results

In table 6 the panel regressions for sulphur dioxide monthly averages are reported[5]. It can be observed that both personal and household income have a positive and significant effect on happiness for total sample and the non-movers.

Regarding ground-level ozone monthly averages and the results of table 7 there is a significant negative association between the specific air pollutant and happiness only in the case of household income. Similarly, the sign of the household income is positive and significant. On the other hand, concerning the personal income, ground-level ozone has a significant and negative effect, only when the non-movers sample is taken into consideration, while this effect becomes insignificant in the case of the total sample. Moreover, the personal income is significant and positive only when the estimations are based on the total sample. Additionally, both personal and household incomes are insignificant, when the sample of the movers within GB is considered. Furthermore, the sign of the household income and ozone present the wrong sign.

Finally, in table 8 the estimations for nitrogen oxides monthly averages are reported. Overall, the estimated coefficients are insignificant, except from the household income and considering the total sample.

Additionally, the sign of the age, as well as, for gender, concerning random effects is consistent with other studies' findings (Rehdanz, and Maddison, 2008; MacKerron and Mourato, 2009).

5.Based on Hausman test fixed effects are preferred to random effects.

It should be noticed that the estimations based on movers sample and household income show a negative, but insignificant association, between happiness and income. Furthermore, the household income presents the expected positive sign using random effects, but it is significant only in the case of ground-level ozone. Additionally, other specifications of the air pollutants have been examined, as quadratic and cubic, instead of linear terms, but the coefficients are found to be insignificant. Finally, in tables 9-11 the regression results for the weekly air pollution average levels are reported. In this case, the air pollutants present significant and similar effects to those found when the monthly averages are taken into consideration. In addition, tables 12-14 present the regression estimates of daily air pollution levels. The only significant effects are reported in the case of sulphur dioxide, while the effects of ground-level ozone and nitrogen oxides become insignificant. Nevertheless, ozone's effects are again very close with the estimates reported in table 7.

5.2 Marginal willingness-to-pay and price effects

We now compute the marginal willingness-to-pay (MWTP) for our base model. of sulphur dioxide for the total sample and the non-movers. The individuals are willing to pay a monthly average of £12 and £15 respectively for a reduction in sulphur dioxide.

5.Based on Hausman test, random effects are chosen.

Similarly, marginal willingness-to-pay (MWTP) of sulphur dioxide for the total sample and the non-movers, regarding the household income, is 0.0057 and 0.0070 pounds. Thus, the respective average values for household income are £14 and £18.

Regarding, household income and ground-level ozone the MWTP for the total sample is £3 per month and the maximum monthly value is £100. As for the non-movers the MWTP is increased to a monthly average of £6 and up to a maximum value of £173 per month. Moreover, regarding the household income the MWTP is 0.00116 and 0.00237 for the total sample and the non-movers respectively. Similarly, for nitrogen oxides the MWTP is 0.00173 and 0.00073 for personal and household income respectively and the total sample. Moreover, the MWTP is significant lower to those of ozone and sulphur dioxide. More specifically, it is £2 in average per month and the maximum monthly value is £63, while the estimates concerning the personal income are insignificant.

5.3 General Discussions

Overall, the results show that sulphur dioxide presents the strongest negative effects on happiness followed by ground-level ozone and nitrogen dioxides. These findings are as expected for the following reasons. Firstly, SO2 emissions in United Kingdom are dominated by combustion of fuels containing sulphur, such as coal and heavy oils by power stations and refineries. Furthermore, SO2 is classified as a significant air pollutant because of its role in forming winter-time smogs. This may be an artefact of the sampling strategy with no interviews taking place in June and July. At this point it should be noticed that the highest and peak values of O3 are reported during those months because O3 is depended in a major degree on temperature, as well as it is know as summer-time air pollutant. Therefore, it is very possible that the estimations for O3 might be underestimated. Furthermore, even if BHPS takes place during August, it should be mentioned that the respondents interviewed during this month are very few. Even if the monthly averages of the air pollutants are taken, the interviews take place during the last days of August. Concluding, both air pollutants, SO2 and O3 are responsible in forming winter-time and summer-time smogs respectively, thus the specific air pollutants can be observed by the individuals.

Finally, in table 15 the MWTP for a drop of a standard deviation is reported. More specifically, regarding the personal income the individuals are willing to pay £92 and £108, based on total sample and non-movers sample respectively, for a drop of a standard deviation in sulphur dioxide. This value is increased at £99 and £120 when the household income is taken into consideration. On the other hand, concerning ground level ozone, the values are significant only in the case of household income. In particular the values are £57 and £115 for total sample and non-movers respectively. Finally, in the case of nitrogen oxides, only value of the total sample considering the household income is significant and it is £122.

6. Conclusion

This study has used a set of panel micro-data on self-reported well-being happiness from the British Household Survey. The results showed that the MWTP for sulphur dioxide ranges between £12-15 and £14-18 per month for personal and household income respectively, while the respective monthly maximum values range between £785-980 and £494-510. The MWTP for ground-level ozone and nitrogen oxides is significant lower ranging between £3-6 and £2 per month respectively. The respective maximum values are £173 and £63. As it was discussed the estimates for ground-level ozone might be underestimated. The contribution of this paper is that the life satisfaction approach and air pollution is examined in micro-level data using panel surveys. Moreover, the results show that the life satisfaction approach contains very useful information on individuals' preferences and at the same time expands the economic tools in the area of non-market evaluation.

Life satisfaction approach has been used to assess how willingness to pay varies over time and by region, age, income, education and level of pollution among others. Additionally, one very strong and useful point of the life satisfaction approach is that the estimated coefficients can be used to calculate the marginal rate of substitution between income and air quality directly, and thus it does not suffer from the contingent valuation problem of large gaps between stated willingness to pay and willingness to accept. Moreover, the life satisfaction approach can be very helpful in environmental and economic policy planning and decisions.

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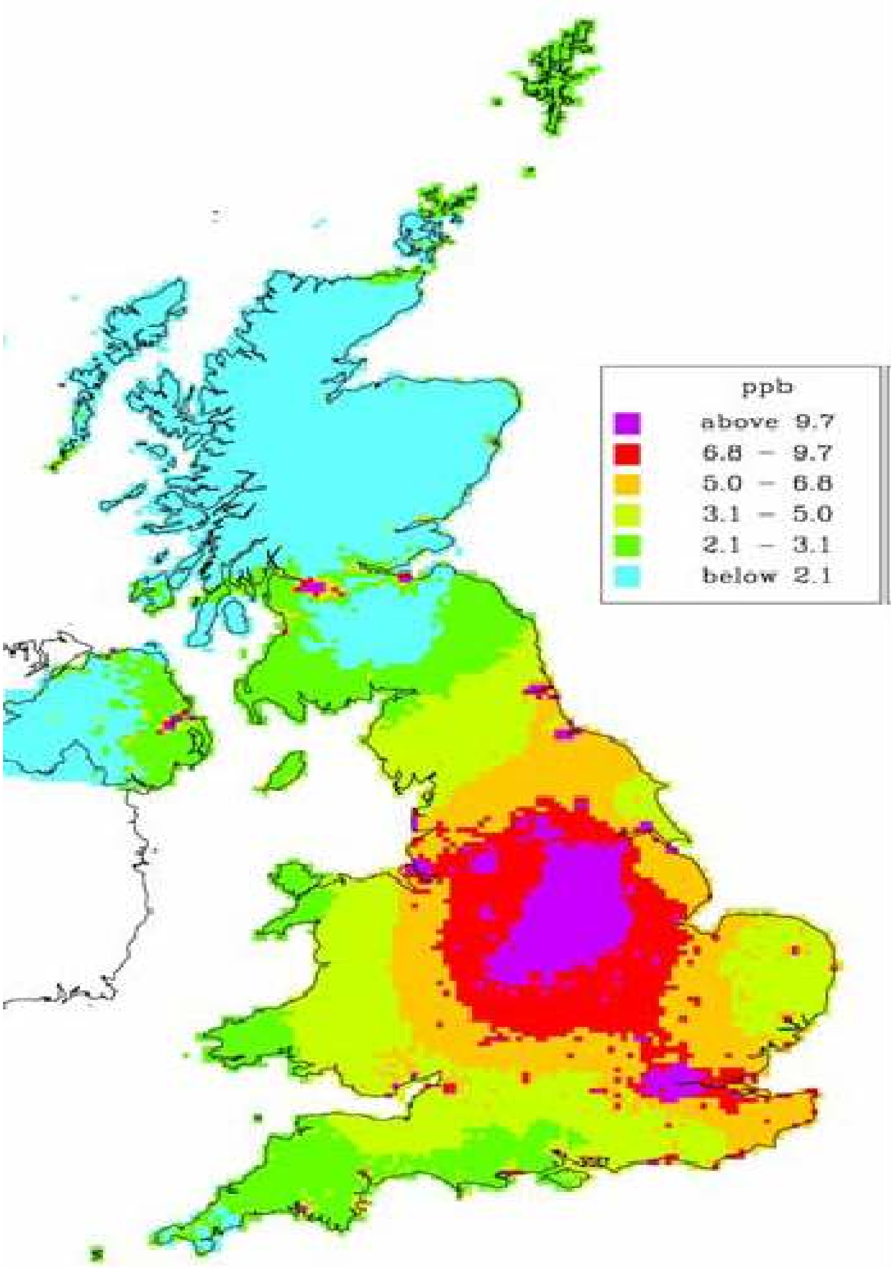
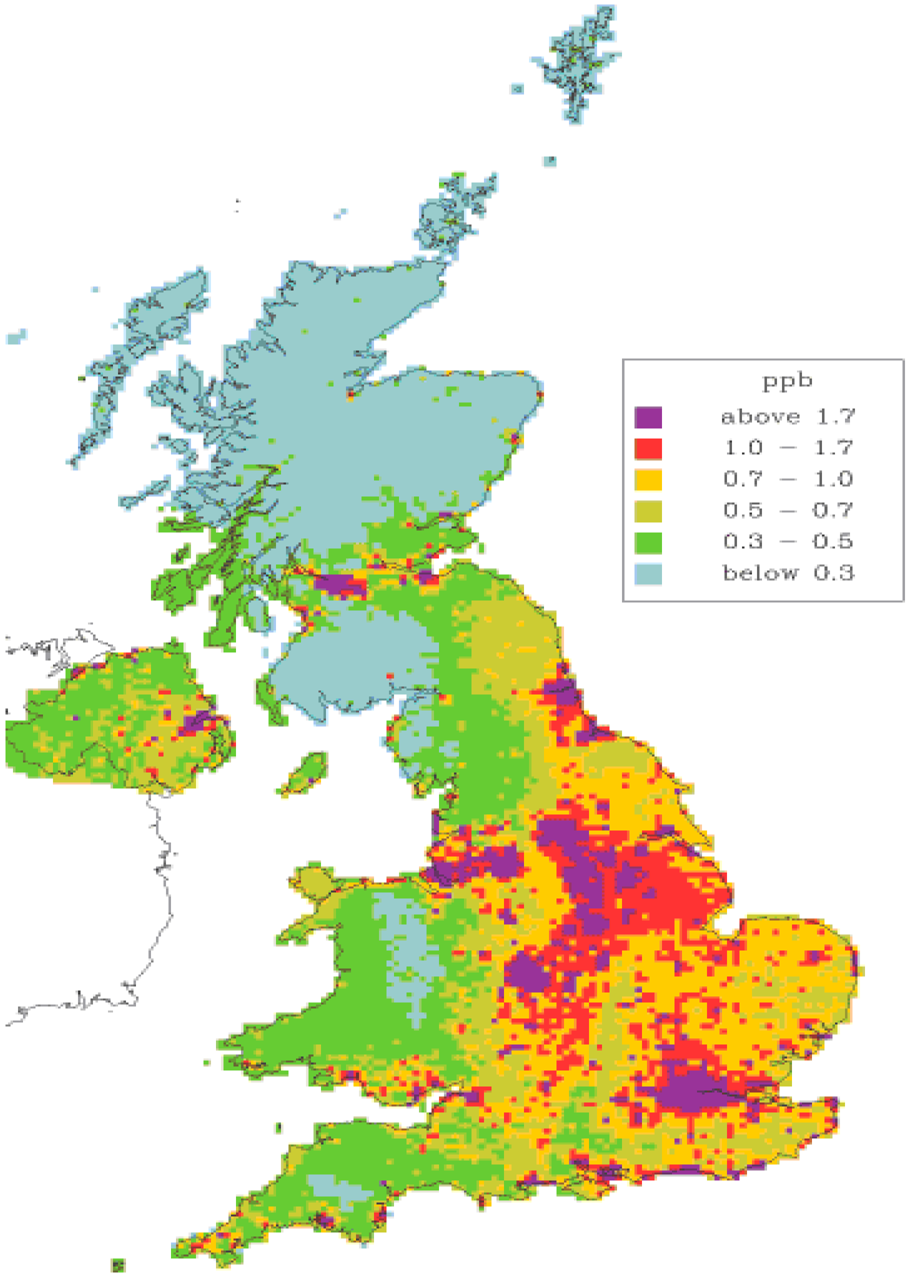
Map 1. Annual total SO_2 concentrations in 1987 expressed in part per billion (ppb)



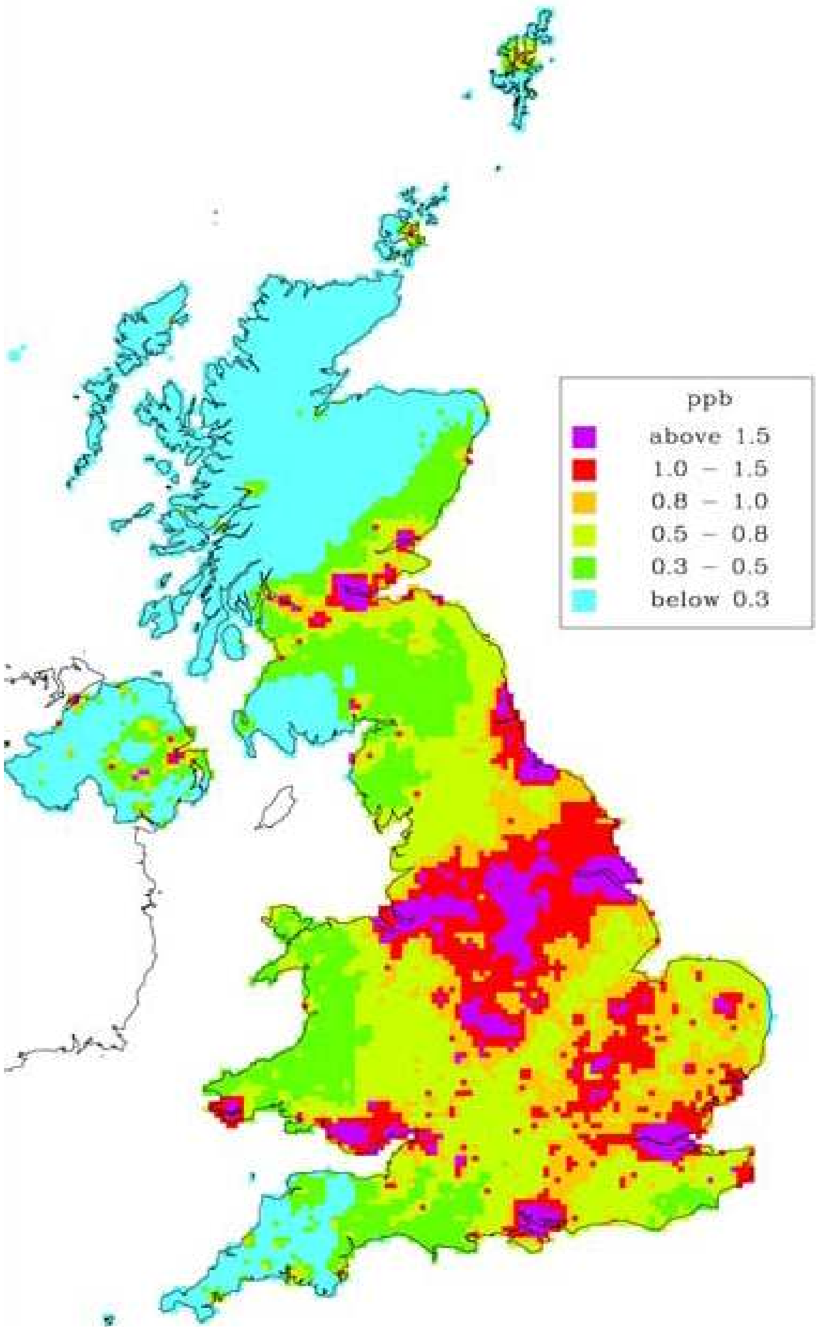
Source: RoTAP 2011: Review of Tranboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. www.rotap.ceh.ac.uk

Map 2. Annual total SO_2 concentrations in 2004 expressed in part per billion (ppb)



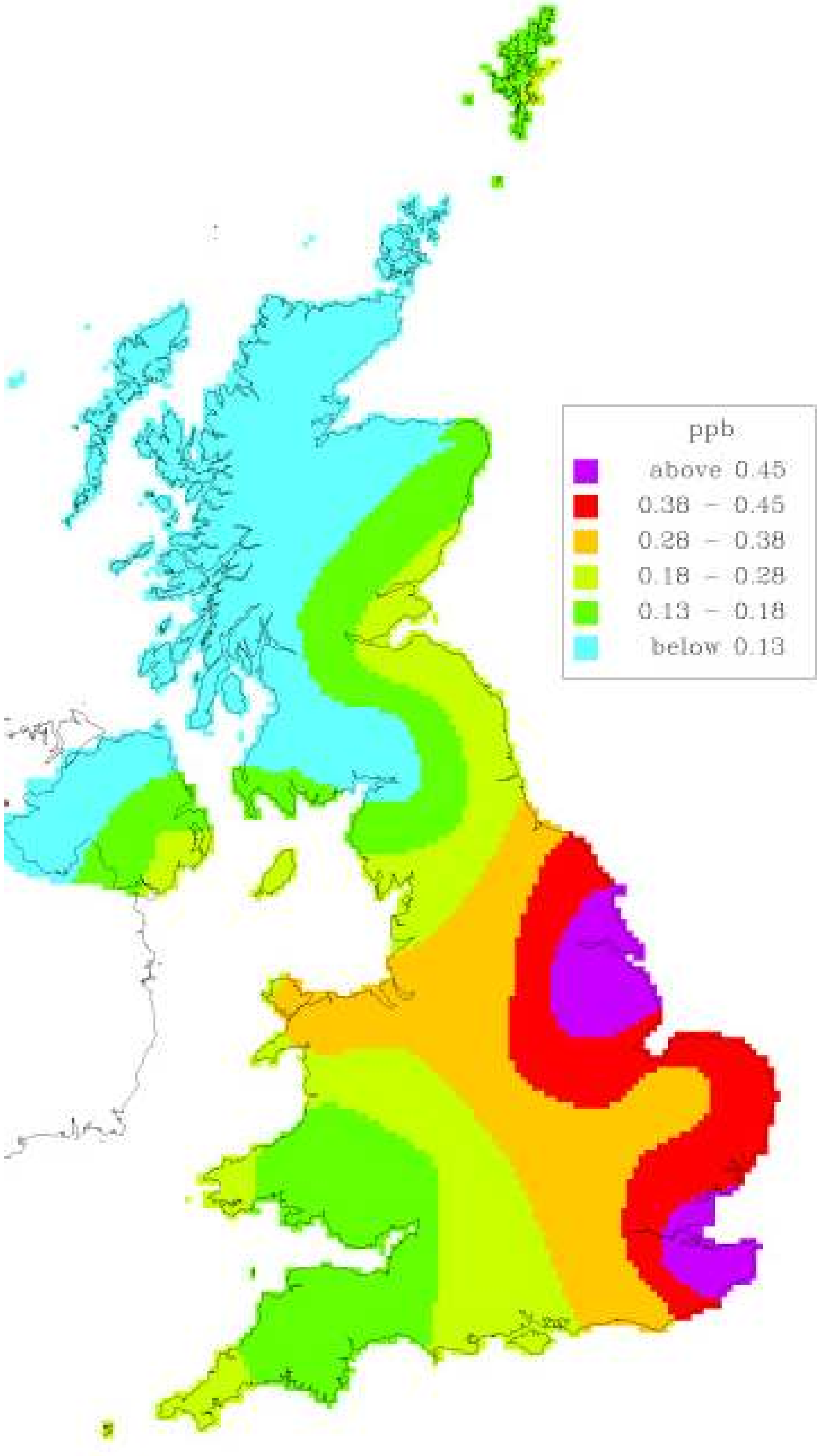
Source: Department for Environment Food and Rural Affairs, http://pollutantdeposition.defra.gov.uk

Map 3. Annual total SO_2 concentrations in 2006 expressed in part per billion (ppb)



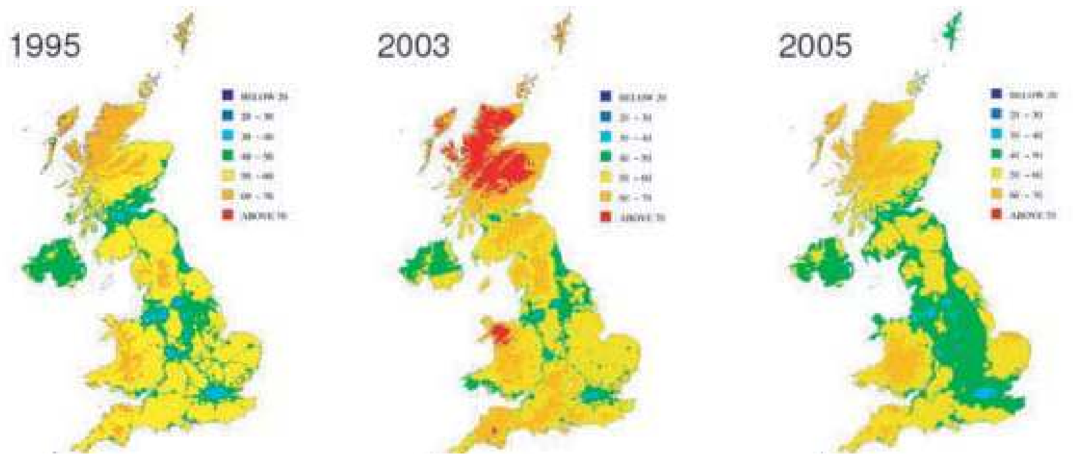
Source: RoTAP 2011: Review of Tranboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. www.rotap.ceh.ac.uk

Map 4. Annual total SO_2 concentrations in 2009 expressed in part per billion (ppb)



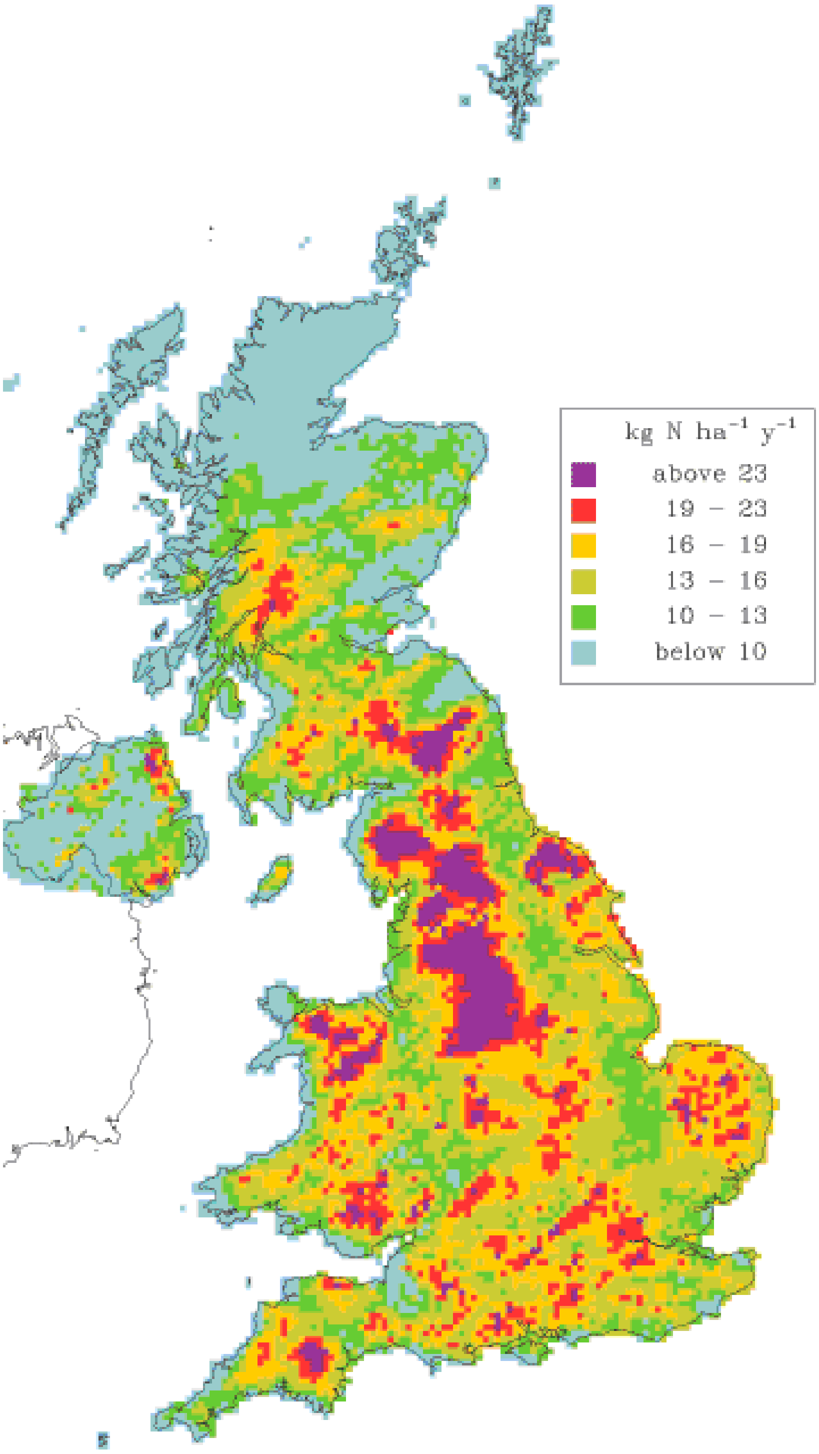
Source: Department for Environment Food and Rural Affairs, http://pollutantdeposition.defra.gov.uk

Map 5. Annual total O_3 concentrations in 2009 expressed in part per billion (ppb)



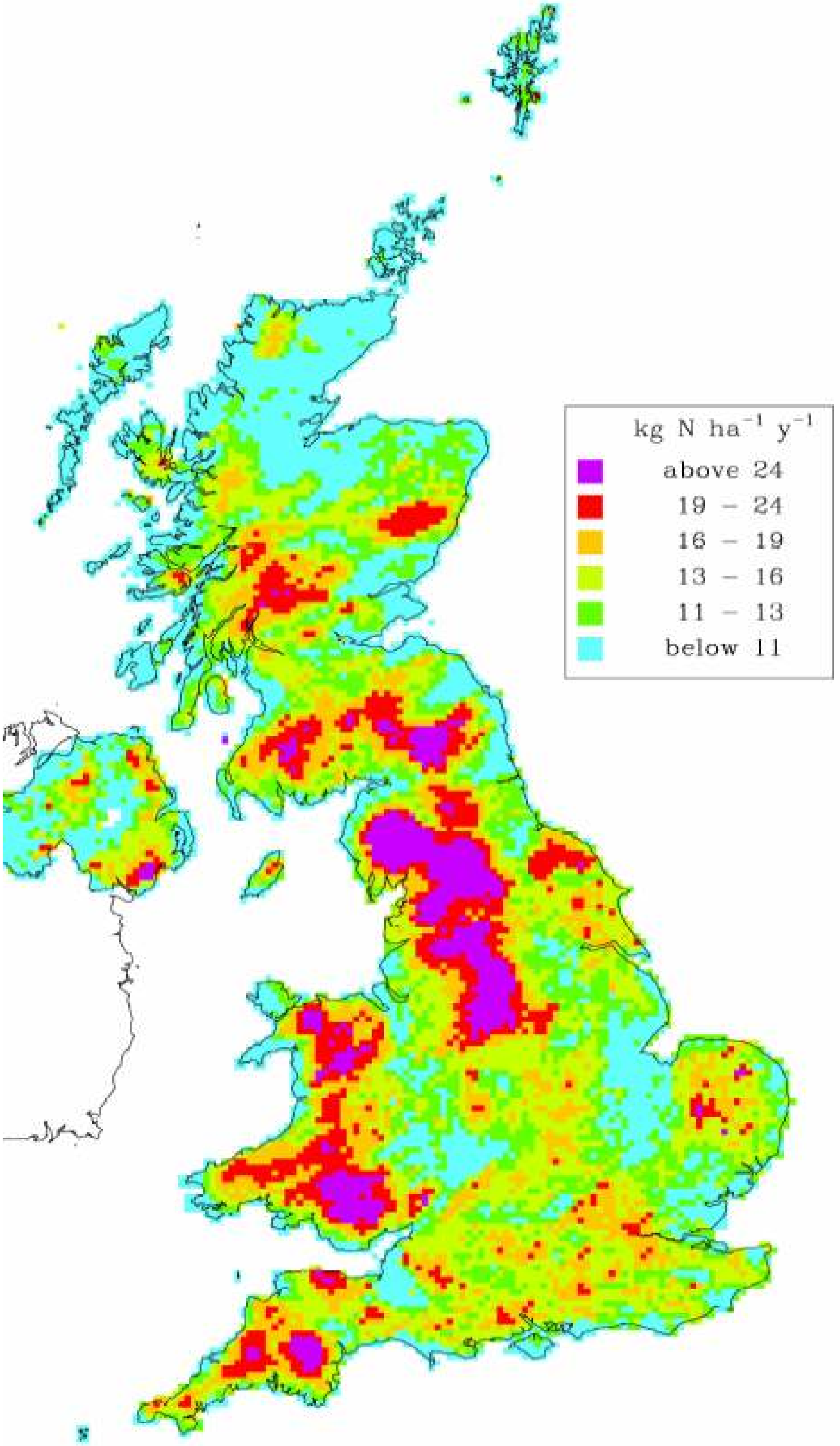
Source: Air Quality Expert Group (2009), Ozone in the United Kingdom, http://archive.defra.gov.uk/environment/quality/air/airquality/publications/ozone/documents/aqeg-ozone-report.pdf

Map 6. Annual total NO_X concentrations in 2004 expressed in kilograms per cubic meter (kg/m^3).



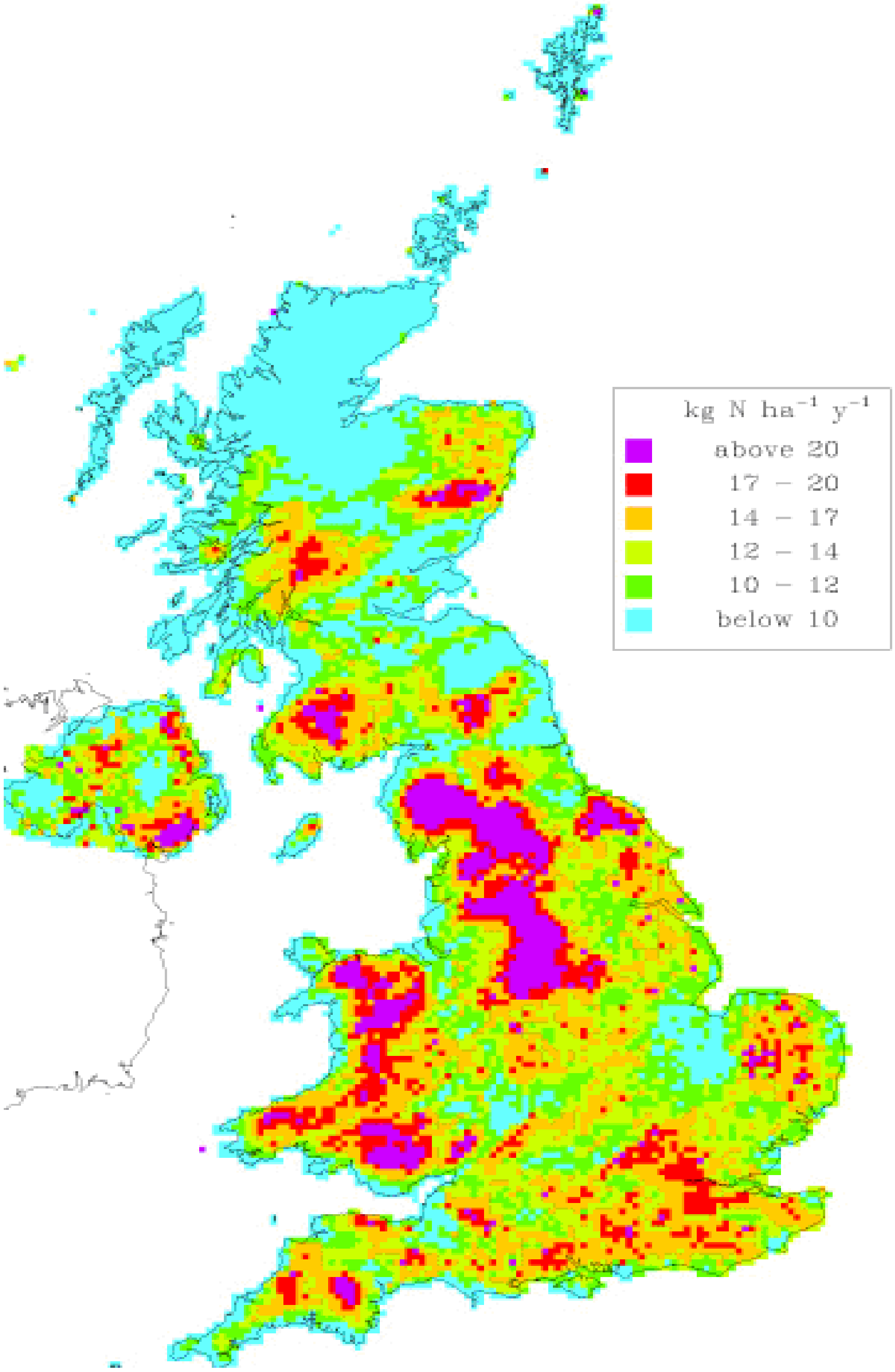
Source: Department for Environment Food and Rural Affairs, http://pollutantdeposition.defra.gov.uk

Map 7. Annual total NO_X concentrations in 2006 expressed in kilograms per cubic meter (kg/m^3).



Source: RoTAP 2011: Review of Tranboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. www.rotap.ceh.ac.uk

Map 8. Annual total NO_X concentrations in 2009 expressed in kilograms per cubic meter (kg/m^3).



Source: Department for Environment Food and Rural Affairs, http://pollutantdeposition.defra.gov.uk

Table 1. Summary statistics of income and air pollutants

Variables	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
Panel A: Total Sample				
Personal income	1,115.378	1,167.831	0.0	72,176.51
Household income	2,449.341	1,970.468	0.0	86,703.29
Sulphur Dioxide (SO_2)	9.076	15.721	0.1	287.63
Ozone (O_3)	34.655	18.204	1.57	135.67
Nitrogen Dioxides (NO_X)	93.474	120.078	0.1	1,742
Panel B: Non-Movers				
Personal income	1,142.206	1,181.836	0.0	71,058.95
Household income	2,516.326	1,981.367	0.0	72,927.47
Sulphur Dioxide (SO_2)	8.823	16.075	0.1	287.63
Ozone (O_3)	34.645	18.346	1.57	133
Nitrogen Dioxides (NO_X)	90.839	118.914	0.1	1742
Panel C: Movers within GB				
Personal income	1,191.819	1269.678	0.0	72,176.51
Household income	2,398.644	2070.24	0.0	86,703.29
Sulphur Dioxide (SO_2)	9.115	14.949	0.1	232
Ozone (O_3)	34.360	18.484	0.0	135.67
Nitrogen Dioxides (NO_X)	96.743	120.175	0.2	1,681

* The air pollutants are measured in micrograms per cubic meter ($\mu g/m^3$)

Table 2. Summary statistics of income and air pollutants controlling for individual fixed effects

Variables	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
Panel A: Total Sample				
Personal income	1,115.378	880.5111	0.0	16,889.5
Household income	2,449.341	1723.534	0.0	86,703.29
Sulphur Dioxide (SO_2)	9.076	10.594	0.3	293
Ozone (O_3)	34.655	11.457	1.57	109
Nitrogen Dioxides (NO_X)	93.474	75.366	0.2	1,369
Panel B: Non-Movers				
Personal income	1,142.206	944.772	0.0	28,166.67
Household income	2,516.326	1728.377	0.0	33,490.25
Sulphur Dioxide (SO_2)	8.823	10.172	0.3	220
Ozone (O_3)	34.645	11.470	1.57	98
Nitrogen Dioxides (NO_X)	90.839	71.361	0.2	1,369
Panel C: Movers within GB				
Personal income	1,191.819	1,042.628	0.0	22,064.25
Household income	2,398.644	1,900.061	0.0	86,703.29
Sulphur Dioxide (SO_2)	9.115	13.358	0.1	232
Ozone (O_3)	34.360	16.778	1.0	124
Nitrogen Dioxides (NO_X)	96.743	109.248	0.3	1681

* The air pollutants are measured in micrograms per cubic meter ($\mu g/m^3$)

Table 3. Fixed effects logistic regressions

	Mover status	*Mover status*	*Mover status*
Sulphur Dioxide	-0.0022 (0.0021)		
Ground-Level Ozone		-0.695-04 (0.0009)	
Nitrogen Oxides			-0.905e-04 (0.0002)
No. observations	22,545	26,716	20,253
LR chi-square	1534.42 [0.000]	2111.22 [0.000]	1789.57 [0.000]

Standard errors between brackets, p-values between square brackets

Table 4. Correlation between air pollutants

	Sulphur Dioxide	*Ground-Level Ozone*
Ground-Level Ozone	-0.0813 (0.000)	
Nitrogen Oxides	0.0106 (0.000)	-0.0559 (0.000)

p-values are reported between brackets.

Table 5. Fixed effects estimates for air pollution variation.

	Sulphur Dioxide	*Ground-Level Ozone*	*Nitrogen Oxides*
February	0.303	1.299	5.952
	(0.513)	(0.689)*	(3.232)*
March	2.827	2.184	-13.427
	(0.582)***	(0.942)**	(3.649)***
April	6.193	2.427	-20.692
	(0.724)***	(1.209)**	(3.871)***
May	7.812	0.911	-25.395
	(1.795)***	(1.519)	(3.917)***
August	-6.925	4.223	-18.478
	(6.522)***	(0.590)***	(47.356)
September	-1.760	-4.466	-34.429
	(0.335)***	(0.574)***	(2.594)***
October	-3.956	-3.549	-18.763
	(0.316)***	(0.519)***	(2.518)***
November	-4.42	-2.413	3.238
	(0.329)***	(0.543)***	(2.552)
December	-5.550	0.954	20.761
	(0.428) ***	(0.647)	(2.957)***
No. observations	96,549	95,072	82,338
R squared	0.2520	0.4756	0.3553

Standard errors between brackets, p-values between square brackets
***, ** and * indicate significance at 1%, 5% and 10% level

Table 6. Happiness panel regressions for SO_2 monthly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0147 (0.0059)**	0.0142 (0.0067)**	0.0012 (0.0681)			
Household income				0.0255 (0.0099)**	0.0256 (0.0112)**	-0.0307 (0.0715)
Sulphur Dioxide (SO_2)	-0.00104 (0.0006)	-0.00132 (0.0067)*	-0.0052 (0.0064)	-0.0011 (0.0006)*	-0.00134 (0.0006)**	-0.0061 (0.0059)
Age	-0.0397 (0.0185)**	-0.0254 (0.0237)	-0.0220 (0.201)	-0.0372 (0.0184)**	-0.0257 (0.233)	0.0405 (0.195)
Average Temperature	-0.00024 (0.0009)	0.00030 (0.00074)	-0.00049 (0.00044)	0.00018 (0.00066)	0.00054 (0.00073)	0.00044 (0.00043)
Wind speed	0.00047 (0.00040)	-0.00041 (0.00068)	0.00063 (0.00065)	0.00071 (0.00054)	-0.00037 (0.00067)	0.00077 (0.00063)
$(\partial f / \partial e)/(\partial f / \partial \ln y)$	0.0109	0.0138	0.1428	0.0057	0.0070	0.0264
No. observations	83,056	71,423	7,029	86,623	73,344	7,261
R squared	0.3965	0.4111	0.2664	0.3948	0.4091	0.2669

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
** and * indicate significance at 5% and 10% level

Table 7. Happiness panel regressions for O_3 monthly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0142 (0.0055)**	0.0094 (0.0064)	0.0258 (0.0605)			
Household income				0.0410 (0.0093)***	0.0371 (0.0112)***	-0.0212 (0.0812)
Ground Level Ozone (O_3)	-0.00031 (0.0002)	-0.0006 (0.00021)**	0.0002 (0.0029)	-0.00035 (0.00019)*	-0.00066 (0.0002)***	0.00056 (0.0028)
Age	-0.0256 (0.0182)	-0.0380 (0.0212)*	-0.152 (0.241)	-0.0258 (0.0173)	-0.0384 (0.0207)*	-0.115 (0.235)
Average Temperature	-0.0004 (0.0010)	0.00030 (0.00074)	-0.00049 (0.00044)	-0.00026 (0.00069)	-0.00013 (0.00084)	-0.0126 (0.0069)*
Wind speed	-0.00039 (0.00044)	-0.00041 (0.00068)	0.00063 (0.00065)	-0.41e-04 (0.00032)	-0.00032 (0.00030)	0.0909 (0.0130)
Precipitation	-0.0012 (0.0010)	0.00030 (0.00074)	-0.00049 (0.00044)	-0.00018 (0.00066)	-0.00035 (0.00023)	0.00012 (0.00042)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.0050	0.0967	0.0010	0.00116	0.00237	0.00350
No. observations	91,679	71,429	7,029	94,191	73,506	7,332
R squared	0.4042	0.4314	0.2113	0.4014	0.4283	0.2085

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
***, ** and * indicate significance at 1%, 5% and 10% level

Table 8. Happiness panel regressions for NO_X monthly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0077 (0.0066)	0.0129 (0.0075)*	-0.0804 (0.144)			
Household income				0.01823 (0.0103)*	0.01812 (0.0120)	-0.0918 (0.127)
Nitrogen Oxides (NO_X)	-0.09e-04 (0.56e-04)	-0.075e-04 (-0.06e-04)	-0.42e-04 (0.6e-04)	-0.0001 (0.000054)*	-0.09e-04 (0.06e-04)	-0.00045 (0.66e-04)
Age	-0.0409 (0.0167)**	-0.0379 (0.0188)**	-0.1310 (0.2613)	-0.0409 (0.0167)**	-0.0355 (0.0187)*	-0.151 (0.253)
Temperature	-0.59e-04 (0.00091)	0.00062 (0.00104)	0.0012 (0.0134)	0.00018 (0.00088)	0.00084 (0.00101)	0.0018 (0.0128)
Wind speed	0.58e-04 (0.00032)	-0.00024 (0.00037)	0.00017 (0.00075)	0.57e-04 (0.00031)	-0.00026 (0.00037)	0.80e-04 (0.00070)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.00173	0.0009	0.00077	0.00073	0.00065	0.00064
No. observations	72,978	61,464	6,032	75,218	63,312	6,190
R squared	0.4344	0.4520	0.1915	0.4328	0.4503	0.1875

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
** and * indicate significance at 5% and 10% level

Table 9. Happiness panel regressions for SO_2 weekly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0166 (0.0059)***	0.0145 (0.0067)**	0.0141 (0.0568)			
Household income				0.0260 (0.0101)**	0.026 (0.0113)**	-0.0023 (0.0568)
Sulphur Dioxide (SO_2)	-0.00103 (0.0006)	-0.00134 (0.0066)**	-0.0037 (0.0051)	-0.0011 (0.0006)*	-0.0013 (0.0006)**	-0.0043 (0.0051)
Age	-0.0345 (0.0184)*	-0.0200 (0.0239)	0.0032 (0.171)	-0.0367 (0.0181)**	-0.0251 (0.230)	0.0703 (0.168)
Temperature	-0.00162 (0.00086)*	-0.0014 (0.00092)	-0.0123 (0.0111)	-0.0012 (0.00084)	-0.00115 (0.00088)	-0.00837 (0.0089)
Wind speed	0.00068 (0.00057)	0.00086 (0.00068)	0.00018 (0.0024)	0.00071 (0.00056)	0.00091 (0.00065)	-0.00097 (0.0022)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.0094	0.0137	0.0393	0.0051	0.0071	0.0132
No. observations	79,177	67,270	6,447	81,764	69,391	6,665
R squared	0.3962	0.4121	0.2660	0.3949	0.4088	0.2695

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
***, ** and * indicate significance at 1%, 5% and 10% level

Table 10. Happiness panel regressions for O_3 weekly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0159 (0.0164)**	0.0101 (0.0075)	0.0172 (0.0217)			
Household income				0.0407 (0.0112)***	0.0327 (0.0131)***	-0.0423 (0.0930)
Ground-Level Ozone (O_3)	-0.00043 (0.00025)*	-0.00081 (0.00029)***	-0.00094 (0.00036)	-0.00045 (0.00025)*	-0.00083 (0.0003)***	0.00053 (0.0035)
Age	-0.0226 (0.0203)	-0.0283 (0.0251)	-0.244 (0.269)	-0.0256 (0.0200)	-0.0331 (0.0252)	-0.205 (0.262)
Temperature	-0.00041 (0.00088)	-0.00087 (0.00110)	-0.00036 (0.0226)	-0.00035 (0.00087)	-0.00069 (0.00109)	-0.00042 (0.00758)
Wind speed	-0.00066 (0.00077)	0.00138 (0.00117)	-0.00190 (0.00380)	0.00059 (0.00079)	0.00132 (0.00119)	-0.00055 (0.00446)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.0041	0.0119	0.0081	0.00147	0.00331	0.00350
No. observations	70,917	54,167	5,222	73,302	59,987	5,878
R squared	0.4467	0.4565	0.1632	0.4317	0.4523	0.1654

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
***, ** and * indicate significance at 1%, 5% and 10% level

Table 11. Happiness panel regressions for NO_X weekly averages

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0083 (0.0068)	0.0109 (0.0074)*	0.0062 (0.094)			
Household income				0.0227 (0.0101)**	0.0153 (0.0119)	-0.0918 (0.127)
Nitrogen Oxides (NO_X)	-0.25e-0.4 (0.49e-0.5)	1.82e-05 (0.57e-0.5)	-0.00043 (0.00063)	-0.29e-0.4 (0.49e-0.5)	2.15e-05 (0.56e-05)	-0.00045 (0.00066)
Age	-0.0443 (0.0173)**	-0.0374 (0.019)**	-0.0487 (0.210)	-0.0406 (0.0175)**	-0.0352 (0.0191)*	-0.0414 (0.202)
Temperature	-0.00111 (0.00009)	-0.0007 (0.00106)	-0.00253 (0.0156)	-0.00089 (0.00094)	-0.00062 (0.00106)	-0.65e-0.4 (0.0144)
Wind speed	-0.00022 (0.00016)	0.00030 (0.00156)	0.00505 (0.00346)	-0.00019 (0.00084)	0.00030 (0.00150)	0.00288 (0.00191)
$(\partial f / \partial e)/(\partial f / \partial \ln y)$	0.0004	0.0002	0.0009	0.0012	0.0002	0.0004
No. observations	67,812	57,221	5,458	69,915	58,948	5,606
R squared	0.4476	0.4617	0.2174	0.4460	0.4604	0.2220

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
** and * indicate significance at 5% and 10% level

Table 12. Happiness panel regressions for daily SO_2

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0164 (0.0098)*	0.0176 (0.0111)	0.0969 (0.179)			
Household income				0.0243 (0.0141)*	0.0230 (0.0141)	0.143 (0.273)
Sulphur Dioxide (SO_2)	-0.0017 (0.0010)*	-0.0015 (0.0011)	-0.0061 (0.0221)	-0.0018 (0.0010)*	-0.0017 (0.0011)	-0.0069 (0.0208)
Age	-0.0568 (0.0333)*	-0.0446 (0.0356)	-0.0202 (0.708)	-0.0502 (0.0316)	-0.0403 (0.0336)	-0.0205 (0.687)
Temperature	-0.00201 (0.00140)	-0.00120 (0.00156)	-0.0101 (0.0376)	-0.00191 (0.00142)	-0.00141 (0.00159)	-0.00139 (0.0372)
Wind speed	0.00039 (0.00054)	0.00038 (0.00078)	0.00081 (0.00421)	0.00041 (0.00054)	0.00039 (0.00078)	0.00113 (0.00390)
$(\partial f / \partial e)/(\partial f / \partial \ln y)$	0.00016	0.0128	0.0094	0.0103	0.0074	0.0063
No. observations	39,922	34,596	2,778	41,339	35,772	2,896
R squared	0.5150	0.5306	0.1669	0.5129	0.5297	0.1530

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
* indicates significance at 10% level

Table 13. Happiness panel regressions for daily O_3

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0112 (0.0073)	0.0074 (0.0082)	0.0180 (0.0600)			
Household income				0.0413 (0.0121)***	0.0367 (0.0139)***	-0.0067 (0.0873)
Ground-Level Ozone (O_3)	-0.00036 (0.0004)	-0.0005 (0.00051)	-0.0003 (0.0064)	-0.00033 (0.0004)	-0.00051 (0.0005)	-0.0008 (0.0062)
Age	-0.0272 (0.0225)	-0.0475 (0.0245)*	-0.152 (0.241)	-0.0265 (0.0213)	-0.0481 (0.0236)**	-0.0540 (0.323)
Temperature	-0.00058 (0.00108)	-0.00145 (0.00125)	0.0183 (0.0200)	-0.00081 (0.00107)	-0.00179 (0.00122)	0.0197 (0.0191)
Wind speed	0.00021 (0.00032)	0.00010 (0.00037)	0.0018 (0.0031)	0.00017 (0.00033)	0.00011 (0.00036)	0.00113 (0.00334)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.0101	0.0179	0.0035	0.00091	0.0015	0.0014
No. observations	54,251	45,185	4,217	56,150	46,747	4,341
R squared	0.4818	0.5015	0.1738	0.4785	0.4998	0.1701

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
***, ** and * indicate significance at 1%, 5% and 10% level

Table 14. Happiness panel regressions for daily NO_X

Model	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Personal Income	0.0099 (0.0065)	0.0115 (0.0076)	0.0029 (0.1040)			
Household income				0.0182 (0.0100)*	0.0154 (0.0118)	-0.0269 (0.081)
Nitrogen Oxides (NO_X)	0.31e-04 (0.51e-04)	0.49e-04 (0.59e-04)	0.00026 (0.00062)	0.24e-04 (0.51e-04)	0.34e-04 (0.59e-04)	0.00033 (0.00061)
Age	-0.0377 (0.0191)**	-0.0349 (0.0236)	0.0861 (0.2939)	-0.0335 (0.0181)**	-0.0329 (0.0224)	-0.1204 (0.273)
Temperature	-0.00084 (0.00096)	-0.00103 (0.00109)	-0.00114 (0.0124)	-0.00082 (0.00099)	-0.00094 (0.00111)	-0.00073 (0.0027)
Wind speed	0.00062 (0.00038)	0.00029 (0.00046)	-0.00468 (0.0240)	0.00022 (0.00048)	0.00022 (0.00049)	-0.00471 (0.0200)
$(\partial f / \partial e)$/ $(\partial f / \partial \ln y)$	0.0005	0.0006	0.0132	0.0002	0.0003	0.0016
No. observations	64,392	54,382	5,121	66,383	56,020	5,256
R squared	0.4531	0.4741	0.2076	0.4510	0.4726	0.2169

Standard errors between brackets, p-values between square brackets
(1) refers to total sample (2) refers to non-movers and (3) to movers within GB for personal income.
(4) refers to total sample (5) refers to non-movers and (6) to movers within GB for household income
** and * indicate significance at 5% and 10% level

Table 15. MWTP for a drop of one standard deviation

	Sulphur Dioxide	*Ground-level ozone*	*Nitrogen oxides*
Personal Income (total sample)	£92 *	£70	£120
Household income (total sample)	£99 *	£57 *	£122 *
Personal Income (non-movers sample)	£108*	£61	£83
Household income (non-movers sample)	£120 *	£115*	£127

* Indicates significance