

Willingness to Pay for Reduction in Immediate Risk of Mortality Related to Air Pollution in Sao Paulo, Brazil

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Abstract

Epidemiological studies report significant associations between urban concentrations of air pollution and cardiovascular mortality and respiratory mortality. In this context, a governmental intervention is required to formulate policies that contribute to increase air quality, and Cost-Benefit analysis may be an important tool to evaluate the environmental legislation. Reductions in risk of death are arguably the most important benefit underlying environmental programmes that aim to reduce air pollution. Valuing health benefits associated with air pollution require site-specific parameters that demand a great effort of research and data collection. This paper presents the results of a contingent valuation study conducted in Sao Paulo, the largest city in Brazil, in order to estimate the population's willingness to pay (WTP) to reduce their risk of death. The results suggest a value of a statistical life (VSL) ranging between US\$ 1.1 – 1.9 million.

1. Introduction

Sao Paulo is a large city with a remarkable industrial and economic strength. In consequence of its economic dynamics and also the high population density - more than 10 million people live within the urban area (IBGE, 2000) - the population faces serious environmental problems. For example, it presents one of the highest air pollutant concentration levels in the world. Furthermore, given its geographic characteristics, Sao 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 (Saldiva *et al.* 1994, 1995; Gouveia and Fletcher, 2000b). Studies have provided evidence of positive associations between air pollution and several mortality causes, suggesting that fine particulate matter (PM₁₀) is the most harmful pollutant for human health. 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, 2000b).

A governmental intervention is required to implement policies that aim to increase air quality, and Cost-Benefit analysis can be an interesting tool to evaluate the

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environmental legislation. The monetary evaluation of the health effects is an essential input to the cost-benefit analysis of any policy implementation, since these health effects seem to correspond to the major component of the benefits of policies to improve air quality. Reductions in risk of death are widely believed to be the most important benefit underlying many environmental programmes, including those concerned to reduce air pollution. Thus, when undertaking a cost-benefit analysis of environmental programmes that reduce air pollution, economists must estimate the benefit of reducing risks of death. The success of risk management policies is, arguably, judged in terms of their effect on individuals' expected utility. In order to allow reliable cost benefit analysis and maximise social benefits, it is necessary to estimate as accurately as possible how individuals value the changes in their probabilities of death caused by certain environmental policies or programmes.

This paper presents the results of a recent contingent valuation survey conducted in Sao Paulo to estimate the willingness to pay to reduce individuals' probability of death in Brazil. It is organised as follows. The next section presents a brief literature review followed by some survey characteristics presented in section 3. The results are presented in the sequence and the concluding remarks.

2. Literature review

Researchers have identified two alternative general approaches for valuing the benefits of lifesaving activities, including environmental programmes that reduce risks of death: the Human Capital approach and the willingness-to-pay approach (Cropper and Freeman, 1991; Shepard and Zeckhauser, 1982; Berger *et al.* 1994; Johannsson, 1995). The first approach, the human capital, estimates measures of 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 among consumption and goods or services that increases their safety. These 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 assumption 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 other consumption good and reveal their preferences through the choices that involve changes in the risk of death and other economic goods whose values can be measured in monetary terms. That is, in many situations individuals act as if their preference functions included 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. When what is being changed can be measured in monetary terms, the individual willingness to pay is revealed by these choices, which are the basis of measures of the economic value of reductions in the risk of death.

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 individual's own risk. The underlying assumption is that individuals are the best judge of their own welfare and even in matters including life and death, individual preferences must be considered. Thus, the willingness-to-pay measure is a reasonable one for using 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 have been used to develop economic models to define willingness to pay for a change in health risks is based on economic models of individual choice under uncertain lifetime, which focus on the conditional probability of death. Economic models of individual choice under uncertain lifetime are based in the interplay between the ‘impatience’ to consume and the productivity of resources. These models offer insights into consumption, saving, investment, portfolio selection and purchase of life insurance and annuities (Yaari, 1965; Shephard and Zeckhauser, 1982). They are based on the assumption that individuals maximise their expected utility by choosing among alternatives that change their risk of dying. Then, 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.

Willingness to pay (WTP) in the context of risks to life is defined as “the breakeven payment, per unit reduction in the probability of death, that leaves an individual’s overall expected utility unchanged.” (Shepard and Zeckhauser, 1982). In a more general context, the willingness to pay for a specific good or service is the sum of the amount of money individuals spend on the good or service plus the consumer surplus measure associated to the consumption of this good or service.

The value of a statistical life is a convenient figure 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. Alternatively, the value of a statistical life is given by the mean, over the affected individuals, of their marginal rates of substitution between income and risk. 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, which is the same benefit formulation used in all policy evaluation context. 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.

Several empirical methods have been used to estimate willingness-to-pay measures, among them the most popular are the compensating-wages method and contingent valuation. 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, it is drawn 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 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 obtained as well. If it can be shown that individuals’ preferences are not random, instead vary systematically and 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 knowledge on the method’s advantages and disadvantages (Mitchell and Carson, 1989).

In the context of mortality risk associated with air pollution, some recent studies using the contingent valuation framework to elicit willingness to pay for a reduction in risks of death have been developed in several countries (Krupnick *et al.*, 1997, 1999, 2000; Alberini *et al.*, 1997, 2001; and Cifuentes *et al.*, 1999; EC NewExt, 2003). The common feature of these studies is that they all reject Compensating Wages estimates of the value of a statistical life for valuing risk changes produced by air pollution reduction programmes. The main reason is that Compensation Wages estimates are measures of compensation received by working-aged individuals for immediate risk reductions and, according to the epidemiological literature, the significant correlation between air pollutants and deaths occur among people over the age 65. (Pope *et al.*, 1995; Schwartz, 1991, 1993; Schwartz and Dockery, 1992a, 1992b).

EC NewExt (2003) recently reported the results of three case studies developed in Europe using the same methodology applied to US, Canada and Japan. The report had as its objective the derivation of unit values to account in monetary terms for the incidence of premature death, estimated to result from air pollution in Europe. These values were derived from surveys undertaken simultaneously in UK, France and Italy, using a common survey instrument. Table 1 summarises the results of those contingent valuation studies that estimated annual willingness to pay for changes in probabilities of death in several countries. The implied value of a statistical life was calculated for a ten-years period.

Table 1: Summary of annual willingness to pay (WTP) for a immediate risk reduction and the implied value of a statistical life (VSL) – € 2002

Country	Risk reduction	(WTP)		(VSL)	
		Median	Mean	Median WTP	Mean WTP
UK	5-in-1000	387.6	736.3	775,104	1,472,640
	1-in-1000	88.2	330.8	881,920	3,308,160
France	5-in-1000	479	---	958,000	---
	1-in-1000	---	---	---	---
Italy	5-in-1000	724	1,448	1,448,000	2,896,000
	1-in-1000	309	698	3,090,000	6,980,000

3. The survey

Krupnick *et al.* (1997) first presented the survey instrument developed to fill some gaps in the contingent valuation literature concerning the elicitation of willingness to pay for reduction in risks of death. This survey instrument was adapted to the Brazilian specific characteristics and used to elicit the willingness-to-pay measure related to reductions in risk of death in Brazil². First, a brief introduction to the respondents regarding the survey informed the strict academic – non-commercial – purposes of the research, preceded by its general objectives. Follows some characteristics of the self-administered computer based survey:

- (i) Targeted the 40-75 years old population

² A especial acknowledgement here is devoted to Mrs Brigitte Desaignes, Laboratoire de Stratégie Industrielle – Université de Paris 6 Sorbonne, and Mr. Kene Bounmy, BETA - Université de Strasbourg, who developed the survey software adapted for the Brazilian case.

This feature was appropriate considering that the goal of the survey was to discuss reductions in mortality risks in the context of environmental policy, particularly regarding air pollution, and it is only in middle age that risks of death from air pollution related diseases - cancer, cardiovascular and respiratory diseases - become significant.

(ii) Mortality risks in annual risk changes during ten years intervals

The use of ten years intervals was important because allowed to represent risks in terms of chances per 1,000, which could be represented graphically, facilitating the respondents' comprehension of risk concepts. It was used graphs containing 1,000 squares to inform probabilities of death, where white squares denoted chances of surviving, red squares represented chances of dying, and blue squares showed reductions in the risk of dying. Because annual risk changes associated with air pollution policy are smaller than 1-in-1000, the risk change was expressed as change over 10 years. Baseline risks and payment schedules were also put in 10-year terms. The use of this mechanism was important to reduce potential scope problems.

(iii) General baseline risk per age and gender

After obtaining the respondent's age and gender, the Brazilian life table was used to provide the risk of death of an average individual of the same age and gender. The objective was to insert respondents into the context of risks of death and to show them the effect of age on baseline risks in ten-year increments. The respondents were presented a grid with red squares representing their 10-year baseline risks. This procedure, along with other specific features within the study, was intended to ensure that hypothetical bias was reduced.

(iv) Costs of life-saving activities

Examples of risk reducing activities, like visiting a doctor and taking medication, were provided along with a remind that these activities cost some amount of money, although no specific amount of money was provided. The reason for not illustrating the actual cost estimates involved the possibility of these costs anchoring later willingness-to-pay responses. Also, the purpose of these explanations was to illustrate that in every day life, respondents do pay small amounts of money to reduce their mortality risks. Furthermore, information was presented on age and gender specific leading causes of death and common risk-mitigating activities, both medical and non-medical.

(v) Concept of probabilities and test of comprehension

The survey instrument showed the concept of probabilities in general and specifically about risks of death, testing for comprehension of the basic concepts. The examples used involved coin flips and a throw of dice. The comprehension test was performed describing two people identical in every way, except that one had a 5-in-1000 chance of dying over the next 10 years while another had a 10 in 1,000 chance of dying over the next 10 years. The respondents were shown side-by-side grids of the risks for both people and asked to select which person had the largest chance of dying. In case of a wrong answer, an explanation was provided and another test was performed. Even if respondents could distinguish these risks, they might not feel that the difference in risk was significant. Therefore, it was asked which of these two people they would rather be or if they were indifferent.

(vi) Risk reduction as a private good

It was considered the method of delivering risk reductions as a private good rather than as a public good, that is, not covered by health insurance nor delivered by environmental programmes, which reduces the risk of death for all the population not only for the respondent. This feature could make the respondents think on their own risks and avoid the free-rider behaviour.

(vii) Health status

Respondents were asked whether they have ever been diagnosed as suffering from several diseases, like cancer and chronic heart or lung diseases. The same questions were posed in regard of the respondents' relatives, brothers and sisters. Individuals were asked to respond a series of questions in order to capture the severity of the disease and other chronic health condition, physical and psychological. These questions had several purposes, including encouraging the respondents to think about their health before responding to the WTP questions. From these questions, it was possible to construct physical health scores that measure symptoms of psychological distress. In addition, the respondents were asked to rate their current health relative to others of their age and gender, and to rate their expected health in ten years relative to their health today. They were also asked to rate their expected health at age 70 relative to their expected health in 10 years.

(viii) The willingness-to-pay questions

The respondents were asked to consider two risk reductions occurring over the following ten years, the first risk reduction reduced the baseline risk in 5 to 1,000, while the second change reduced the baseline risk by 1-in-1000. The willingness-to-pay question was presented to the respondents for each baseline risk reduction, and finally another willingness-to-pay question was introduced regarding future risk reductions (asked only for individuals aged 60 or less)³. A screen to elicit the strength of respondents' conviction in their willingness-to-pay responses followed each question.

The willingness-to-pay question format used in the survey was the closed-ended format or dichotomous choice format with follow-up question. This format involves offering a value (bid value) to the respondents and asking if they would be willing to pay that amount of money to buy the product that would reduce their probability of death in the following ten years. Depending on the respondent's answer, another dichotomous choice question with a different value was posed. The dichotomous choice elicitation method is supposed to reduce the possibility of strategic bias, while follow-up questions are used to allow the researcher to improve the statistical efficiency of the willingness-to-pay estimates obtained. According to Haab and McConnell, 2002, double-bounded models increase efficiency over single dichotomous choice models in three ways. First, the answers sequences 'yes-no' and 'no-yes' yield clear bounds on willingness to pay. For the 'no-no' and 'yes-yes' pairs, there are also efficiency gains due to additional questions, even when they do not bound willingness to pay completely, further constrain the part of the distribution where the respondent's willingness to pay can lie. Finally, the number of responses is increased, so that a given function is fitted with more observations, although statistically the number of

³ This last question is specifically important for valuing environmental improvements related to conventional air pollutants and carcinogens, given that the benefits related to the risk reduction involved occurs in the future while the costs of implementing such improvements are incurred in the present. The respondents were reminded that there is a chance they do not survive to age 70, making a payment today useless. The issue of chronic mortality (or mortality risks in the future) will be discussed in another forthcoming paper.

observations is not doubled, as there is correlation between responses from a single individual. Independently of both dichotomous questions' answers, in the sequence an open-ended question asked what would be the maximum value the respondent would be willing to pay for the product.

(ix) Debriefing questions

The debriefing questions intended to elicit the respondent's perceptions regarding the survey, the payment instrument and other aspects of the survey when answering the willingness-to-pay questions. Answers to these questions were used to explain variation in stated willingness to pay.

The surveys – pilot and final – were conducted in Sao Paulo, Brazil, in October-November 2002 and March 2003, respectively. The professional contracted for sample selecting was an experienced firm with its own database consisting of thousands of residents in Sao Paulo, their directions and socio-economic profile. The individuals filtered in this database were contacted by telephone and invited to attend an interview in a computer lab in an agreed date and hour⁴. An average of 70 interviews were performed per day, ten computers were used simultaneously from 9:00-19:00 daily. The criteria used in the sample selection involved residents in Sao Paulo, 40-75 aged (percentages per age intervals reflecting the population statistics), minimum literacy at least (read and write), A, B and C social classes (percentages reflecting the population statistics), and not having participated in the pilot survey (November-December, 2002).

The reason for neglecting classes D and E was the high level of illiteracy among poor people in Brazil, their possible misunderstanding of the questionnaire and probability concept, and also the very low-income level observed among them. Given the low budget profile of the research, it has been privileged those classes more likely to have the capacity of responding the survey, instead of taking the risk of wasting resources. According to the last Brazilian official Census (IBGE, 2000), the population living in Sao Paulo has the following characteristics:

Table 2: Statistics of the population of Sao 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: Fundacao Seade (www.seade.gov.br)

4. Results

Initially, it was performed a series of tests involving the risk comprehension and the monetary values informed by the respondents. Two of them were considered particularly important and are used in all statistics for comparison of the results. They refer to the flags 0 and 4. Flag 0 indicates the individual who reported inconsistent values in both risk reduction willingness-to-pay questions. It means, for example, that the individual reported a maximum willingness to pay lower than the bid he or she had

⁴ Initially, one can point out a possible bias referring to the fact that all respondents must have had a telephone to be invited for the interviews. But a quite usual procedure in Brazil involves those who cannot buy a telephone: they use someone else's numbers for an initial contact and then reply the call. In general, even in very poor communities some kind of public communal number is available.

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

Table 3: Debriefs in the sample – risk comprehension

Flag	Description	Occurrences n	% 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 has to be observed that although the survey has targeted middle class and upper income individuals the average (individual) income was still low, approximately US\$ 3,000 a year. The gender distribution of the sample, as well as the social group distribution, is quite close to the population's distribution showed in Table 2.

Table 4: Descriptive statistics of the respondents

Variable	Total sample	Without Flag0 = 1	Without Flag4 = 1
Observations (n)	283	202	251
% of male	44.9	45.5	45.0
Age – mean (stdev)	56 (9.46)	56 (9.46)	55 (9.3)
Household monthly income – mean (stdev)	R\$ 1,185 (R\$ 1,590)	R\$ 1,277 (R\$ 1,710)	R\$ 1,230 (R\$ 1,664)
Individual monthly income – mean (stdev)	R\$ 844 (R\$ 1,140)	R\$ 912 (R\$ 1,273)	R\$ 872 (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 shows the percentage of respondents who accepted given features of the scenario presented. The figures are similar among the different types of samples - total and cleaned samples, suggesting that those respondents who answered incorrectly to the probability tests and those who stated inconsistent maximum willingness-to-pay values had on average the same perceptions of the survey scenario. The relatively high percentage of respondents that had doubts about the product's effectiveness may have

influenced negatively the willingness-to-pay estimates, suggesting that these scenario acceptance variables have to be tested in the validity tests of willingness-to-pay estimates.

Table 5: Scenario acceptance

Percentage of respondents who...	Total sample	Without Flag0 = 1	Without Flag4 = 1
Did not believe the stated risks applied to them	22.3	23.8	20.7
Had doubts about the product's effectiveness	36.4	35.6	36.2
Had doubts about the product's effectiveness and stated that doubts affected WTP	12.7	11.9	12.3
Thought product might have side effects	36.4	35.6	35.1
Thought about other benefits of the product	48.4	46.5	50.2
Said other benefits influenced WTP	8.1	7.4	7.6
Did not understand the payment scheme	11.7	13.4	11.9
Did not consider whether they could afford the payment	24.7	27.3	25.5

Table 6 shows the values offered to the willingness-to-pay questions in the dichotomous choice format, while Table 7 presents the percentage of 'yes' responses for each risk reduction evaluated. It can be observed a high percentage of 'yes' responses even for the highest bids suggesting that the bid values were too low or individuals did not consider their income constraint when stating their preferences. The latter alternative is now assumed, since the highest bid (R\$2,700 a year) corresponds to approximately 2.4 times the average household monthly income.

Table 6: 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 7: 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	50.0
	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

Table 8: Respondents who reported willingness to pay equal to zero (%)

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
17.7	24.7	17.1	29.7	40.6	27.5
7.8	7.4	6.8	3.2	2.0	3.2
25.5	32.1	23.9	32.9	42.6	30.7

a) First line refers to possible protest responses, second line refers to inconsistent responses and third line is the total.

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 the estimates of willingness to pay are not sensitive to the choice of distribution for the unobserved random component of individuals' preferences, or for the functional form of the preference function. However, when the distribution or the functional form can have some effect on the estimates of willingness to pay the non-parametric distribution-free estimator can provide the basis for comparison of the parametric estimates of willingness to pay.

According to Haab and McConnell (2002), responses to discrete choice contingent valuation questions offer the researcher only limited information regarding each respondent's true willingness to pay. If the respondent says 'yes' then willingness to pay is greater or equal to the bid offered, whilst the answer is 'no', willingness to pay is less than the bid. The Turnbull estimator involves using the responses to the initial (dichotomous choice) payment questions, ignoring the follow-up questions responses, to compute the relative frequencies of the given willingness-to-pay intervals.

$$\left(E_{LB}(WTP) = \sum_{j=0}^M t_j \cdot f_{j+1} \right), \quad (1)$$

where:

$(t_j, j = 1, 2, \dots, M)$ are the distinct prices or bids offered to the respondent;

(M) is the number of distinct prices or bids offered;

$(f_j = F_j - F_{j-1})$ is the weight of the distribution falling between price (j) and the previous price. In this form, the vector of probabilities $(\mathbf{f} = f_1, f_2, \dots, f_M, f_{M+1})$ represents a discrete form of the density function.

This lower bound estimate of willingness to pay offers a conservative estimate of willingness to pay for all non-negative distributions of (WTP) , regardless of the true underlying distribution. The estimate produced in (1) represents the minimum expected willingness to pay for all distributions of (WTP) defined from zero to infinity, since $(E_{LB}(WTP))$ will always bound expected willingness to pay from below as long as the true distribution is defined only over the non-negative range.

Regarding the Turnbull median willingness-to-pay estimates, it can be provided a range in which it falls. Since the no-response proportions are consistent estimates of the distribution point masses at each price, the price for which the distribution function passes 0.5 is the lower bound on the range of median willingness to pay. Since the

Turnbull only gives point mass estimates at a discrete number of points, the median can only be defined within a range (Haab and McConnell, 2002, pp 72).

Table 9: Non-parametric (lower-bound) Turnbull estimation of annual willingness to pay (US\$ 2003) – final sample

	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
Median	> 794.12	794.12	> 794.12	529 - 794	70 - 176	176 - 529

Distribution-free and conservative estimates. US\$ 1 = R\$ 3.40 during the survey period (March/2003).

As can be seen in Table 9, it is observed that the lower bound mean willingness to pay are slightly, but consistently, higher when individuals with poor understanding of the concept of probability are removed from the sample. However, those estimates are (initially) lower when inconsistent respondents are removed. The observed decrease in mean willingness to pay was of around 11% in the case of the 5-in-1000 immediate risk reduction, and approximately 26% for the 1-in-1000 immediate risk reduction.

Regarding the parametric willingness-to-pay estimates, according to Bateman *et al.* (2002), the bid function explains the variation in willingness-to-pay response based on the change in the characteristics of a non-market good, prices of market goods, income and other socio-economic characteristics of the respondents. The theoretical background relies on an indirect utility function ($v(\cdot)$), that describes the maximum amount of utility a respondent can derive from his or her income, (y), given the prices of goods, (p), and the level of provision of the non-market good, (q). The individual utility function is assumed to be dependant on other demographic and economic factors, (s). A quantity (c) is defined as the maximum monetary payment that would ensure that the respondent's well being with the higher level of provision of the non-market good is equal to his or her well-being at the lower level of provision. In other words, (c) represents the compensating variation measure of a change in welfare, that is, is the respondent's maximum willingness to pay to achieve the increase in provision of a non-market good. In mathematical form:

$$v(y, p, s, q^0) = v(y - c, p, s, q^1) \quad (2)$$

The bid function can be written in general form as:

$$c = c(q^0, q^1, y, p, s, e) = WTP \leq y, \quad (3)$$

where (e) is assumed to be the part of willingness to pay that is determined by the unobservable tastes of the respondent for the non-market good.

The simplest specification for the bid function is given by the constant-only bid function model, and is of great importance in deriving estimates of the mean and median willingness to pay of a survey sample. It is specified as:

$$c = a + e \text{ and } 0 \leq c \leq y, \quad (4)$$

where (a) represents the location parameter of the assumed probability distribution, or the measure of central tendency of willingness to pay and corresponds to the 'average'

willingness to pay of respondents in the sample⁵. It is recommended the constant-only bid function estimation when the objective is to estimate mean and median willingness-to-pay values. In such situations, it is not interesting to determine if willingness to pay is systematically influenced by the respondents' characteristics. That is, it is desired that the (*a*) parameter be not represented as a function of covariates.

With this theoretical background in mind, the mean and median willingness-to-pay values were estimated for the interval data model, which can be generated from the referendum or dichotomous-choice with follow-up question format.

The responses for willingness-to-pay and follow-up questions were combined to generate intervals in which the unobservable respondents' willingness-to-pay are. This model offers the greatest increase in efficiency of willingness-to-pay estimates because it allows the analyst to identify smaller intervals where the unobserved true willingness to pay is. By combining the respondents' answers to both willingness-to-pay questions, more information on the distribution of willingness to pay is obtained and this information lowers the variance of the mean and median willingness-to-pay estimates.

It was assumed that the respondents' true willingness to pay are bounded by their income. That is, to generate intervals for willingness to pay given the answers to the binary-choice questions, it was assumed the bound interval [0, annual income] when the respondent answered 'no-no' and 'yes-yes', respectively. Bounding willingness to pay is consistent with the economic theory and leads to more reliable and plausible willingness-to-pay estimates (Haab and McConnell, 2002, pp 106).

Different probability distributions were assumed for the random variable willingness to pay, with emphasis to the non-negative distributions, including the Weibull, exponential, lognormal and log-logistic distributions. Non-negative distributions do not admit negative values for willingness to pay, which is a desired characteristic in this study since respondents should state a non-negative amount for the reduction is his or her risk of death. 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 (*AIC*) was used. Akaike (1974), proposed comparing each log likelihood adjusted by the specific number of parameters being estimated in a particular model. That is:

$$AIC = -2(\log \text{likelihood}) + 2(c + p + 1), \quad (5)$$

where (*c*) is the number of model covariates (in the case of this study $c=0$ for all distributions), and (*p*) is the number of model-specific ancillary parameters. Although the best-fitting model is the one with the largest log likelihood, the preferred model is the one with the smallest information criteria value. Table 10 shows the relevant figures.

Although the log-logistic probability distribution presented the best goodness-of-fit indicator according to the Akaike method, the Weibull distribution was assumed in this study for two reasons. First, the Weibull distribution is assumed in the majority of similar studies in the literature, which facilitates the comparison between the estimates. Second, the estimation of mean and median willingness-to-pay values is straightforward under the Weibull distribution. Finally, the log-logistic and Weibull

⁵ The majority of probability distributions assumed in contingent valuation studies are based on the parameters representing (i) central tendency (location parameter) and (ii) the spread of willingness to pay values (scale parameter) around the central tendency parameter.

models have similar goodness-of-fit indicators with the sample data, which supports the choice of the Weibull probability distribution.

Table 10: Goodness of fit of different non-negative willingness to pay probability distributions – Akaike procedure

	Weibull	Exponential	Log-logistic
Ancillary parameters	1	0	1
5-in-1000 immediate risk reduction			
Log likelihood	-507.50232	-547.00417	-495.63821
Akaike criteria	1,019	1,096	995
1-in-1000 immediate risk reduction			
Log likelihood	-517.66081	-567.25677	-498.93342
Akaike criteria	1,039	1,137	1,002

The statistical willingness-to-pay model assuming the Weibull distribution is estimated using the method of maximum likelihood (Alberini *et al.*, 2002). The log likelihood function of the responses is:

$$\log L = \sum_i \log [F(WTP_i^U; \theta; \sigma) - F(WTP_i^L; \theta; \sigma)], \quad (6)$$

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:

$$F(z; \theta; \sigma) = 1 - \exp\left(-\left(\frac{z}{\sigma}\right)^\theta\right) \quad (7)$$

Table 11 shows the parameters of the Weibull model for both risk reductions.

Table 11: Weibull accelerated failure-time model

Regressors	Total sample		Flag0 = 0		Flag4 = 0	
	Coefficient	Robust standard errors	Coefficient	Robust standard errors	Coefficient	Robust standard errors
5-in-1000 immediate risk reduction						
Constant	8.1019 ^(*)	0.0944	8.1183 ^(*)	0.1156	8.0977 ^(*)	0.1012
Ancillary parameter	0.6943 ^(*)	0.0241	0.6681 ^(*)	0.0269	0.6879 ^(*)	0.0253
Log likelihood	-507.50232		-373.48989		-452.4669	
N	269		194		239	
1-in-1000 immediate risk reduction						
Constant	7.9502 ^(*)	0.0975	7.8312 ^(*)	0.1177	7.9877 ^(*)	0.1045
Ancillary parameter	0.6717 ^(*)	0.0226	0.6855 ^(*)	0.0259	0.6657 ^(*)	0.0236
Log likelihood	-517.66081		-383.01611		-461.23367	
N	271		198		240	

Notes: Flag0 = Inconsistent maximum willingness-to-pay responses for both immediate risk reductions.

Flag4 = Wrong answer to both probability tests.

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

Table 12 shows the results of mean and median estimates for the Weibull distribution, according to Bateman *et al.* (2002, pp 244).

Table 12: Parametric estimation of mean and median annual willingness to pay (US\$ 2003) – Weibull distribution

	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	970.80	986.82	966.75	834.21	740.61	866.03
Median	572.61	570.16	567.46	483.38	422.34	499.39

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

The mean and median willingness-to-pay estimates shown in Table 12 are consistent regarding some aspects. First, the mean values are all greater than the non-parametric mean values (Table 9), which are supposed to be lower-bound estimates of mean willingness to pay. Second, it is observed lower values for the lower risk reduction in all estimates. However, the economic theory predicts that the willingness-to-pay estimates for different risk reductions must be proportional to the reduction in risk, that is, it is expected that the willingness to pay for a 5-in-1000 risk reduction be five times bigger than the willingness to pay for a 1-in-1000 risk reduction. Table 13 shows the ratios between both estimates.

Table 13: 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 starting now		
	Total sample	Without Flag0 =1	Without Flag4 =1
Mean	1.1637	1.3324	1.1163
Median	1.1846	1.3500	1.1363

As can be seen in Table 13, neither means willingness-to-pay estimates nor median values increases in proportion to the size of the risk reduction, although median willingness-to-pay estimates present a bit more sensitivity to the size of risk reduction. Interestingly, the ratio is higher – for both mean and median estimates – when the sub-sample without respondents who presented inconsistent willingness-to-pay answers in both questions (*flag0=1*), when it would be expected a similar result when used the sub-sample without respondents who failed in both probability tests. Although the ratios are lower than five, this is in accordance with other results in the literature, for example, the ratios observed in similar tests in US and Canada were 1.931 and 1.259, respectively (Alberini *et al.*, 2002).

Regarding the validity test of the parametric willingness-to-pay estimates, it 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 the 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. That is, it must be identified the variables that influenced the stated willingness-to-pay values. In general, such tested 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. For testing the validity of willingness-to-pay responses, these variables are included as covariates in the willingness-to-pay model. This model may not necessarily make the same distributional

assumptions as that used to evaluate mean and median willingness to pay. However, the Weibull distribution was assumed again for the sake of easing the comparison of the results with those figures presented in the relevant literature.

Because the objective now is to establish the degree of randomness of willingness-to-pay responses, all available variables were tested regardless of whether they are considered to be endogenous or exogenous to the decision of stating the willingness-to-pay values⁶. This is possible because the parameters themselves are not of interest, but their significances are important to establish the explanatory power of the model. The resultant statistical model is:

$$\log WTP_i = x_i \cdot \beta + \varepsilon, \quad (8)$$

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 14 and Table 15 show the statistical significant covariates and, eventually, those insignificant ones but essential for the analysis, like income, gender, age and education.

Table 14: Validity test - willingness-to-pay for a 5-in-1000 immediate risk reduction

Weibull model Regressors	Total sample		flag 0 = 0		flag 4 = 0	
	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z
Constant	6.0665 ^(*)	0.000	6.0890 ^(*)	0.000	6.4069 ^(*)	0.000
Gender	0.1199	0.369	0.1435	0.426	0.1157	0.409
Age	0.0054	0.543	0.0027	0.806	-0.0012	0.893
Self-assessed comprehension of the concept of probabilities	0.0972 ^(**)	0.072	0.1270	0.111	0.1196 ^(**)	0.045
If respondent considered his/her finances when stating WTP	0.3122 ^(**)	0.040	0.3251	0.107	0.1912	0.233
If respondent considered only his/her risks	0.3298 ^(**)	0.012	0.2382	0.171	0.3358 ^(**)	0.019
Smokes	-0.0128	0.930	0.0650	0.734	-0.0842	0.584
Degree of faith in religion	0.0301	0.704	0.0124	0.914	-0.0298	0.754
Has health insurance	-0.3180 ^(**)	0.023	-0.2904	0.119	-0.3063 ^(**)	0.039
If respondent is married	0.1071	0.504	-0.0150	0.941	0.1441	0.406
Children	0.0519	0.816	-0.1677	0.657	0.0629	0.786
Years of education	0.0123	0.500	0.0393	0.105	0.0096	0.628
Income	0.0008 ^(*)	0.000	0.0007 ^(*)	0.001	0.0007 ^(*)	0.000
Role limitation physical score	0.0032	0.149	0.0030	0.318	0.0058 ^(**)	0.013
Scale parameter	1.122043		1.174093		1.126147	
N	269		194		239	
Log likelihood	-461.01888		-339.89907		-409.50336	

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

The most important result in Table 14 regards the significance level and positive sign of the individual income variable. As it can be expected from the economic theory, willingness to pay for a reduction in risk of death has a positive relation with the respondent' income, since reducing mortality risk is considered to be a normal and

⁶ Econometric theory states that parameter estimates are biased when endogenous variables are included in the willingness-to-pay model.

desired good. The fact that income is the most statistically significant covariate – for all sub-samples – is also in line with the contingent valuation literature, which states that willingness to pay is the maximum amount of money that the respondent is willing to pay for the provision of the good being valued.

It can also be observed that, apart from income, the statistical significant covariates are not the same among the sub-samples. Among the statistically significant regressors are (i) the self-assessed comprehension of the concept of probabilities, which was ranged between one and five in an increasing scale of comprehension, (ii) a dummy variable indicating if respondents considered their finances when stating willingness-to-pay values, (iii) a dummy variable representing if respondents considered only their own risks or any other benefit of the proposed product, (iv) the role limitation physical score, and (v) if the respondent has any health insurance. Interesting to note that income was the only socio-economic variable statistically significant related to the 5-in-1000 risk reduction willingness-to-pay estimates, while all other significant covariates were behavioural variables.

Important to report that private health insurance is a relatively expensive service in Brazil not affordable for lower social classes and also part of the middle class, which depends on the public health service in general a service of very poor quality. As described before, this survey targeted middle and upper social classes only, which would suggest that the majority of the respondents possibly had health insurance. However, as can be seen in Table 4, only 43.8% of the sample stated having this service. This is a good indicator of how individuals in Sao Paulo take risks regarding health and the possibility of death. Also, this relatively low percentage of individuals with health insurance can be seen as an indicator of how important this service can be in the household's budget, which confirms the importance of income as a determinant of willingness-to-pay estimates.

Important socio-economic variables that would be expected to be statistically significant and were not are gender, age, education and marital status. According to a correlation analysis performed in this study, these covariates were not significantly linearly correlated with income, which indicates 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, the fact that respondents smoke or not was not significant to determine willingness-to-pay values, which would be expected when the good being valued is related to several respiratory diseases and cancer, also related to smoking. Furthermore, the variable representing if the respondents have children, which can be an indicator that respondents' may have more concern about their future health and capacity of providing support, was not statistically significant as well.

Very similar results are obtained when the same analysis was performed for the 1-in-1000 risk reduction willingness-to-pay estimates (Table 15). The most important differences rely on the fact that additional to income and other behavioural significant variables, the fact that respondents smoke or not and the degree of faith in religion are now statistically significant for some sub-samples. 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.

Table 15: Validity test - willingness-to-pay for a 1-in-1000 immediate risk reduction

Weibull model Regressors	Total sample		flag 0 = 0		flag 4 = 0	
	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z
Constant	8.8786 ^(*)	0.000	7.9983 ^(*)	0.000	7.9222 ^(*)	0.000
Gender	0.1084	0.464	0.1828	0.331	0.2074	0.173
Age	-0.0136	0.113	-0.0013	0.900	-0.0060	0.518
Self-assessed comprehension of the concept of probabilities	0.1233 ^(**)	0.046	0.2218 ^(**)	0.004	0.1967 ^(*)	0.004
If respondent considered his/her finances when stating WTP	0.2618	0.103	0.2719	0.197	0.1584	0.353
Smokes	-0.2439	0.122	-0.5193 ^(*)	0.007	-0.3517 ^(**)	0.030
Degree of faith in religion	-0.2679 ^(**)	0.011	-0.3550 ^(*)	0.006	-0.2506 ^(**)	0.040
Has health insurance?	-0.2796 ^(**)	0.069	0.0191	0.928	-0.2130	0.229
If respondent is married	-0.0394	0.823	-0.0868	0.697	0.0090	0.963
Has children	0.0156	0.945	0.0501	0.885	-0.0130	0.959
Years of education	0.0113	0.595	0.0329	0.261	0.0235	0.304
Income	0.0007 ^(*)	0.003	0.0005 ^(**)	0.053	0.0007 ^(*)	0.006
Change in health score	-0.0064 ^(**)	0.085	-0.0122 ^(*)	0.007	-0.0049	0.217
Scale parameter	1.191454		1.249916		1.198744	
N	271		198		240	
Log likelihood	-475.13769		-353.70386		-422.98607	

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

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 possible to avoid discounting the respondents' annual payments. Table 16 shows the results.

Table 16: Value of a statistical life using parametric estimation of mean and median annual willingness to pay (US\$ 2003) – Weibull distribution

VSL	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	1,941,598	1,973,636	1,933,501	8,342,087	7,406,110	8,660,291
Median	1,145,223	1,140,316	1,134,919	4,833,828	4,223,352	4,993,896

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

As can be seen in Table 16, 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. The reason for this discrepancy relies on the lack of proportionality between the willingness-to-pay estimates regarding the differences in the size of risk reductions (Table 13). For this reason, it is suggested the value of a statistical life in Sao Paulo ranging between US\$ 1.1 – 1.9 millions for policy assessments.

When compared with European and North American estimates these values (mean and median estimates for an immediate 5-in-1000 risk reduction) seem to be higher than expected. Given the close link between willingness-to-pay estimates and the

population income, it would be expected lower willingness-to-pay values for developing countries. One reason for this unexpected result may rely on the fact that this study focused on middle and higher social classes in Sao Paulo, which corresponds to 69% of the total population. Other possibility refers to the great inequality observed in the Brazilian society. The difference in income levels between the social classes is considerable, that is, those wealthier individuals in class A (7% of total population) are rich even for developed societies' patterns, which may have been responsible for the high estimates observed.

5. Conclusion

Air pollution is one of the most serious environmental health risks in Brazil, particularly in Sao Paulo, the largest and most polluted city in South America. The medical literature presents a number of studies linking air pollution with several-causes 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 the key part of estimating benefits and costs of policies that change individuals' probability of surviving.

This study used the recent methodology designed to estimate the willingness to pay for reducing individual's risk of death, consisting of a contingent valuation survey instrument developed throughout years and tested in many countries. This instrument was adapted to the peculiarities of the Brazilian population and used to estimate the willingness to pay for different reductions in probabilities of death, regardless the context in which the risks are analysed. The results imply a value of a statistical life ranging between US\$ 1.1 – 1.9 million.

It has to be highlighted that one limitation of this study regards the representativeness of the willingness-to-pay and value-of-a-statistical-life estimates, which refer to middle and upper social classes individuals residents in Sao Paulo, roughly 69% of the total population. It was not attempted any adjustment to consider individuals of lower social classes (31%). This has to be considered when the results are to be used for policy evaluations. However, given the context-free characteristic of the survey, these results can be applied to a large number of policy evaluations, not only in the context of air-pollution policies. That is, any policy that involves the increase of individuals' probabilities of death in Sao Paulo can be evaluated using the estimates presented in this paper, once adjusted to the remaining social classes.

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