Communicating a Gain in Life Expectancy from Air Pollution Reduction in a Contingent Valuation study: An Alternative Approach

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Abstract

Establishing willingness to pay values for a life expectancy gain in stated preference studies encounters a number of problems, both conceptual and practical. This paper focuses on the key empirical problem of communicating the concept of a "gain in life expectancy" to members of the public and how such a gain might be generated, these being issues that are crucial for the elicitation of a meaningful monetary valuation based on individual preferences. We introduce a new protocol for estimating the value of a life year (VOLY) gained from air pollution reduction programmes. While the results are internally reliable (a minimum criterion), we provide two further tests of their validity: a quantitative comparator study and a qualitative face validity test. We conclude that the communication methods used in this study constitute a significant step forward on previous studies (including our own) and provide a viable alternative method with scope for further improvements and refinements in the future.

Keywords: Life Expectancy Gains, Willingness to Pay, Value of a Life Year (VOLY)

JEL Classification J17

I. Introduction.

The adverse health effects of air pollution have become a matter of increasing concern to policy makers both nationally and internationally. Broadly speaking, the damage to human health from air pollution can be classified as falling into one of two broad categories, namely *acute* and *chronic* effects.

Acute effects, which result from "bad air day" upward "blips" in air pollution lasting for only short periods, affect mainly those who are already old and in poor health. The result of such effects is typically the exacerbation of existing heart or lung disorders and the loss of a matter of days or weeks of life expectancy. By contrast, chronic effects are a consequence of ongoing levels of air pollution and can, in theory, impact over the whole lifetime of an affected individual. Here, exposure essentially weakens peoples' bodies and internal organs at a slightly faster rate than would have been the case in the absence of air pollution. This effect may lead to substantially larger losses of life expectancy across the affected population than in the case of acute effects, amounting to months rather than days or weeks (Elliot *et al.* 2007; Abbey *et al.*, 1999; Dockery *et al.*, 1993; Pope *et al.*, 2002). Whilst many unresolved issues exist, both conceptually and empirically, in respect of the monetary valuation of the gains in life expectancy that could be expected under air pollution reduction programmes, there is a growing body of evidence that suggests that these values could be quite substantial (see for example Desaigues *et al*., 2007; Krupnick *et al*., 2002, 2006; Alberini *et al*., 2004; Chestnut *et al*., 1997; Corso *et al*., 2001; Dziegelewska and Mendelsohn, 2005; Hammit and Zhou, 2006; and Viscusi *et al*., 1991).

It can be argued convincingly that the concept of the Value of a Life Year (VOLY) framework is the most appropriate framework for the valuation of changes in life expectancy generated in an on-going manner from sustained reductions in the level of air pollution (Rabl, 2003). Specifically in the context of air pollution, the evidence suggests that in addition to its impact on morbidity, the mortality effect of a given change in the ongoing level of particulate air pollution in a specific geographical region will be to produce a *proportionate* change in the so-called “hazard rate” for people living in that region, where the hazard rate is the overall probability of death at a given age conditional on survival to that age. For developed western countries the effect of, say, an ongoing 10% reduction in the level of particulate air pollution will, on average, result in a 1% reduction in the hazard level[1], which in turn will raise average life-expectancy by a little over one month. Correspondingly, a 25% reduction in particulate air pollution would reduce the hazard rate by 2.5% and increase life expectancy by about three months[2].

Moving into the domain of VOLYs, however, is not straightforward. For example, a particular gain in life expectancy can, in principle, be generated by any one of an infinite number of different perturbations in the probability density function for an

[1] See Rabl (2003).

[2] This evidence forms the basis for the gains in life expectancy presented to respondents in the study, although we also include a six month gain given the general epidemiological uncertainty. It is of course debateable whether a six month gain is in fact a marginal change or, indeed an upper limit. However, regarding the latter, previous experience suggests that trying to value a one year change in life expectancy would run into severe budget constraint problems, impacting negatively on any scope sensitivity. In addition, compared with the risk reductions (and implied life expectancy gains) in a standard VSL-surveys even a six months gain in life expectancy is a substantial good (the risk reduction is a VSL survey is usually of the order of magnitude of days with the maximum of one month). Hence with the VSL-literature as the starting point it is hard to argue that a one year gain would be-marginal. Also, , it is not possible by reducing only the hazard rate in the first decade (i.e. would results in a survival probability above one) to deliver a gain in life expectancy of one year for say a 40-year old, since it would result in an implied survival probability greater than one. Finally, even a complete reduction in the risk of death to that 40 year old would only result in about a nine month gain in life expectancy. So, even if respondents were not budget constrained, a one year gain seems implausible.

individual's remaining length of life. It does not seem unreasonable to consider the possibility that, provided a person is adequately informed of this, they may well have a marked preference for one way of generating a particular gain in life expectancy rather than another. For example, a person may prefer a sustained, on-going risk reduction generated by a serious of very small one-period, but consecutive changes in conditional probabilities of survival to a relatively large, but one-period only risk reduction even if both resulted in the same average gain in life expectancy[3]. Put another way, in the context of a willingness-to-pay (WTP) study, if people *understood* how the life expectancy gain was generated, they may offer a different WTP for the *same* gain, one that was arguably more in line with their preferences

Thus, while it seems clear that most people will regard a *ceteris paribus* increase in life expectancy as being a 'good thing', in order for a survey to generate a fair reflection of its value, it seems desirable that respondents be given some information on the particular form of the perturbation in the individual's underlying age-specific survival probability distribution that gives rise to the gain in life expectancy under consideration. In the context of this study, the gain in life expectancy arises from small perturbations immediately on inception of the policy but which increase in magnitude quite significantly towards the end of life.

This leads us to the significant empirical problem which is the main focus of the present paper and concerns the means by which one might convey to members of the public the essential nature of the effect on life expectancy of changes in these underlying probability perturbations, bearing in mind peoples' cognitive limitations

[3] See Seested-Nielsen *et al*. (2009) for an experimental investigation of this particular issue.

regarding small probabilities, uncertainty and discounting which are well known and hence there is little need to review them in detail here. We simply note they are an on-going and ever present limitation to *all* VOLY studies. We adopt a pragmatic approach to their existence in the sense we assume that they undoubtedly affect values, but that the results, if controlled for as many factors as possible, tell policymakers *something* useful in respect of peoples' preferences.

As such, the emphasis changes to one of controlling factors that we can do something about. Describing and communicating the attributes of the good in an intuitively meaningful but scientifically acceptable manner is perhaps the most obvious. This may explain, at least in part, the amount of care and effort that is put into this in (good) stated preferences studies in the environmental economics literature, particularly in later years where the goods valued e.g. biodiversity, natural resource damage have become increasingly complex and unfamiliar to respondents viewpoint, and is well reflected in the environmental economic literature. Our view is that the same degree of effort applied in other domains such as the VOLY may provide significant improvements in the reliability and validity of resulting values. This contrasts with the dominant approach to date which is to generally focus on the length of the gain, without explaining how it is generated, for example describing an X-month gain in life expectancy as an average extension of survival time by X months either for an individual or all members of a household, as in Chilton *et al.* (2004). The avoidance of any mention of conditional probabilities in such studies is more a reflection of our acceptance of our inability to turn people into functioning 'probability processors' than any wilful attempt to mislead or simplify for the sake of it. Nevertheless, this approach carries with it the danger that respondents perceive this as being, quite simply, an "add-on" at the end of life.

Facing up to this seemingly intractable dilemma led us to consider and develop a third approach, The survival prospects of an individual of a given age, randomly selected from a large population can be formally summarised in a number of different ways, including the so-called "survival" and "hazard" functions. These are set out in detail in the Appendix. A quick glance reveals the rather technical nature of these concepts. The challenge therefore would be to convey, at least intuitively, to people the essential nature of the way in which this average gain is actually achieved and how, in turn, this translates into a gain in life expectancy in a more 'user-friendly' manner, without severely compromising the scientific validity. We (economists in conjunction with an epidemiologist) did this by introducing and developing the idea of a personal "ability to survive" curve. This was effectively a simplified depiction of the graph of a survival function for the average person, and its key features are set out in more detail below in Section 2. Separate quantitative and qualitative validity follow up studies were subsequently developed to enable an assessment of the efficacy of the new approach compared to a more conventional approach and are described later in the paper

The remainder of the paper is organised as follows. Section 2 describes the protocol developed and employed in this study in some detail. Sections 3 and 4 detail and discuss the results of the contingent valuation survey and the validity studies respectively. Section 5 concludes.

II. Study Protocol.

A total of 152 people were interviewed. Although this sample (Table 1) was more or less representative of the demographics of the North East England region in the 2001 Census we would be reluctant to make policy recommendations on the basis of this study alone. Nonetheless, in terms of its primary purpose of methodological development – to demonstrate the applicability and economic consistency of our procedures – while a larger sample size is always to be preferred to a smaller one, our sample size is adequate for its intended purpose.

Table 1 Sample Demographics

Indicator	**North East England**	**Study sample**
Male/Female (%)	52/48	54/46
Mean Age (years)	37.8	38.2
Household Size	2.3	3.1
Home ownership (incl. mortgaged) (%)	52.9	62
Job Classification:		
Stay at home wife	-	1
Employed (unskilled/semi skilled)	30	29.
Middle level employee	21	28
Self employed	5	6
Professional	27	17
Unemployed	10	3
Retired	N/A	8
Full time student	7	7

Information on life expectancy was presented in relatively intensive group sessions moderated by a member of the research team and an assistant. These sessions lasted about 1 hour and 20 minutes, of which approximately 35 minutes was devoted solely to an explanation of a life expectancy gain and how it is derived[4]. The protocol included some open-ended discussion of a general nature, but mostly focussed around directed exercises to clarify understanding of our graphical presentations. While it is possible that there may be some correlation between the open-ended discussions and individual willingness to pay (WTP) responses, this risk was considered small since the discussions did not concern directly any valuation issues and instead focused on introducing definitions and terms and clarifying apparent misunderstandings.

Early piloting had indicated that a graphical presentation fared best as an information presentation mode, provided that it was accompanied by clear verbal descriptions of the information portrayed in the graph. Care was taken in relation to the associated exercises to ensure that all respondents in all groups had access to the correct factual information at the end of the process, irrespective of what might have been said in any one individual group. All WTP questions which would form the basis of the subsequent VOLY calculations were answered on a strictly individual basis. Below, we summarise the main procedures/stages within the protocol.

In the first stage, participants were introduced to the general nature of the study and the particular health impact of air pollution that they would be dealing with,

[4] This protocol was developed and refined over a nine month period prior to implementation to ensure that respondents would understand the various definitions and questions and to highlight areas where additional discussions and/or explanatory information was necessary. Space precludes an in-depth discussion of this, by nature, iterative process. Whilst we can never be sure that our respondents fully understood our explanations in the final application, we were certain in the earlier stages when they did not. As in all such studies, a judgement call must be made as to when the instrument is fit for purpose.

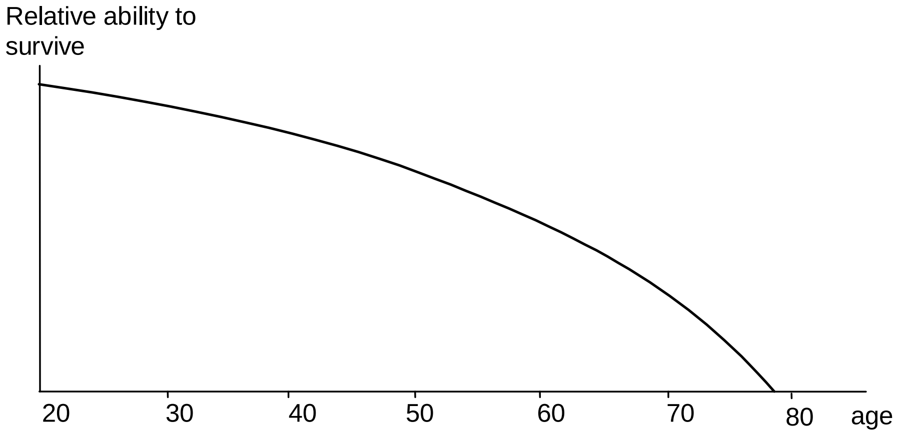
specifically chronic effects leading to premature death. The purpose of this stage was to clarify that, while other health benefits may arise, the only benefit they would be asked to focus on in this study would be an extension of life expectancy; that they understood the concept in general terms and were aware of the process by which the increased costs of any reduction in air pollution would be passed onto them (i.e. the "payment vehicle") namely by an increase in the general cost of living[5].

This part of the session was interspersed with general open-ended questions and discussion on issues such as the causes of air pollution and why and how air pollution had different affects on different age groups. It was explained that as people age, their risk of dying from air pollution increases, so while everyone is to some extent vulnerable to the effects of air pollution, this vulnerability increases with age and is much higher towards the end of the average person's life.

The protocol then moved on to explain the process by which reductions in air pollution result in such gains using a series of diagrams based around an 'ability to survive' curve. Figure 1 shows such a curve for an average 20 year old, although each respondent also saw a similar curve corresponding to their own age cohort).

[5] This payment vehicle follows that used in Chilton *et al*. (2004).

Figure 1 'Ability to Survive' Curve (Average 20 Year Old)[6]



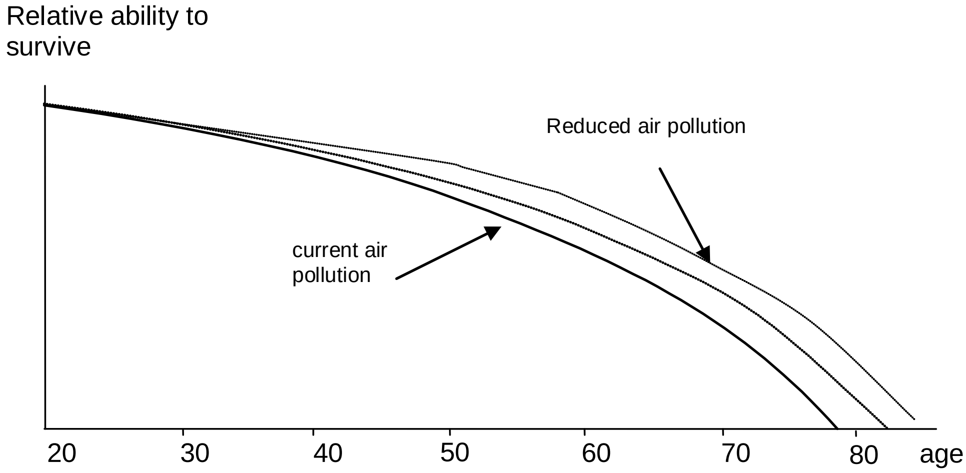
This curve simply reflects the intuition (and fact) that as we age, we become more susceptible to illnesses and accidents until at some point we can no longer expect to survive. Underlying this is the formal concept of a survival function which specifies the proportion of a given sample of individuals surviving at each age. The relationship between this function and the corresponding individual survival function for a specific member of the sample clearly depends on a number of factors including the personal characteristics and circumstances of the individual concerned. In addition, the graph of the survival function will typically be "S"- shaped and beyond some point will asymptotically approach zero, reflecting the fact that a small number of individuals will live to a very old age. The difficulties involved in communicating and explaining these and other properties to the average respondent would be substantial. For this reason we elected to compromise and work instead with our essentially qualitative depiction, in which the 'ability to survive' curve, declines at an increasing rate and reaching zero at current UK life expectancy of about 80 years[7].

[6] A scale on the relative ability to survive axis would be inappropriate as this concept cannot be quantified, we simply stated that higher points reflected a greater ability to survive.
[7] This is for the average person. Qualitatively, 'an ability to survive' curve is the same for a man and a woman as is the principle in which the life expectancy gain is generated, so there seemed little to be gained in providing 'ability to survive' curves customised for gender (i.e. for a male life expectancy of 78 and a female life expectancy of 82).

This was followed by a further qualitative description of how a reduction in air pollution impacts on the curve i.e. shifts it outwards and upwards, analogous to the same type of shift in the underlying survival function. The link between the magnitude of the shift and the size of this reduction (Figure 2) was emphasised in that the smaller the risk reduction the smaller the shift. To the extent that this pictorial representation displayed an increasing vertical gap between the original and the post - pollution reduction 'ability to survive' curves and hence indirectly the original and the post - pollution reduction survival curves- which is precisely what would result from an ongoing proportionate reduction in the hazard rate - we believe, based on discussions in the piloting and development phases of the study, that respondents were provided with as clear and accurate an explanation as they were able to handle. In addition, it was emphasised that although the new curves (dotted lines) appeared to suggest years of life expectancy gain, this was not the case and, instead the expected gain would be in terms of months.

It was stressed that while most of the risk reduction (or increased chance of survival) occurs towards the end of a person's life, *conditional* on them reaching this stage, some benefit accrues as soon as the risk reduction is implemented. In addition, it was pointed out that the change in expected age at death was magnified for illustrative purposes in the sense that we would be have been unable to make visible the change if (months) if drawn to scale and did *not* constitute the addition of a substantial number of years at the end of life.

Figure 2 'Ability to Survive' Curves Following Reductions in Air Pollution

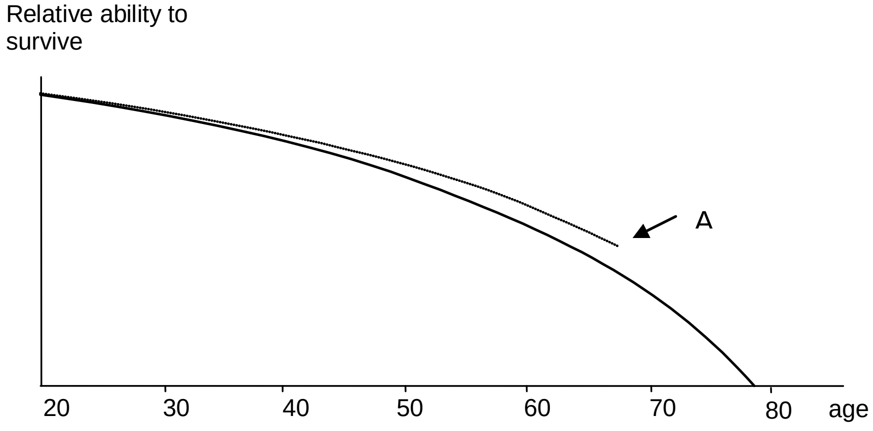


An explanation was also provided on the need to maintain lower levels of air pollution -and hence an increased cost of living - indefinitely (i.e. for the rest of life), if the full life expectancy gain was to be realised (Figure 3). As a further clarification, participants were asked to discuss what might happen to air pollution levels and hence the 'Ability to Survive' curve if the higher level of expenditure ceased at point A and current levels resumed[8], although they were not asked to write their responses down.

Up to now, the protocol had focussed on the average person, who could expect to be in average health along his/her 'ability to survive' curve. Whilst it is certainly true that policymakers do not have evidence as to how a particular individual's gain in life expectancy would differ from the average and hence would use the average in any calculations of aggregate life expectancy gains, it seems plausible that a given individual's WTP for the gain might be affected by how they perceive themselves

[8] For the interested reader, the 'ability to survive' curve would now bend and move gradually in the direction of its original location, although it would never actually touch due to the impact of the risk reductions (and hence improved ability to survive) already enjoyed, up to point A

Figure 3 The Effect on 'Ability to Survive' Curves Following a Return to the Original Cost of Living (and Air Pollution)



relative to the average. For example, if they thought that their own risk reduction was likely to be minimal relative to that of the average person they may wish to adjust WTP downwards. Then, again, they may not. But it seems appropriate that an attempt is made to allow them to consider this feature.

Therefore, the protocol moved onto consideration of each individual's own particular circumstances. Participants were asked to consider the health state of an average person and how that might be expected to change over time. They were then asked to rate themselves in relation to the average person in terms of their perceived health status. Information was provided on how any air pollution reduction might affect people of average, below average and above average health in order to highlight the uncertainties that surround the benefits to any one individual[9]. Participants were also reminded that, depending upon their health, genetic make-up and general lifestyle and

[9] Reductions in air pollution levels might be expected to have a relatively larger effect on people in poorer than average health than on people in relatively better than average health, but for any one individual this proviso may not hold.

lots of other things, including where they live, the effect of air pollution may have a much greater or much smaller impact on them individually.

Taken together, their relative health status and individual characteristics combine to the extent that the shift in an individual's 'ability to survive' curve may differ significantly or otherwise from the 'average' person[10]. While this effect cannot be quantified, by considering the uncertainty surrounding her own gain, an individual may, if she wishes, take this into account in some way in his or her valuation.

In the final phase, WTP responses were elicited on an individual, "self-interested" basis for three different and separate gains in life expectancy – one month, three months and six months to check for scope sensitivity. Further, two variants of the protocol were employed i.e. (WTP 1 month, WTP 3 months, WTP 6 months) and (WTP 6 month, WTP 3 months, WTP 1 months) in an attempt to control for any order effects in the resulting data sets. We used the full disclosure method (Bateman *et al.*, 2004) so that respondents were aware they would be asked to value the three different gains at the outset. It was also made clear that these were three separate, as opposed to sequential, valuations.

Respondents were asked if they would be willing to pay anything in principle for a gain in their life expectancy through sustained higher prices. Those that were not noted their reason in the response sheet. For those who said that they would be

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[10] We note here that different risk reductions *might* accrue to different individuals, depending on the variance of the life expectancy gain. The epidemiological data is not available to establish this definitively. However, this study (along with all others) assumes that the 'on average' risk reduction leads to a gain in life expectancy to the average person of X months. As such, respondents are asked in the CV study for their personal value for an average life expectancy gain.

prepared to pay, the interviewer described again the policy change and highlighted the gain in life expectancy. A card-sort procedure (described in detail in Carthy *et al*., 1999 and Chilton *et al*., 2004) was utilised, whereby WTP cards were sorted into three piles ("Definitely Would Pay", "Definitely Would Not Pay" and "Unsure") to help them arrive at their maximum WTP for each year for the rest of their lives for the different gains in life expectancy[11]. Each participant was asked to remember when making their decision how much they could afford to pay and, further, was asked to write down what they thought they might give up (in terms of expenditure or savings) in order to obtain this increase in their life expectancy. Following the WTP questions demographics details were collected and the interview terminated. We now turn to the results.

III. Results.

The data were pre-screened for protest bids, where in follow-up questions respondents indicated that they had given a zero bid for a reason other than as a reflection of the value of the life expectancy gain to themselves. Three outliers whose bids were more than 10% of their annual income [12] were then eliminated from the data sets corresponding to each gain[13]. Mean WTP increases with the number of months gain in life expectancy while the number of zero bids decreases, as might be expected.

[11] In an attempt to avoid 'starting point bias', respondents themselves chose the card at random themselves. In addition, they were able to view the range of cards on offer if they wished.
[12] Whilst it could be argued (but not proved with the data set we have) that these respondents were valuing the change as non-marginal given their stated payment as a proportion of their individual income - and hence their responses are not in accord with the standard underlying economic (valuation) theory applicable to the remaining responses – our main reason for removing them is their disproportionate impact on the regression analysis, in that all significant variables become insignificant if they are included..
[13] To balance the impact of removing these three outliers, three 'non-protest' zero responses were removed, these were selected at random, one from each of the interviewers.

Table 2 Mean Monthly WTP for Gains in Life Expectancy

	WTP 1 month	WTP 3 months	WTP 6 months
Total number (n) of respondents	152	152	152
Zero WTP	109	78	52
Protest Zeros	43	38	22
Mean WTP (£) (n = 152) (Std. Dev.)	6.62 (45.33)	8.86 (44.57)	14.45 (43.32)
Mean WTP excluding protest Zeros (£) (Std. Dev.) n =	9.22 (45.33) 109	11.81 (44.57) 114	16.90 (43.32) 130
Mean WTP excluding protest Zeros and 3 outliers top and bottom (£) (Std. Dev.) 95% Confidence Interval n =	2.88 (7.93) (1.35 -4.41) 103	5.91 (10.86) (3.86 - 7.96) 108	12.00 (17.44) (8.93 - 15.07) 124
Turnbull lower bound estimates	2.66	5.25	13.05
Median WTP (£)	0.00	0.00	2.08
Median WTP excluding protest Zeros (£)	0.00	1.88	4.17

III.I Regression Analysis

The observations for each life expectancy period gain were then pooled under the assumption that WTP values, which were point estimates, were distributed parametrically. Non-parametric bounds for the means (Turnbull Estimates) were also estimated and lie within the 95% confidence intervals of mean WTP. Several different models were applied, to allow for different possible underlying assumptions regarding the data i.e., a negative binomial regression, an OLS regression in levels, a log-log model and finally a Tobit regression. The results, given in Table 3, do not reflect the outliers for the reasons stated in footnote 11.

Regression coefficients have the same orders of significance across all models and for statistically significant variables the sign is the same. The count data model is based on the number of occurrences of an event and if the 'Incidence Rate Ratios' (IRR) are multiplied by 'exposure' the expected number of events can be calculated, in this context the 'exposure' is the mean value of the dependent variable. The OLS model assumes that the independent variables interact additively, whereas the Log-Log models allows for a multiplicative relationship. The coefficients of the Tobit specification are always higher than the simple OLS, reflecting the left-censored nature of the WTP data. This accounts for the fact that a proportion of the respondents who stated zero as their valuation would have given a negative amount if this had been offered to them, as they felt that the 'good' on offer, a reduction in their probability of dying prematurely, was for them a 'bad', perhaps reflecting a negative connotation of life in old age on the part of at least some respondents.

Table 3 Regression results

Regression Models	**Negative binomial**	**Negative binomial IRR**		**OLS**	**Log-Log**	**Tobit**
Dependant variable **WTP**						
Independent Variables[1]						
Income	0.0003 (0.00006***)	1.0002 (0.00006***)		0.002 (0.0008***)	0.321 (0.093***)	0.003 (0.0007***)
Expected Pollution Reduction Benefit	0.499 (0.106***)	1.647 (0.184***)		2.253 (0.645***)	0.903 (0.129***)	5.605 (0.996***)
Increase in Life Expectancy	0.261 (0.047***)	1.298 (0.065***)		1.317 (0.367***)	0.399 (0.086***)	2.233 (0.5***)
Health Status	0.343 (0.157**)	1.409 (0.236**)		2.107 (0.996**)	0.084 (0.091)	2.996 (1.549***)
Level of Air Pollution	-0.432 (0.209**)	0.649 (0.126***)		-2.99 (1.193**)	-0.214 (0.119*)	-4.8 (1.93***)
Age	0.006 (0.048)	1.006 (0.052)		-0.226 (0.343)	dropped	-0.074 (0.509)
Private Health Insurance Subscriber	0.262 (0.231)	1.30 (0.315)		1.552 (1.879)	0.085 (0.166)	0.321 (2.495)
Charity Donator	0.679 (0.282**)	1.973 (0.571**)		3.7 (1.346***)	0.362 (0.155**)	8.622 (3.062***)
Number of Children	-0.061 (0.132)	0.94 (0.133)		0.043 (0.738)	-0.018 (0.13)	-0.797 (1.25)
Education Level	-1.019 (0.212***)	0.361 (0.081***)		-5.769 (1.812***)	-0.506 (0.148***)	-7.725 (2.234***)
Gender	-0.265 (0.198)	0.767 (0.158)		-1.86 (1.215)	-0.054 (0.127)	-1.173 (2.095)
Age squared	-0.0001 (0.0006)	1.00 (0.0006)		0.002 (0.004)	-0.056 (0.089)	0.0001 (0.006)
Sequence	-0.362 (0.202)	0.697 (0.15)		-0.144 (1.503)	-0.037 (0.134)	0.441 (2.165)
Constant	-0.829 (1.13)			0.672 (6.23)	-1.644 (0.816**)	-22.545 (10.992**)

1. The figures in parenthesis are standard errors. Statistical significance at the 1%, 5% and 10% level is indicated by: ***, **, and *.

If we consider the underlying economic theory of the respondent's decision, then for an individual, it seems reasonable to suppose that willingness to pay will depend not only on the magnitude of the gain in life expectancy (T) (and, as noted earlier, the way in which it is generated) but also on a variety of other factors such as income, age, health status and so on. Given this, it would seem reasonable to assume that:

$$WTP = \alpha T\alpha^{\beta 1} Y^{\beta 2} Z_1^{\beta 3} Z_2^{\beta 4} \ldots Z_n^{\beta n+2} \eta \qquad (1).$$

The β's reflect the contribution of the particular variables to WTP and η is an error term which given the prevalence of upper-tail outliers in WTP surveys, will be assumed to be lognormally distributed. Taking logs of both sides then gives

$$\ln(WTP) = \ln(\alpha) + \beta_1 \ln(T) + \beta_3.\ln(Y) + \ldots + \varepsilon \qquad (2).$$

To confirm that this theoretical specification is matched by the data, we conducted a Box-Cox test which compares the fit of the OLS and the Log-Log models. The results show that the log-log specification has the best overall fit. However, to construct the WTP variable for the log specification we shifted the vector of responses to the right as the log of zero cannot be taken.

Accordingly, each of the regression models in Table 3 contains some element that can be challenged and we therefore present them all. Turning first to the positively signed significant coefficients, 'Increase in Life Expectancy' is the length of life expectancy gain associated with each WTP observation. Respondents were willing to pay more for a greater gain in their life expectancy as we would anticipate. 'Expected Pollution

Reduction Benefit' reflects the perceived benefit participants would receive on a five point scale ranging from 'no benefit' to a 'very big benefit'- given the positive sign, we infer that those who perceive a larger benefit are willing to pay more. 'Income'[14] available to the respondent is positively signed with an income elasticity of 0.23, indicating that gains in life expectancy are treated as a normal good. A 'Charity Donator' is a respondent who regularly makes charitable donations. As this is significant, it might reflect to some extent that this it is controlling for a type of 'moral satisfaction' (Kahneman and Knetsch, 1992) effect on parameter estimates.

There are two significant negative coefficients: 'Level of Air Pollution' reflects whether the respondent lives in an area that in their perception has higher than average air pollution. As this is negative, it suggests that people living in such areas would be willing to pay on average a lower amount than those living in lower than averagely polluted areas. This appears counterintuitive, and might reflect different attitudes to the stated risk amongst the groups or it may be that those people who live in lower than averagely polluted areas are bringing in 'other' issues such as quality of life into their valuations. Finally, 'Education Level' is the highest attained education level[15], as this is negative it implies that the more highly educated a person is, the less they would be willing to pay.

Taken together, the consistency of the variables across the regressions and their general consistency with economic theory provide some indication of the reliability of the responses. In addition, comparing the results to those reported in Morris and

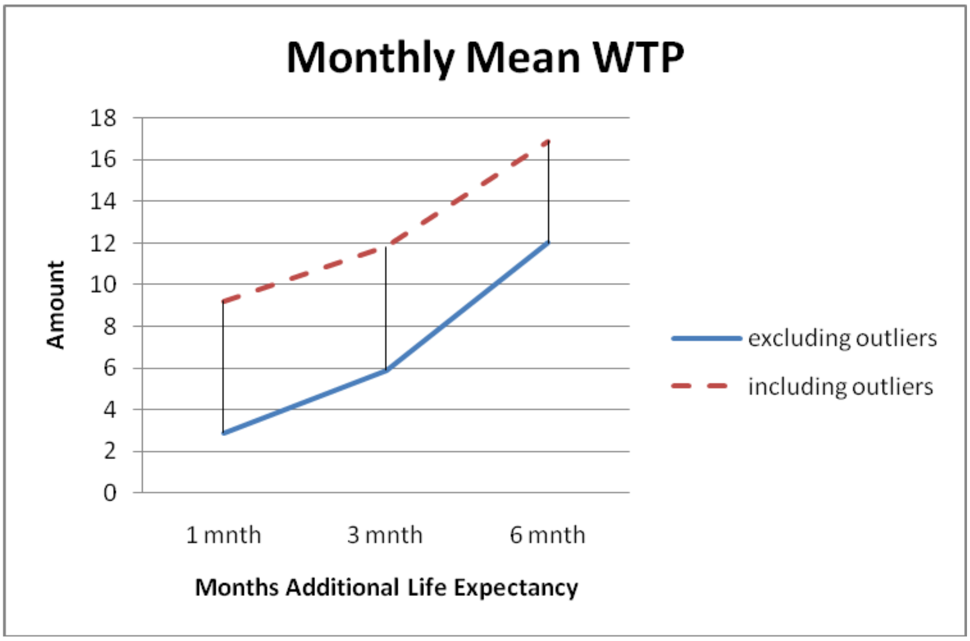
[14] The income variable was constructed using either a person's household or personal income, depending on which budget she indicated she used in the WTP question. The income coefficient was insignificant if either household or personal income was used exclusively.
[15] The education levels were: primary school; secondary school; further education.

Hammitt (2001), which used life expectancy in a health context, we find that that income is positively related to WTP and variables such as Age and Gender are insignificant in both studies while education is negatively significant. As a whole, such parallels provide some reassurance as to the overall reliability of the estimations.

The "Life Expectancy" variable can be considered as an internal[16] scope test on the data. Morris and Hammitt (2001) suggest that a parameter value of one should be expected in cases where the good in question is a short-term reduction in the probability of death. The good in question here has both short-term and long-term impacts on the probability of death and therefore there are plausible reasons for values other than one. The coefficients in the regression models (other than the Tobit) are such that while a t-test would reject the hypothesis of one, at the 5% confidence level it would not at the 1% confidence level, suggesting that the predictions of the model conform to theory and result in scope sensitive responses[17]. Further, the 'Sequence' parameter (Table 3) tests whether one of the sequences (WTP for 1 month, 3 month and 6 month gains or WTP for 6 month, 3 month and 1 month gains – see Section 2) generated systematically higher responses. As it is statistically insignificant we conclude that the sequencing had no effect. Figure 4 shows diagrammatically the scope sensitivity of the pooled data with mean WTP, for the data with and without outliers, for the one, three and six month gains respectively.

[16] This should be viewed in conjunction with additional validity tests to be reported in section IV.
[17] Conventional t-tests indicate the mean WTP responses are statistically significantly different from each other at the 1% level (all t-statistics are greater than 7.0).

Figure 4. Mean Willingness to Pay and Scope Sensitivity



III.II VOLY Calculation

If a VOLY is calculated based on each individual's remaining life expectancy and the monthly payment they stated, but without applying discounting, the values of the VOLYs are, £17,869 when the six month data is used, £11,826 using the three month data and £11,596 using the one month data. Another way of approaching this is to take the mean vales of each of the variables and use 'average life expectancy'. We used the parameters from the Log-Log model to estimate an air pollution VOLY. Applying the mean value of each of the variables of the 'Log-Log' coefficients generates WTP annual values for one, three and six month gains in life expectancy of £15.12, £28.92 and £41.04 respectively. These were then used as the basis for the subsequent VOLY calculations of £14,152, £9,023, and £6, 402[18] whereby the VOLY is calculated under the assumption that we have a representative individual who will live for 78 years, following the rationale in Chilton *et al*. (2004)[19]. Note that we choose not to discount this calculation. In this case, we have no strong evidence to suggest that respondents, who represented all age groups, were not considering their WTP response in terms of current wealth (i.e. that a payment of £x/ in Y years time had the same purchasing power as a payment of £x now and, further, that real income was assumed to be more or less the same over the time period). So, for the purposes of this paper, we simply use a zero discount rate. However, it could be argued that even if correct, there may be grounds for discounting at either the public sector discount rate of 3.5% or the pure utility discount rate of 1.5% (as in the Treasury Green Book, Annex 6 [H.M. Treasury, 2003]).

IV. Validity

So far, this paper has outlined a new procedure for conveying information concerning gains in life expectancy to respondents in a stated preference survey. We claim that it addresses a key problem within empirical VOLY elicitation, that of describing and communicating the good to be delivered by an air pollution reduction policy i.e. the life expectancy change and, implicitly, that it does so in such a way that it constitutes a significant improvement on past practice, making all the additional effort worthwhile. A direct assessment of the accuracy of any values is of course

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[18] For the one month change in life expectancy this is: £15.12*12*78. For the three month gain this is: £28.92*4*78 and for the six month gain this is: £41.04*2*78.

[19] Chilton *et al*. (2004: footnote 16, p.35): "78 years is the mean period of time over which the benefit of a reduction in air pollution will be enjoyed by anyone *born after the reduction is effected*. However, if attention were to be restricted solely to the population *alive at the time of the introduction of the measure*, then the mean period over which its effects will be enjoyed by that population is approximately 44 years…" It is also shown that as the planning horizon increases the mean benefit approaches 78.

impossible. An alternative approach to validity might be to compare the results to existing studies in the literature but this is problematic. Any differences or similarities are in fact difficult to interpret unambiguously, given the confounds arising from different methods, samples, different sampling procedures and so on and so forth.

Instead, we carried out two further customised validity studies, termed studies 2 and 3. The quantitative based study (study 2), is a new WTP study on a similar demographic in Newcastle (n = 158), designed to mimic a conventional approach in which the length of the life expectancy gain is specified but no details are provided as to how it is generated. This is in the spirit of studies that compare different risk reduction methods, such as Morris and Hammit (2001) and Corso *et al*., 2001). For illustrative purposes, Appendix 2 contains the information given to respondents which was identical to the information given to respondents in the original study (Study 1) and the detailed question relating to the one-month gain in life expectancy only. Meanwhile, the qualitative based study (study 3) focuses on the 'face validity' of respondents' own descriptions of the good.

IV.I. Quantitative validity (study 2)

We choose here to focus on the number of zero bidders in the two samples, under the rationale that the level of understanding of the respondents could have an impact on this. Based on this, we hypothesise that study 1 should produce fewer zero bids in total. In addition, the increased level of understanding should generate fewer protest bids caused by reduced scenario rejection.

Table 4 compares rates of zero bidders in addition to differences in mean and median WTP generated by the two studies. There are clearly fewer zero WTP's in Study 1 and a test of proportions shows that the number of zero bids differs statistically significantly across the two versions for three months at the 3% level and six months at the 1% level, implying that our protocol had some effect. A similar test on protest zeros show fewer occurring in Study 1 at the 1% level for one, three and six months, which gives support to our hypothesis.

Table 4 Mean Monthly WTP for a One, Three and Six Month Gain in Life Expectancy in the UK

	Study 1				**Study 2**		
	WTP 1 month	WTP 3 months	WTP 6 months		WTP 1 month	WTP 3 months	WTP 6 months
Total number of respondents	152	152	152		158	158	158
Zero WTP	109	78	52		119	97	81
Protest Zeros	43	38	22		67	53	40
Mean WTP (£) (Std. Dev.)	6.62	8.86	14.45		18.44	47.88	109.32
Mean WTP excluding protest Zeros (£) (Std. Dev.)	9.22 (45.33)	11.81 (44.57)	16.90 (43.32)		32.45 (122.83)	71.13 (206.02)	145.50 (394.72)
Mean WTP excluding protest Zeros and 3 outliers top and bottom (£) (Std. Dev.) 95% Confidence Interval	2.88 (7.93) (1.35 - 4.41)	5.91 (10.86) (3.86 - 7.96)	12.00 (17.44) (8.93 - 15.07)		15.91 (45.28)	40.10 (73.98)	94.80 (173.28)
Turnbull lower bound estimates	2.66	5.25	13.05				
Median WTP (£)	0.00	0.00	2.08		0.00	0.00	0.00
Median WTP excluding protest Zeros (£)	0.00	1.88	4.17		0.00	5.00	10.00

A t-test on mean WTP shows a significant difference across all life expectancy gains (t = 2.8 for one month, 4.7 for three months and 5.3 for six months). Similarly the variance of each distribution is significantly smaller for the original study at the 1% level (f = 0.3, 0.2, 0.1).]. So, once again, there is a clear impact.

IV.II. Qualitative Validity (Study 3)

A follow-up qualitative study[20] was carried out designed to address a number of issues relating to this study which are outwith the remit of this paper. However, the analysis of responses to two of the verbal probes included in this study is particularly pertinent here. At the end of the individual semi-structured qualitative interviews within the study, respondents (n=24) were asked:

• *So you said you'd pay £X for say a 6 month gain in life expectancy. If you were to explain to a friend when you went home what you were going to pay for, how best would you describe it to them*?

……

Followed by

• *Some people have described it as an additional 6 months at the end of their life. Would you agree with that?*

Responses were content analysed (Krippendorf, 1980) by two independent coders using the coding frame in Table 5 and carried out under consistently applied rules which were agreed upon in advance. The coding frame contained codes derived by two members of the research team from a randomly stratified sample of 5 interviews. The coding scheme was tested for reliability and further refined using 5 randomly

[20] We gratefully acknowledge funding from the British Academy Small Grants Scheme (grant number SG-45834) which enabled us to carry out this work.

sampled transcripts. The remaining 17 transcripts were analysed using the finalised coding scheme and a common set of coding instructions. The resulting codes were then tested for reliability and any discrepancies resolved through discussion'

The associated kappa statistic (Statacorp, 2007), which measures above-chance agreement by coders, is given in Figure 5, which can be interpreted in the following way. Assuming that each coder had allocated a code randomly (but with probabilities equal to the overall proportions, we would expect the coders to agree on 50.87 of the codings, as opposed to the 76.47% they actually agreed on (alternatively, 52.1% of the way between random agreement and perfect agreement. We can reject the hypothesis that the coders made their coding decisions randomly.

Table 5 Content Analysis Coding Frame

CODE	SUMMARY DESCRIPTION
EXTRANEOUS	Extraneous (to life expectancy changes) impacts of air pollution reduction (e.g. environment, quality of life, other people, altruism, health state at end of life)
CUMULATIVE GAIN	Indication that the benefits build up over their life time.
UNCERTAINTY	An acknowledgement of/reference to the fact that even if life expectancy increases you may not end up living longer (because for example, some other external risk might kill you prematurely, unknown genetic influence etc)
ADD-ON	Life expectancy is translated into guaranteed additional time at the end of life.
ADD-ON Y,N	Yes or No response to the probe: *Some people have described it as an additional 6 months at the end of their life. Would you agree with that?*

Figure 5 Coding Frame Reliability Statistics

Agreement	Expected Agreement	Kappa	Std. Err.	Z	Prob>Z
76.47%	50.87%	0.5211	0.2355	2.21	0.0134tt

Table 6 contains an example quotes associated with each code.

Table 6 Qualitative Codes: Example Quotes

CODE	EXAMPLE QUOTE
EXTRANEOUS	*"Er, no, because that implies that you were thinking about living another 6 months when you were 80 but I think it's more quality of life for me. That's how I looked at it. Better quality of life if you have less wear and tear on your body overall then it must be better quality of life rather than just having another 6 months added on."*
CUMULATIVE GAIN	*"NO, as I said, it's not a tagging-on. If you see it like that, like I'm going on holidays, then I'll pay it for an extra 6 months and I'll take it whenever, ah you're going to die and here's another 6 months, I'd say it's not. And you won't really know but like it won't be on your records you lived 6 months longer than you your score year s and four at the time it's not 6 months. It's still quite small at that. It's not measurable so to think like that. It's not realistic."*
UNCERTAINTY	*"I think you could probably compare yourself to your parents who have lived through all he pollution and whatever and when compared to them you would think you were doing better than they were at that age so you would comparing it that way and just looking at how fit they were age and whatever and what problems they had and if you compared them you may just see the difference over a longer period, do you know what I mean."*
ADD-ON	*"I'd say, you know, I would pay £21 pounds a month for the rest of my life for an extra six months at the end of my life."*

The first point to make before presenting our interpretation of the qualitative data is to remember that respondents were not given an 'examination' about their understanding of all of the concepts explained to them. They were asked to explain in their own words the 'good' that they had just 'bought' and to answer a question that, on the face of it, provided a much simpler (and potentially plausible) explanation. Interpretation of this type of qualitative data is not straightforward since failure to mention an important issue does not necessarily imply that it was not absorbed and understood by a respondent during the valuation task. There is the added possibility that notions that are perceived to be 'shared understandings' remain unspoken. For example, a respondent who is asked whether they expect to gain 6 months of life (in order to explore issues of uncertainty and expectancy) might reply 'yes' but not add 'if I live that long', or 'or thereabouts, it might be more or less than 6 months for me'.

In order to assess the overall face validity of our explanations, we do not count 'frequencies of mentions' of a code. The conventions that drive qualitative analysis dictate that it would be inappropriate to draw conclusions from counts such as these. Instead, we examined the final set of agreed codes in a holistic manner and tried to draw some general inferences and lessons for the future. The most striking finding was that a significant minority (seven) of transcripts did not contain any reference to the 'add-on' concept, focusing on the cumulative gain and/or uncertainty and that a small majority of responses (nine) contained a mix of desirable (cumulative gain; uncertainty) and 'undesirable' codes (add-on). The latter should be treated with some caution – of the nine respondents that answered 'yes' to the direct question only four verbalised this further elsewhere - but nevertheless we must acknowledge its presence.

The main conclusion that we draw is that most respondents had to a greater or lesser degree taken on-board some of our information. Only two further respondents failed to mention any desirable attributes at all and focussed entirely on the add-on concept. Less than half the transcripts (eight) contained references to extraneous attributes, mostly quality of life. While are unable to say definitively on the basis of this analysis that our efforts at information provision unambiguously perform better than any alternatives, if taken in conjunction with the quantitative validity test, it has made a difference.

V. Discussion and Conclusions

A critical reflection leads us to conclude that the resulting values - elicited under full disclosure from respondents who participated in an in-depth procedure designed to describe explicitly the way in which the life expectancy gain occurs following implementation of an ongoing air pollution programme - appear defensible, internally reliable and valid.

Nevertheless, our study, along with all others that we have seen to date, suffers from the potential criticism that since our respondents were not told the quantitative changes in conditional probabilities for the average person generating the life expectancy gain, they would be not be in a position to provide a fully informed valuation, assuming they could interpret these probabilities correctly. A protocol combining both qualitative and quantitative descriptions may be the ideal solution in the longer term, although the difficulty in distinguishing the individual from the average may ultimately be insurmountable, given the underlying epidemiology.

By focusing exclusively on the respondent's own health and safety, then altruistic concerns for the health and general wellbeing of other family members should, in principle, have had no impact on WTP responses. Studies which ask for a value at the household level (e.g. Chilton *et al*., 2004) may well be confounded by altruistic concerns. Of course, in principle, if such altruistic concerns were purely safety-focused, then their inclusion in the form of augmented WTP responses would be quite appropriate – see Jones-Lee (1982). If, by contrast, altruistic concerns took the "pure" form, then presumably respondents would have taken account of the fact that other household members would have to "bear their share" of the cost of reducing the adverse health effects of air pollution and would have taken account of this in giving their WTP responses. By eliciting 'self-focused' individual WTP these issues related to altruistic concern are avoided, or at least their impact should be reduced.

Finally, as argued in Section 2, introducing individual uncertainty might reasonably be expected to influence WTP. Due to the inevitable resource constraints, we were forced to adopt an experimental design which involved the introduction of two new concepts, namely the 'ability to survive' function and person-specific uncertainty related to health state etc., into the same survey. As a result, we are unable to disentangle the separate effects related to each of these two concepts and have, instead, only been able to observe their combined, positive impact via the scope test.

If there exists little individual uncertainty – or individuals do not care about it - then procedures which concentrate on 'average' gains might be more or less sufficient and less cognitively taxing, with the proviso of the need to demonstrate scope sensitivity.

However, if ‘average’ values mask a high degree of individual heterogeneity then studies which build on the approach adopted in this study may be more appropriate. While our respondents appeared capable of considering their own relative current and future health state and accepting the fact that they may die prematurely from another cause, anecdotally at least from debriefings it seemed to us they were unable to synthesise this fully into their valuations. Assisting respondents in this is therefore an important priority to be addressed in future research in this area, ideally in conjunction with the development of mechanisms or explanations that clarify further the notion of ‘expected’ gains and quantitative changes in underlying conditional survival probabilities. If researchers in this field do not address these challenges to the degree that it is possible to do so then we must all question the validity of our VOLY values arising from our surveys.

Appendix 1

Treating the present as "time zero" and denoting the time of an individual's death by $t(\geq o)$, there would appear to be five (statistically equivalent) possible ways of conveying the information concerning the impact of a reduction in air pollution on an individual's survival prospects, namely:

1. Specification of the perturbation in the individual's *probability density function* for time of death, f(t).

or,

2. Specification of the perturbation in the individual's *cumulative distribution function* (or "*lifetime" distribution function)* for time of death, F(t) = $\int_o^t f(x)dx$ which gives the probability that the individual will die *before* time t.

or,

3. Specification of the perturbation in the individual's *survival function*, S(t) = 1 – F(t), which gives the probability that the individual will survive until *at least* time t.

or,

4 Specification of the perturbation in the individual's *hazard function* $h(t)=\frac{f(t)}{S(t)}$ which gives the probability density for death at time t *conditional on having survived until that time.*

or,

5. Specification of the impact upon the individual's *remaining life expectancy* $\int_o^T t\, f(t)dt$ where T is the latest time until which the individual could conceivably survive. Given the definitions of f(t), F9t) and S(t) it follows from elementary integral calculus that remaining life expectancy is equal to the area under the survival function.

* It would be highly unlikely that respondents realised that a survival function drove the exact magnitude of the shift of the ability to survive curve and, further, intuitively interpreted this shift in the survival function (correctly) as reflecting a proportionate reduction in the hazard rate from $h(t)$ to $\hat{h}(t) = kh(t)$, $o < k < 1$, or by contrast (strictly incorrectly) as reflecting a "parallel" rightward shift by a given time-change of α in the survival function from S(t) to $\hat{S}(t) = S(t - \alpha)$. Even if k was such that the gain in life expectancy resulting from the proportionate hazard rate reduction was equal to the magnitude of α in the "parallel" rightward shift, purists would nonetheless point out that the changes in the underlying density function for time of death differed between the two cases, so that a respondent's interpretation of the probability associated with their time of death might also differ, even though the impact on life-expectancy was the same. However, admittedly somewhat to the research team's surprise, it transpires that with S(t) specified so as to reflect UK mortality statistics, the change in the *variance* of t resulting from the two different types of perturbation in S(t) is, to all intents and purposes, effectively identical provided that the increase in life expectancy is the same.

Appendix 2

AIR POLLUTION STUDY 2

Life expectancy is the number of years you can expect to live, depending on how old you are now. For example a baby girl born today has a life expectancy of 83 years, and a baby boy has a life expectancy of 76 years. Of course it is an average calculated for the whole population. The table below shows remaining life expectancy for different ages

YOUR REMAINING LIFE EXPECTANCY
(BASED ON AN AVERAGE OF THE POPULATION OF YOUR AGE)

Age	Men	Women
Birth	75	80
20	55	60
30	45	50
40	36	41
50	27	31
60	19	23
70	12	15

It has been shown that the daily inhalation of air pollutants gradually damages the body and accelerates the aging process. Individuals (of all ages) who are already more vulnerable because they suffer from respiratory or cardiovascular illnesses are more sensitive to air pollution than the averag eperson because it aggravates their symptoms.

By reducing the general level of air pollution, everyone would not suffer as much wear and tear and thus would not age as fast. Average life expectancy would therefore be increased. If life expectancy was increased by for example 1 month, this means that the average person might live one month longer.

The government could introduce a policy and/or legislation to reduce air pollution to a lower level. This new, lower level of air pollution would remain so long as the policy was in place and would be funded through slightly higher prices (an increase in everyones' cost of living)

Question 1(a).

How beneficial do you think this would be for you personally if life expectancy was increased by **1 month.** Please tick one.

A "very unbeneficial" ☐
B "fairly unbeneficial" ☐
C "make very little difference" ☐
D "fairly beneficial" ☐
E "very beneficial" ☐

Question 1(b) as 1 (a), but 3 months

Question 1(c) as 1 (a), but 6 months

Question 2

Please answer Yes or No

(a) I would be willing to pay something in principle to extend life expectancy by **1 month** while living in my normal state of health?

YES □
NO □

IF NO, GO TO QU. 3(a)

IF YES:

Bearing in mind what you can afford and other things you would like to spend your money on, what is the:

Maximum amount you would be willing to pay each year to extend life expectancy by **1 month** £ _________?

Imagine instead that it was 3 months…
Imagine instead that it was 6 months

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