Willingness to Pay for Mortality Risk Reduction Associated with Air Pollution in São Paulo*

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Contents: 1. Introduction; 2. Background and Previous Work; 3. The Survey; 4. Results; 5. Conclusion.

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Epidemiological studies report significant association between air pollution and cardiovascular and respiratory mortality. Governmental intervention is required to implement policies aiming to increase air quality, and cost-benefit analysis can be useful to evaluate such policies. Reductions in risks of death are arguably the most important benefit underlying air-quality policies, and therefore need to be valued in money terms. This paper presents a contingent valuation study conducted in São Paulo to estimate the population's willingness to pay (WTP) to reduce their risk of death and the correspondent value of a statistical life (VSL). Results ranged between US$ 0.77 – US$ 6.1 million.

Estudos epidemiológicos associam a poluição atmosférica a mortes por doenças respiratórias e cardiovasculares. Nesse contexto, políticas governamentais que melhorem a qualidade do ar são necessárias e a análise de custo-benefício dessas políticas impõe que se estime, em termos monetários, o mais importante benefício associado a essas políticas: a redução do risco de morte da população. Este trabalho apresenta um estudo de avaliação contingente realizado em São Paulo que estima a disposição a pagar (DAP) da população para reduzir seu risco de morte e o valor de uma vida estatística (VVE). Os resultados variam entre US$ 0.77 – US$ 6.1 milhões.

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1. INTRODUCTION

Air pollution is one of the most serious environmental health risks in developing countries and in particular in big cities like São Paulo. As a consequence of its economic dynamics and high population density, the population faces serious environmental problems, such as high air pollutant concentration levels. In addition, given its geographic characteristics, São Paulo is subject to thermal inversions that can lead to the increasing accumulation of atmospheric pollutants (Saldiva et al., 1995).

Several studies have reported significant associations between urban concentrations of air pollution and all-cause mortality, cardiovascular mortality, and respiratory mortality, plus deaths due to more specific causes such as pneumonia and chronic obstructive pulmonary disease. Studies have provided evidence that fine particulate matter (PM10) is the most harmful pollutant for human health (Saldiva et al. (1994, 1995); Gouveia and Fletcher (2000)). Pollutants such as sulphur dioxide (SO2), nitrogen dioxide (NO2) and ozone (O3) have also been related to health events (Pereira et al. (1998); Gouveia and Fletcher (2000)).

A government intervention is required to implement policies that aim to improve air quality, and cost-benefit analysis can be a useful tool to evaluate the environmental-policy options. The monetary evaluation of the health effects is an essential input to the cost-benefit analysis of any air-quality policy assessment, since these health effects are likely to correspond to the major component of the benefits of policies to improve air quality. Reductions in the risk of premature death are widely believed to be the most important benefit underlying many environmental programmes, including those related to reduce air pollution ("...in two recent analyses of the benefits of US air quality legislation... over 80 percent of monetized benefits were attributed to reductions in premature mortality" – Krupnick et al. (2002)). Thus, when undertaking a cost-benefit analysis of environmental programmes that reduce air pollution, it is important to estimate the benefit of reducing risks of death.

This study aims to estimate the population's willingness to pay (WTP) to reduce risks of death associated with "typical" air pollution policies and, consequently, the value of a statistical life (VSL) in São Paulo, Brazil. Uniquely for that country, the study uses a methodology that has previously been tested in several industrialised countries (USA, Japan, Canada, South Korea, England, France and Italy) and involves a computer-based contingent valuation survey. This survey instrument was adapted to the Brazilian context and used to elicit willingness-to-pay measures of reductions in risk of death in Brazil. Key features of the survey instrument involve eliciting the health status of the respondents and their family; explaining basic concepts of probability, and proposing simple practice questions to familiarise the respondents with the probabilities concepts introduced; presenting the leading causes of death for a Brazilian individual of the respondent's age and gender, and setting these in the context of common risk-mitigating behaviours; and finally, asking individual's willingness to pay for risk reductions of a given magnitude that occur at a specified time.

This paper provides details of the survey assumptions and elicitation instrument; a descriptive analysis of the obtained sample; and the (parametric and non-parametric) willingness-to-pay estimates for different risk reductions. The results suggest a value of a statistical life (VSL) in São Paulo ranging between US$ 0.77 – 6.1 million, while our suggestions for VSL in policy analysis range between US$ 0.77 – 1.31 million. It is organised as follows. The next section presents a review of related work followed by the description of the survey instrument. The results are presented in Section 4 whilst the conclusions are given in Section 5.

2. BACKGROUND AND PREVIOUS WORK

Researchers have identified two alternative general approaches for valuing the benefits of lifesaving activities, including those associated with environmental programmes: the human capital approach and the willingness-to-pay approach (Cropper and Freeman (1991); Shepard and Zeckhauser (1982);

Berger et al. (1994); Johansson (1995)). The first approach, based on human capital, estimates the economic productivity of the individual whose life is at risk. It uses an individual's discounted lifetime earnings as its measure of value, assigning valuations in direct proportion to income. The willingness-to-pay approach assumes that the preferences of individuals can be characterised by substitutability between income and safety, that is, individuals make trade-offs between consumption of goods or services and factors that increase consumer's safety. The trade-offs reveal the values individuals place on their safety or on the reduction on the risks of death.

The willingness-to-pay approach has its basis in the premise that changes in individuals' economic welfare can be valued according to what they are willing (and able) to pay to achieve that change. According to this assumption, individuals treat longevity like a special consumption good and reveal their preferences through the choices that involve changes in the risk of death and the consumption of other economic goods whose values can be measured in monetary terms. That is, in many situations individuals act as if their preference functions include life expectancy or the probability of death as arguments, and make a variety of choices that involve trading off changes in their risk of death for other economic goods.

The focus of the willingness-to-pay approach relies on the individualistic dimension of human behaviour, which means that the expressed willingness to pay to reduce the probability of death refers to an individual's own risk. The underlying assumption is that individuals are the best judge of their own welfare and that even in matters involving life and death individual preferences must be considered. Thus, the willingness-to-pay measure can be seen to be a reasonable one for use in cost-benefit analysis. However, because the probability of surviving is a normal good, income differences rather than preferences can explain some of the variance in willingness-to-pay estimates.

The theoretical framework that has been used to develop economic models that define willingness to pay for a change in health risks is based on economic models of individual choice that focus on the conditional probability of death under uncertain lifetime. Such models are based on the interplay between the 'impatience' to consume and the productivity of resources. The models offer insights into consumption, saving, investment, portfolio selection and purchase of life insurance and annuities (Yaari (1965); Shepard and Zeckhauser (1982)). They are based on the assumption that individuals maximise their expected utility by choosing among alternatives, some of which change their risk of dying. Thus, the willingness to pay for a reduction in the risk of death is the maximum amount that can be taken from the individual without reducing his or her expected utility.

The value of a statistical life is a convenient metric for evaluating policies that reduce risk of death and is represented as the total willingness to pay for the policy that results in one less death in the population. Johansson (1995) defines the value of a statistical life as the aggregate willingness to pay for a measure saving a number of lives divided by the number of lives saved. The appropriate measure of the value of a statistical life from the point of view of government policy is society's willingness to pay for the risk reduction. It is expected that the value of a statistical life may vary with the type of the risk involved in the analysis – if voluntary or involuntary, the initial risk level, the size of the risk change, age and income (e.g. (Freeman, 2003, p. 318); Johansson (1995)).

Several empirical methods have been used to estimate willingness-to-pay measures; among them the most popular are the "compensating-wages" method, contingent valuation, and the averting behaviour method. The 'compensating-wages' method uses labour market data on wage differentials for jobs with different levels of health risks, assuming that workers understand the workplace risk involved, and that the additional wage that workers receive when they undertake risky positions reflect risk choice. In other words, the 'compensating-wage' approach relies on the assumption that workers will accept exposure to some level of risk in return for some compensation.[1]

[1] The reader can refer to Viscusi and Aldy (2003), Mrozek and Taylor (2002) and Dionne and Lanoie (2004) for a complete literature review of compensating-wage studies.

The averting behaviour method assumes that individuals spend some of their money on activities that reduce their risk of death, such as buying smoke detectors, and that these activities are pursued to the point where their marginal cost equals their marginal value of the reduced risk of death. The marginal costs incurred by individuals to reduce their probability of death are used to value individuals' willingness to pay to reduce their risk of death. The relevant measure of the effect of the averting behaviour on risk of death is, according to Cropper and Freeman (1991), the individual's perception of this risk reduction. Although this is a potentially useful technique, in practice there are often difficulties in evaluating such perceptions in an appropriate quantitative form.

Contingent Valuation is a survey method in which respondents are asked to state their preferences in hypothetical or contingent markets, allowing analysts to estimate demands for goods or services that are not traded in markets. In general, the survey draws on a sample of individuals who are asked to imagine that there is a market where they can buy the good or service evaluated, stating their individual maximum willingness to pay for a change in the provision of the good or service, or their minimum compensation (willingness to accept) if the change is not carried out. Socio-economic characteristics of the respondents – gender, age, income, education etc. – and demographic information are also obtained. If it can be shown that individuals' preferences are not random, but that instead they vary systematically and are conditioned to some observable demographic characteristics, then population information can be used to forecast the aggregate willingness to pay for the good or service evaluated. There is a large body of literature on the appropriate use of the contingent valuation method (e.g. Mitchell and Carson (1989); Bateman et al. (2002)).

In the context of mortality risk associated with air pollution, some studies have used the contingent valuation framework to elicit willingness to pay for a reduction in risks of death (Krupnick et al. (1997, 1999, 2002); Alberini et al. (2004, 2006)). The common feature of these studies is that they all reject 'compensating-wage' estimates of the value of a statistical life for valuing risk changes produced by air pollution reduction programmes. The main reason they give is that 'compensating-wage' estimates are measures of compensation received by working-aged individuals for immediate risk reductions whilst, according to the epidemiological literature, the significant correlation between air pollutants and deaths occurs among people over the age 65 (Pope et al. (1995); Schwartz (1991, 1993); Schwartz and Dockery (1992a,b); Gouveia and Fletcher (2000); Saldiva et al. (1995)).

Alberini et al. (2006) reported the results of three case studies developed in Europe using the Krupnick et al. (1997) methodology that had previously been applied to the US, Canada and Japan. WTP values were derived from surveys undertaken simultaneously in the UK, France and Italy, using a common survey instrument. Table 1 summarises the results of the contingent valuation studies that have used the same survey instrument to estimate annual willingness to pay for changes in probabilities of death. In these studies, the implied value of a statistical life was calculated for risk change occurring over a ten-year period.

3. THE SURVEY

The survey instrument, first developed by Krupnick et al. (1997, 1999, 2002), was adapted to the Brazilian context. For example, the baseline risks per age and gender were estimated from official Brazilian life tables; the main causes of death presented to respondents were based on official statistics; questions relating to race were removed from the questionnaire because there are no mortality statistics in Brazil disaggregated by race; and questions related to religious matters were not specific to any religion, given the multitude of religions and sects in Brazil. The general structure of the computer-based survey instrument is as follows:[2]

[2] The reader can refer to Krupnick et al. (1997, 1999, 2002) and Alberini et al. (2004, 2006) for a complete description of the survey instrument and the methodological justification of its characteristics.

Table 1 – Summary of annual WTP for different risk reductions and the implied VSL – US$ 2002

Country		(WTP)		(VLS)		Annual household income(sample)	
	Risk reduction	Median	Mean	Median WTP	Mean WTP	Median	Mean
US$^{(a)}$						55.000	53.000
	5-in-1000	350	770	700.000	1.540.000		
	1-in-1000	111	483	1.110.000	4.830.000		
Canada$^{(a)}$						50.000	46.800
	5-in-1000	253	466	506.000	933.000		
	1-in-1000	131	370	1.312.000	3.704.000		
Japan$^{(b)}$						51.855	63.000
	5-in-1000	113	—	193.000	—		
	1-in-1000	50	—	427.000	—		
UK						42.146	43.677
	5-in-1000	422	802	844.000	1.604.000		
	1-in-1000	96	360	960.000	3.600.000		
France						34.872	35.061
	5-in-1000	522	—	1.043.573	—		
	1-in-1000	—	—	—	—		
Italy						27.233	43.698
	5-in-1000	788	1.577	1.576.000	3.154.000		
	1-in-1000	336 760	3.360.000	7.600.000			

Notes: Adapted from Alberini et al. (2004, 2006); (a) US$2000; (b) US$1999; Krupnick et al. (1999).

- *Initial comments about the survey* (e.g. informed the respondents that it was part of a strictly academic – non-commercial – research, followed by a statement of its general objectives);
- *Elicits respondent's age and gender*;
- *Elicits the occurrence of cancer, cardiac and respiratory diseases in the respondent's family and his or her own*: One purpose of these questions was to encourage the respondents to think about their health before responding to the willingness-to-pay questions;
- *Illustrates the concept of probabilities*;
- *Presents baseline risks per age and gender*: the Brazilian life-table statistics were used to provide the risk of death of an average individual of the same age and gender. The purpose of this was to help respondents better appreciate the context of mortality risks and to show them the effect of age on baseline risks in ten-year increments;
- *Examples of life-saving activities and associated costs* (e.g. use of medication). The purpose of these explanations was to illustrate that in everyday life respondents do pay small amounts of money to reduce their mortality risks.
- *Probability tests of comprehension*: the survey instrument introduced the concept of probabilities to the respondent, and specifically the probability risks of death, testing for comprehension of the

concept. The comprehension test was performed by describing two hypothetical people identical in every way, apart from the fact that one had a 5-in-1000 chance of dying over the next 10 years while another had a 10 in 1000 chance of dying over the next 10 years;

- *Willingness-to-pay questions*:
  - WTP for a *5-in-1000 risk reduction* in the next ten years:[3] "Suppose that the Health Ministry had approved a new product that, when used over the next ten years, would reduce your chance of dying from a disease or illness. This product would reduce your total chance of dying over the next ten years from X to Y. If you were to take this product you would have to pay the full amount of the cost out of your own pocket each year for the next ten years. For the product to have its full effect, you would need to use it every year for all ten years. In answering the next questions, please assume that the product has been demonstrated to be safe and effective in tests required by the Government. Keeping in mind that you would have less money to spend on other things, would you be willing to pay R\$ $\times$ per year for the next ten years (totalling R\$ $10\times$) to buy this product?" Depending on the respondent's answer, another dichotomous choice question was posed (follow-up question) with a greater bid value if the response to the initial question was affirmative or a lower bid value if the initial response was negative. Following these questions a final question (open-ended format) asked what would be the maximum value the respondent would be willing to pay for the product;
  - WTP for a *1-in-1000 risk reduction* in the next ten years using the same format as before: dichotomous choice format with follow-up question followed by an open-ended question;
- *Debriefing questions* of the questionnaire and the good being valued. The debriefing questions were intended to elicit the respondent's perceptions regarding aspects of the survey. Answers to these questions were used to explain variation in stated willingness to pay.
- *Short-form SF-36 questions*:[4] questionnaire designed to enable the construction of physical and mental health scores that measure symptoms of psychological distress (detailed in (Krupnick et al., 2002, annex));
- *Socio-economic questions* (e.g. income, marital status, education);
- *Confirmation or update of WTP values*.

The surveys – pilot and final – were conducted in São Paulo, Brazil, in October-November 2002 and March 2003, respectively. At the outset of the pilot survey a series of institutions that work with mature people in São Paulo were contacted. From these contacts, four universities and a bank allowed the survey to be conducted on-site, on their students/employees. The surveys in the universities involved mainly socio-economic classes B and C, described as upper and lower middle classes. During this initial phase of the survey there were no specific sample selection criteria apart from the age of respondents being between 40 and 75,[5] and that the respondents should be resident in São Paulo. Given an observed

[3] Focus groups and pre-testing in North America showed that respondents find it considerably easier to conceptualise the possibility of dying in a 10-year period than over shorter periods (Alberini et al., 2004). Also, further testing of the questionnaire has shown that people are more able to understand a larger fraction (per 1000) than a smaller one (per 10000). In addition, the one-year risk change is implicitly approximated to 1/10,000 in ten years, which is in the appropriate range for capturing the risk reductions associated with reductions in pollution levels (Krupnick et al., 2002).

[4] Ware et al. (1994).

[5] Epidemiological studies suggest that the effect of air pollution is more severe among children and the elderly. This study focuses on the elderly although there is a growing concern about child mortality issues, which is the subject of specific projects currently undertaken by US EPA and OECD.

initial gender and age bias, the next procedure was to contract professional assistance for the sample selection of 150 extra interviews. The objective was to obtain a socio-economic and demographic respondent profile as similar as possible to the observed for the population of São Paulo. A total of 309 individuals made up the pilot sample.

For the final survey a professional recruitment firm was contracted for sample selection that used its own recruiting. The individuals filtered through this database were contacted by telephone and invited to attend an interview in a computer lab at an agreed date and hour. The criteria used in the sample selection involved residents in São Paulo, aged 40-75 (percentages per age interval reflecting the city population profile), a minimum level of literacy (able to read and write), belonging to A, B and C social classes (percentages reflecting the population statistics), and not having participated in the pilot survey.[6]

The reason for neglecting classes D and E was the high level of illiteracy that exists in these groups and the consequent possible misunderstanding of the probability concept within the questionnaire. Thus, given the limited financial resources for the research, we decided to concentrate the research effort on those groups more likely to be able to respond cogently to the survey. According to the last Brazilian official Census (IBGE, 2000), the population living in São Paulo had the characteristics shown in Table 2.

Table 2 – Statistics of the population of São Paulo – Age between 40 to 75 years

Social Group	%	Gender	%	Age group	%
A	7	Male	47,7	40-49	45,1
B	26	Female	52,3	50-59	29,3
C	36			60-69	19,2
D and E	31			70-75	6,4
				40-64	85,2
				65-75	14,8

Source: Fundação Seade (www.seade.gov.br).

4. RESULTS

Initially, a series of tests was performed on the data collected to assess the risk comprehension of the respondents and the WTP values provided. In general, it can be concluded that respondents had a poor understanding of the concept of probabilities. Two particularly important tests were those that identified individuals who had poor understanding of the probability concept or were not consistent when stating willingness-to-pay responses. We wished to investigate whether excluding those individuals from the sample would significantly modify our estimates. For comparison, we therefore used different sub-samples for all analyses: a full sample and two 'cleaned' sub-samples. The most important tests refer to 'the flags' 0 and 4. Flag 0 indicates respondents who reported inconsistent values in both risk reduction willingness-to-pay questions, i.e. reported a maximum willingness to pay (using

[6] Initially, a total of 300 individuals were contacted to attend the lab and answer the questionnaire, but heavy rains and a strike in the public transport system in São Paulo contributed to a large number of absentees. Also, budget constraints and the collaboration of different institutions during the pilot survey contributed for the pilot sample size being larger than the final sample size.

the open question format) lower than the bid he or she had already accepted to pay, or stated a maximum willingness to pay greater than an amount he or she had refused before. This would indicate that the respondent was not considering the bid values offered or was not paying sufficient attention while responding the questionnaire. Flag 4 refers to individuals who wrongly answered both probability tests in the questionnaire. The first test was performed after providing a series of explanations and examples of the concept of probability for all respondents. In case of a wrong answer, a second test was performed. If the respondent gave a wrong answer again, indicating a poor comprehension of the probability concept, then this respondent was given Flag 4 equal to 1. Table 3 shows the results.

Table 3 – Debriefs in the sample – Risk comprehension

Flag	Description	Occurrences	% of the sample with Flag equal 1
Flag0	Inconsistent WTP values for both risk reductions valued	81	28,6
Flag1	Wrong answer in the first probability test AND shows preference for having the higher risk of death	15	5,3
Flag2	Wrong answer in the first probability test AND initially shows preference for having the higher risk of death, but changed preference when asked to confirm	10	3,5
Flag3	Shows preference for having the higher risk of death	72	25,4
Flag4	Wrong answer in both probability tests	32	11,3
Flag5	Shows preference for having the higher risk of death and confirmed	28	9,9
Flag6	Respondent states that does not understood probability well	38	13,4

Table 4 introduces selected descriptive statistics of the sample. It should be noted that the survey targeted middle class and upper income individuals with an average (individual) annual income of approximately US$3,000 a year (a little lower than city's average annual per capita wage of US$3,725). The gender distribution of the sample, as well as the social group distribution, was fairly close to the population's distributions shown in Table 2.

Table 5 shows the bid values offered in the willingness-to-pay questions in the dichotomous choice format, whilst Table 6 presents the percentage of 'yes' responses to each bid value, for each risk reduction evaluated. Table 6 shows a high percentage of 'yes' responses even for the highest bid value, suggesting either that the bid values were too low or that individuals did not consider their income constraint when stating their preferences.[7]

Contingent valuation models with discrete choice questions allow the use of non-parametric distribution-free estimators of willingness-to-pay measures. When the pattern of willingness-to-pay responses is well behaved (e.g. decreasing acceptance of bid values as these values increase) the estimates of willingness to pay are not sensitive to the choice of distribution for the unobserved random component of individuals' preferences, or to the functional form of the preference function. However,

[7] We believe the latter is more plausible given, for example, the income differentials between US and Brazil. In the US study the bids offered corresponded to US$70, US$150, US$500, and US$725, almost similar to those finally used in our survey. However, official data reports "real average income from main job, received monthly by individuals more than 10 years old, occupied during the reference week for the metropolitan region of São Paulo in March 2003" equal to R$1.055,46 (US$310.43), or approximately R$12.665,00 (US$3,725) per year (www.sidra.ibge.gov.br/bda/tabela/), almost ten times lower than the US average.

Table 4 – Debriefs in the sample – Risk comprehension

Variable	Total sample	Without Flag0 = 1	Without Flag4 = 1
Observations (n)	283	202	251
% of male	44,9	45,5	45
Age – mean (stdev)	56 (9.46)	56 (9.46)	55 (9.3)
Household monthly income – mean (stdev)	R$ 1,185	R$ 1,277	R$ 1,230
	(R$ 1,590)	(R$ 1,710)	(R$ 1,664)
Individual monthly income – mean (stdev)	R$ 844	R$ 912	R$ 872
	(R$ 1,140)	(R$ 1,273)	(R$ 1,197)
Years of education	7.6 (4.2)	7.9 (4.2)	7.8 (4.1)
% has health insurance	43,8	41,6	42,6

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 5 – Bid structure (R$ 2003)

Group of Respondents	Initial payment Question	Follow-up question (If yes)	Follow-up question (If no)
1	240	600	120
2	600	1.800	240
3	1.800	2.700	600
4	2.700	3.600	1.800

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 6 – Percentage of 'yes' responses to the initial payment question

		Initial Bid (Brazilian R$)			
		240	600	1.800	2.700
5-in-1000 risk reduction over 10 starting now	Total sample	77,8	68,2	67,1	59,7
	Without Flag0 = 1	75,9	64,6	59,6	50
	Without Flag4 = 1	78,1	67,2	65,6	63,1
1-in-1000 risk reduction over 10 starting now	Total sample	70,8	51,5	43,8	54,2
	Without Flag0 = 1	66,7	37,5	26,9	39,6
	Without Flag4 = 1	68,7	53,4	45,3	58,5

when the distribution or the functional form may have some effect on the estimates of willingness to pay, the Turnbull non-parametric distribution-free estimator (Turnbull, 1976) can provide the basis for comparison with the parametric estimates of willingness to pay (Haab and McConnell, 2002).

Table 7 – Non-parametric (lower-bound) Turnbull estimation of annual willingness to pay (US$ 2003)

	5-in-1000 risk reduction over 10 years starting now			1-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	522,09	464,74	524,93	277,36	203,24	288,43

Estimates are distribution-free and conservative.

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 7 shows that the lower bound mean willingness-to-pay estimates are lower when individuals who gave inconsistent answers are removed from the sample (sub sample without Flag0 equal to 1). The observed decrease in mean willingness to pay was around 11% in the case of the 5-in-1000 immediate risk reduction, and approximately 26% for the 1-in-1000 immediate risk reduction. However, those estimates are higher when respondents that presented poor understanding of the concept of probability are removed (Flag4). Comparing the figures for the two different immediate risk reductions, it is observed that the lower bound mean willingness-to-pay estimates are consistently lower – approximately 50% – when the risk reduction being valued is lower (1-in-1000).

The parametric willingness-to-pay estimates followed the constant-only bid function model (Bateman et al., 2002), which may be used when the objective is to estimate mean and median willingness-to-pay values. In such situations, it is not as important to determine whether willingness to pay is systematically influenced by the respondents' characteristics. The mean and median willingness-to-pay values were estimated using the interval data model that can be generated from the dichotomous-choice with follow-up question format. The responses to willingness-to-pay and follow-up questions were combined to generate intervals in which the unobservable respondents' willingness to pay are to be found. It was assumed that the respondents' true willingness to pay is bounded by their income. That is, to generate intervals for willingness to pay given the answers to the dichotomous questions, the bound interval [0, annual income/2][8] was assumed when the respondent answered "no-no" and "yes-yes", respectively. Bounding willingness to pay is consistent with economic theory and leads to more reliable and plausible willingness-to-pay estimates (Haab and McConnell, 2002).

Different probability distributions were assumed for the random variable willingness to pay, with emphasis on the non-negative distributions, including the Weibull, exponential, lognormal and log-logistic distributions. In order to select the appropriate probability distribution, that is, the one with better goodness-of-fit to the sample data, the Akaike information criteria was used (Akaike, 1974) and the Weibull distribution was assumed. The statistical willingness-to-pay model using the Weibull distribution is estimated using the maximum likelihood method. The log likelihood function of the responses is defined as (Alberini et al., 2004):

$$\log L = \sum_i \log \left[F\left(WTP_i^U; \theta; \sigma \right) - F\left(WTP_i^L; \theta; \sigma \right) \right] \tag{1}$$

[8]This *ad-hoc* procedure assumes that half of individuals' annual income equals their disposable income. Income tax in Brazil is payable in two levels, 10% and 27.5%, according to earning levels. Other cumulative taxes, such as the compulsory contribution to social security, plus the high cost of living in São Paulo (e.g. housing) seem to suggest that this is a conservative assumption.

where (WTP^L) and (WTP^U) are the lower and upper bounds of the interval around the respondent's true willingness-to-pay value and $(F(WTP;\theta;\sigma))$ is the cumulative density function of the Weibull distribution with shape parameter (θ) and scale parameter (σ), defined as:

$$F(z;\theta;\sigma) = 1 - \exp\left(-(z/\sigma)^{\theta}\right) \tag{2}$$

Table 8 shows the parameters of the Weibull model for both risk reductions and Table 9 shows the results of mean and median estimates, according to Bateman et al. (2002).

Table 8 – Weibull accelerated failure-time model

	Total sample		Flag0 = 0		Flag4 = 0	
Regressors	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
5-in-1000 immediate risk reduction						
Constant	7,61154	0,08311	7,67814	0,10103	7,60078	0,08997
Ancillary parameter	0,83644	0,03642	0,8127	0,04066	0,822	0,03736
Log likelihood	-404,57076		-295,59862		-361,84367	
N	240		172		213	
1-in-1000 immediate risk reduction						
Constant	7,52176	0,08489	7,45842	0,0979	7,5381	0,09251
Ancillary parameter	0,81076	0,03391	0,80993	0,04049	0,7945	0,03451
Log likelihood	-420,68683		-317,18323		-373,77635	
N	245		185		215	

Notes: Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.
Flag4 = Wrong answer to both probability tests.

The mean and median willingness-to-pay estimates shown in Table 9 are consistent with the following criteria. First, the mean values are all greater than the non-parametric mean values, which are normally supposed to be lower-bound estimates of mean willingness to pay. Second, lower values for the smaller risk reduction are observed in all estimates. However, willingness-to-pay estimates for different risk reductions are not proportional to the reduction in risk, *i.e.*, the willingness to pay for a 5-in-1000 risk reduction is not five times larger than the willingness to pay for a 1-in-1000 risk reduction.

As can be seen in Table 10, neither mean willingness-to-pay estimates nor median values increase in proportion to the size of the risk reduction, although median willingness-to-pay estimates present a little more sensitivity to the size of risk reduction. Although the ratios suggest that the estimates fail the internal scope test, this failure is common to other results in the literature. For example, the ratios

Table 9 – Parametric estimation of mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI)

	5-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	653,47 (528.06 − 817.37)	712,06 (549.72 − 936.17)	653,95 (519.25 − 833.58)
Median	383,59 (337.82 − 434.17)	404,79 (346.36 − 471.03)	376,58 (327.93 − 430.92)
	1-in-1000 risk reduction over 10 years starting now		
Mean	609,99 (490.33 − 766.80)	572,95 (444.85 − 749.06)	629,02 (495.97 − 807.12)
Median	345,82 (303.42 − 392.96)	324,45 (279.35 − 375.19)	348,28 (301.67 − 400.75)

US$ 1 = R$ 3.40 during the survey period (March/2003).

Table 10 – Internal scope test: Are willingness-to-pay values proportional to the risk reduction?

Ratio 5-in-1000 / 1-in-1000 risk reduction over 10 years			
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	1,0713	1,2428	1,0396
Median	1,1092	1,2476	1,0813

observed in similar tests in US and Canada were 1.9 and 3.2 (median values), and 1.3 and 1.6 (mean values), respectively (Alberini et al., 2004).[9]

The validity test of the parametric willingness-to-pay estimates aims to test whether the respondents' willingness-to-pay values were influenced by socio-economic and behavioural factors, and if these factors are in accordance with economic theory. Following Bateman et al. (2002), a fully parameterised model should be estimated to establish the degree of non-randomness observed in the sample data. Typically, such variables include income, age, education, details of respondent's attitudes towards the good or service being valued, and information on respondent's current knowledge of the good or service. These variables were included as covariates in our willingness-to-pay model. This model does not necessarily have to make the same distributional assumptions as that used to estimate mean and median willingness to pay. However, the Weibull distribution was assumed again for ease of comparison with results presented in the literature (Alberini et al., 2001, 2006). The resultant statistical model is:

$$\log WTP_i = x_i.\beta + \varepsilon \tag{3}$$

[9] Hammitt and Graham (1999) discussed some reasons why stated willingness to pay many times are not sensitive to variation in risk magnitude. One possible reason, they argued based on the review of several studies, is that respondents might not understand probabilities or lack intuition for the changes in small probabilities of death risk. Other possibility involves the fact that respondents might not treat the given probabilities as given to them, suggesting that stated willingness to pay would not be proportional to the amount of risk reduction given to respondents, but should be proportional to changes in perceived risk. Finally, it is possible that respondents might not value changes in risk levels in a manner that is consistent with expected utility theory.

where (x) is a vector of individual characteristics and risk variables, (β) is a vector of parameters to be estimated and (ε) is the error term. Table 11 shows the covariates and their statistical significance. The figures refer to the 5-in-1000-risk reduction only.

Table 11 – Validity test – Willingness-to-pay for a 5-in-1000 immediate risk reduction

Weibull model	Total sample		Flag 0 = 0		Flag 4 = 0	
Regressors	Coefficient	Robust s.e.	Coefficient	Robust s.e.	Coefficient	Robust s.e.
Constant	8.9349(*)	2,1957	12.880(*)	3,3348	7.0682(*)	2,3275
Gender	0.1989(**)	0,1039	0.2638(**)	0,1304	0.2242(**)	0,1113
Age	-0,0523	0,6927	-0,1804	0,1037	0,0195	0,0746
Age square	0,0005	0,0006	0.0016(**)	0,0009	-0,0002	0,0007
Years of education	0,0087	0,014	0,0069	0,0191	0,0102	0,0155
Income	0.0006(*)	0,0001	0.0005(*)	0,0002	0.0006(*)	0,0001
If smoker	-0,1435	0,1154	-0,2413	0,1575	-0.2128(**)	0,123
Degree of faith in religion	-0,0266	0,0665	0,0125	0,0857	-0,0996	0,0801
Has health insurance	-0.2761(*)	0,1065	-0.3666(*)	0,1376	-0.2848(*)	0,1108
If respondent is married	0,0236	0,1301	-0,0359	0,1665	-0,0007	0,1418
Children	-0,0367	0,1813	-0,2714	0,2737	-0,0972	0,1996
Self-assessed comprehension of the concept of probabilities	0,051	0,0437	0,053	0,0667	0.0866(**)	0,0474
If respondent considered his/her finances when stating WTP	0.2174(**)	0,1254	0,2155	0,1671	0,1406	0,1338
Role limitation physical score	0.0036(**)	0,0019	0.0051(**)	0,0025	0.0058(*)	0,002
Energy vitality score	-0.0069(**)	0,0031	-0,004	0,0036	-0.0076(**)	0,0036
Subjective expected age of death	-0.0691(**)	0,0294	-0.0816(**)	0,0348	-0,0472	0,0324
Scale parameter	0,7437524		0,7490718		0,7504294	
N	240		172		213	
Log likelihood	-273,76743		-193,29854		-240,89826	

Notes: $^{(*)}$ significant at 1%; $^{(**)}$ significant at 10%.

The most important results in Table 11 relate to the significance level and positive sign of the individual income variable. As would be expected from economic theory, willingness to pay for a reduction in risk of death has a positive relation with the respondents' income, since reducing mortality risk is considered to be a normal good. Apart from income, the statistical significant covariates are not the same across the sub-samples. Among the statistically significant regressors are

(i) the self-assessed comprehension of the concept of probabilities;

(ii) a dummy variable indicating whether respondents considered their finances when stating willingness-to-pay values;

(iii) the energy vitality score;

(iv) the role limitation physical score;[10] and

(v) whether the respondent has any health insurance.[11]

Important socio-economic variables that would be expected to explain willingness-to-pay estimates but were not found to be significant include age, education and marital status. According to a correlation analysis performed in this study, these covariates were not significantly linearly correlated with income, which suggests that the importance of income in explaining willingness to pay did not affect the (low) importance of the other socio-economic covariates in explaining the dependent variable. Surprisingly perhaps, whether a respondent smoke or not was not significant in determining willingness-to-pay values (except in one sub-sample); one might have expected it to be significant since smokers already take greater mortality risks and since health risks associated with smoking are well established and advertised. Furthermore, the variable representing whether respondents have children, which might be interpreted to indicate that respondents' may have more concern about their future health and capacity for providing support, was also not statistically significant.

Very similar results were obtained when the same analysis was performed for the 1-in-1000 risk reduction willingness-to-pay estimates. The most important differences were that additional to income and other behavioural variables, respondents smoking or not, and the degree of religious faith were now statistically significant for some sub-samples. It is difficult to establish the reason why these behavioural attitudes are important in explaining willingness to pay for a smaller risk reduction while they are not significant to determine willingness to pay for a 5-in-1000-risk reduction. The negative sign of the coefficient relating to the degree of faith indicates that the more (subjectively) religious the respondents are the less their willingness to pay. This might be expected on the basis that the greater the faith the more the respondents transfer responsibility to the entities they believe in to protect them.

In order to confirm the validity tests performed with the final sample, the same model was executed with the pooled data; that is, appending the pilot sample to the final sample.[12] This makes it possible to investigate if the willingness-to-pay estimates are random or, instead, can be explained by some socio-economic and behavioural variables, regardless of the sample. That is, we can test whether the observed statistically significant variables remain significant when a different sample is considered. Adding the pilot sample into the analysis includes extra 309 respondents. Table 12 shows the results for the 5-in-1000 immediate risk reduction.

As can be seen in Table 12, the same set of variables that were significant in explaining the willingness to pay for a 5-in-1000 immediate risk reduction in the final sample are important in determining the willingness to pay for this risk reduction using the pooled data. The main difference relates to the education and health insurance variables, which are now statistically significant. The reason seems to be the higher education level observed in the pilot survey, one third of which constituted of students of Universities of the third age and highly qualified employees of a private bank.

Similar results were observed for the 1-in-1000-risk reduction. In general terms, the same set of regressors was important in explaining differences in willingness-to-pay values using the pooled data,

[10] Role physical limitation score "measures the extent of disability in everyday activities due to physical problems. Low score indicates problems with work or other daily activities resulting from physical health; high score indicates no problems with work or other daily activities as a result of physical health". Energy vitality health score is a "bipolar scale measuring energy level and fatigue; mid-range score indicates that the respondent does not report feeling tired or worn out; score=100 indicates that in addition, respondent feels full of pep and energy all of the time" (Alberini et al., 2004). Both scales range from zero to 100.

[11] Given the relevance of income in determining WTP estimates, it has been suggested that our results could have been disaggregated according to different income levels. Although we welcome the suggestion, the limited number of observations in our samples would not allow us to obtain statistically significant estimates for each income level. We did, however, estimate the income-elasticity of WTP in our sample and it was around 0.9 in all sub-samples, which is a bit higher (but broadly consistent) with estimates from other studies about mortality risk reductions.

[12] We thank Anna Alberini and other participants of the 14th Annual Congress of Environmental Economists for this suggestion.

Table 12 – Validity test – Willingness-to-pay for a 5-in-1000 immediate risk reduction (Pooled data)

Weibull model	Total sample		Flag 0 = 0		Flag 4 = 0	
Regressors	Coefficient	Robust s.e.	Coefficient	Robust s.e.	Coefficient	Robust s.e.
Constant	7.6057(*)	1,465	8.1527(*)	1,72	7.2762(*)	1,5477
Gender	0,0474	0,087	0,112	0,096	0,0335	0,091
Age	-0,0201	0,0481	-0,0402	0,0565	-0,0049	0,0512
Age square	0,0002	0,0004	0,0004	0,0005	0,0001	0,0004
Years of education	0.0467(*)	0,0108	0.0483(*)	0,0129	0.0483(*)	0,0115
Income	0.0004(*)	0,0001	0.0004(*)	0,0001	0.0004(*)	0,0001
If smoker	0,0782	0,1009	0,0587	0,1137	0,0706	0,1052
Degree of faith in religion	-0,075	0,0523	-0,0801	0,0633	-0.1200(**)	0,0602
Has health insurance	-0.4621(*)	0,0944	-0.4883(*)	0,1175	-0.4603(*)	0,101
If respondent is married	-0,0233	0,0915	0,0001	0,1012	0,0005	0,0971
Children	-0,1675	0,1582	-0,0965	0,1902	-0,1922	0,1731
Self-assessed comprehension of the concept of probabilities	0.0690(**)	0,0391	0,0416	0,0484	0,0706	0,044
If respondent considered his/her finances when stating WTP	0.3194(*)	0,1029	0.3836(*)	0,12	0.2641(**)	0,1059
Role limitation physical score	0,0013	0,0013	0,0005	0,0016	0,0018	0,0015
Energy vitality score	0,0003	0,0027	0,0017	0,0031	0,0001	0,003
Subjective expected age of death	-0,0154	0,0261	-0,0067	0,032	-0,0065	0,0293
Scale parameter	1,077121		1,088961		1,094792	
N	545		426		499	
Log likelihood	-926,86317		-773,14112		-856,33379	

Notes: (*) significant at 1%; (**) significant at 10%.

except that, the education variable is now significant. The variable relating to smoking is now not significant, possibly because of the effect of the education variable. From these results, it can be concluded that the willingness-to-pay estimates to reduce immediate probabilities of death in São Paulo seem to be robust, not sample-dependent, and not assigned randomly.

The corresponding values of a statistical life were estimated using both median willingness-to-pay estimates (conservative estimates) and mean willingness-to-pay values. They were obtained by dividing the willingness-to-pay figures by the corresponding annual risk reduction being valued. It was assumed that respondents implicitly considered the risk reduction evenly over the ten-year period, which makes it possible to avoid discounting the respondents' annual payments. Table 13 shows the results.

As can be seen in Table 13, the values of a statistical life estimated from 1-in-1000 risk reductions are much higher than those estimated using the 5-in-1000 risk reduction. This is purely due to the lack of proportionality between the willingness-to-pay estimates regarding the differences in the size of risk reductions (Table 10). It is suggested that the VSL estimates derived from mean and median willingness-to-pay estimates for a 5-in-1000-risk reduction are of greater policy relevance since they represent more conservative estimates than those estimated using willingness-to-pay estimates for 1-

Table 13 – Value of a statistical life using parametric estimation of mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI)

VSL	5-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	1.306.941 (1,056,127 − 1,634,736)	1.424.114 (1,099,432 − 1,872,330)	1.307.908 (1,038,495 − 1,667,161)
Median	767.187	809.587	753.159
	(675,649 − 868,349)	(692,728 − 942,062)	(655,851 − 861,846)
	1-in-1000 risk reduction over 10 years starting now		
Mean	6.099.858 (4,903,276 − 7,668,017)	5.729.545 (4,448,499 − 7,490,598)	6.290.223 (4,959,711 − 8,071,165)
Median	3.458.245 (3,034,213 − 3,929,572)	3.244.472 (2,793,533 − 3,751,852)	3.482.806 (3,016,684 − 4,007,517)

US$ 1 = R$ 3.40 during the survey period (March/2003).

in-1000-risk reduction.[13] Thus, for policy assessments in São Paulo it is suggested conservative values of a statistical life ranging between US$ 0.77 – 1.31 million.[14]

When compared with European and North American estimates these values seem to be higher than expected. Given the close link between willingness-to-pay estimates and the population income, lower willingness-to-pay values for developing countries might be expected. A possible reason for the high WTP and VSL estimates found in the current study might have been the 'cooperative' behaviour observed in many of the respondents. A possible bias might have been introduced by the use of an incentive payment (R$25 or approximately US$7.5) to each respondent for his or her participation in the survey. Evidence for such a bias arose from a number of comments made by respondents to the effect that they were keen to take part in this survey and other such surveys, since the cash incentive was important to them (minimum wage in Brazil was R$240 per month). It is possible that, those respondents tried to be "cooperative" or helpful by saying "yes" to every question. We believe that the relatively high figures in this valuation exercise may be partly due to this bias.

In order to test the hypothesis of "yeah-saying" responses, the mean and median willingness to pay were estimated using a sub-sample where the 'yeah-say' respondents were excluded. A 'yeah-say' respondent was considered to be the individual who accepted all bid-values offered in both immediate (5 in 1000 and 1 in 1000) risk reductions. Table 14 shows the results, which, however, cannot be claimed as better results than those presented in Table 13 since it is not possible to distinguish genuine 'yes' responses (those obtained after an implicit utility maximising process constrained by income) from 'yeah-say' respondents. In other words, the procedure adopted here may have excluded some genuine 'yes' responses from the sample.

This caveat can be regarded as a possible improvement for future contingent valuation studies in Brazil. On the other hand, as observed in Chesnut et al. (1997) for a study in Bangkok, in general health is seen as a basic necessity (like food or shelter) and those with lower incomes may be willing to pay a higher share of their income to protect their health (Chesnut et al., 1997).

[13] In this survey, the 1-in-1000-risk reduction question is asked after the 5-in-1000-risk reduction question. Prior testing in the North American context indicated that answers to the second question tend to be less reliable than those to the first question. It is also likely to be an easier size of risk change to effectively comprehend.

[14] Our results using cleaned sub-samples were not substantially different from our results using the total sample. Therefore, we suggest the latter set of results for policy analysis in Brazil.

Table 14 – Value of a statistical life using parametric estimation of mean and median annual willingness to pay (US$ 2003) – Weibull distribution (95% CI) – excluding possible 'yeah-say' responses

VSL	5-in-1000 risk reduction over 10 years starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	489.752 (416,964 – 579,800)	497.935 (415,596 – 602,039)	468.760 (395,384 – 560,497)
Median	415.831 (369,841 – 465,793)	416.643 (364,958 – 473,670)	398.711 (351,760 – 450,101)
VSL	1-in-1000 risk reduction over 10 years starting now		
Mean	2.412.626 (2,018,173 – 2,906,148)	2.436.371 (1,991,195 – 3,005,512)	2.319.842 (1,912,481 – 2,838,622)
Median	1.971.617 (1,728,805 – 2,241,120)	1.948.903 (1,675,951 – 2,258,600)	1.883.779 (1,633,927 – 2,163,724)

US$ 1 = R$ 3.40 during the survey period (March/2003).

A different metric has increasingly been proposed to represent premature mortality in the context of air pollution. This is the value of a statistical life year (VOLY, VSLY or VLYL), which arguably has a number of advantages over the VSL (e.g. Alberini et al. (2006)). The reader is referred to Rabl (2001) for further details. In order to compute the value of a statistical life year it is necessary to convert the probability changes of 1 in 1000 and 5 in 1000 into changes in life expectancy. For Europe, Rabl (2001) derives the changes in remaining life expectancy associated with the 5-in-1000-risk change over the next 10 years based on empirical life-tables. According to his calculations, the extension in life expectancy ranges from 0.64 to 2.02 months, depending on the person's age and gender, and averages 1.23 months (37 days) for a European sample Alberini et al. (2006). Similar figures were estimated for Brazil following Rabl (2001). The extension in life expectancy ranged between 0.12 and 1.92 for individuals aged between 40 and 70 years old. For an average individual in our sample (56 years old) this figure equals to 0.96 months or approximately 29 days.

To estimate the value of a life-expectancy extension of a month, we divided a respondent's willingness to pay by that respondent's life expectancy extension and re-estimated the Weibull double-bounded constant-only model. The resulting mean willingness to pay equates to US$1,329 per year for each month of additional life expectancy (total sample). Median willingness to pay by the same method is US$512 for a month of life expectancy gain. Because in our survey the payments would be made every year for ten years, the total willingness-to-pay figures for a life expectancy gain of one month are US$13,288 and US$5,116 respectively. The implied values of a statistical life year (VSLY) are US$ 159,456 and US$ 61,392, respectively.

5. CONCLUSION

Air pollution is one of the most serious environmental health risks in Brazil, particularly in São Paulo, the largest city in South America. The medical literature presents a number of studies linking air pollution with all-cause mortality and morbidity cases, suggesting that policies that aim to reduce air pollution can save lives by reducing the population's risk of death. Estimating the value of such benefit is a key input in to the estimation of the benefits and costs of policies that change individuals' probability of surviving.

This study used a methodology developed in North America, and making use of a contingent valuation survey instrument that was designed to estimate the willingness to pay for reducing individual's

Table 15 – Value of a statistical life year (VSLY) – 5-in-1000 immediate risk reduction – Weibull distribution

Total sample **including** 'yeah-saying' respondents			
	Total sample	Flag0	Flag4
Mean	159.456	176.515	141.811
Median	61.392	63.979	56.522
Sample **excluding** 'yeah-saying' respondents			
Mean	62.944	62.396	55.961
Median	34.729	34.404	32.954

US$ 1 = R$ 3.40 during the survey period (March/2003).

risk of death. This instrument was adapted to the peculiarities of the Brazilian context and used to estimate the willingness to pay for different reductions in probabilities of death. The results suggest a value of a statistical life ranging between US$0.77 and 6.1 million, while our suggestion for policy analysis is to use a range between US$0.77 and 1.31 million. The suggested value of a life year ranged between US$61,392 and 159,456.

We do, however, attach a health warning to these results since a number of problems seem to suggest that our figures are higher than would be expected for a middle-income country like Brazil. The most important problem that could be identified in this study refers to the 'yeah-saying' behaviour observed in some of the respondents. The results using a sub-sample that does not include potential 'yeah-saying' respondents suggest a value of a statistical life ranging between US$0.41 and 0.49 million, and the value of a statistical life year ranging between US$34,729 and US$62,944. As in the studies for industrialised countries, we find problems in eliciting the willingness to pay for risks of the kind experienced through air pollution. The issues that need most attention are

(a) getting the idea of probabilities across to a wider section of the population and

(b) understanding why willingness to pay for different risk levels does not behave consistent with expectations.

However, the analysis of our results and problems faced during this valuation exercise lead us to think that this study could be helpful for future developments of contingent valuation studies in developing countries.

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