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Pricing Environmental Health Risks: Survey Assessments of Risk – Risk and Risk – Dollar Trade-Offs for Chronic Bronchitis[1]

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This study develops a methodology for measuring the values that individuals place on morbidity risk reductions and applies it to the measurement of the benefits from reducing the risks of contracting chronic bronchitis. The survey methodology involves the use of an iterative computer program that presents respondents with a series of pairwise comparisons which are individually designed to measure respondents' marginal rates of substitution for chronic bronchitis risk reduction. The approach is innovative in that it measures the rates of trade-offs for chronic bronchitis risk reduction in terms of the risk of an automobile accident fatality (risk–risk trade-off), as well as in dollars (risk–dollar trade-off). Since it generates estimates for each individual, it can reveal distributions of benefit measures rather than simply a population mean estimate. The resulting rates of trade-off for chronic bronchitis and auto fatality risks suggest that the risk of a chronic bronchitis case is worth 32% of the comparable risk of death, as measured by the median trade-off rate. When risk reduction for chronic bronchitis is compared to a cost of living increase, the median rate of trade-off is $457,000, whereas the comparison between automobile fatality risk reductions and cost of living increases yielded a median rate of trade-off of $2.29 million. The results across different risk–risk and risk–dollar trade-offs were internally consistent.

1. INTRODUCTION

Over the past decade economists have devoted substantial attention to the implicit valuation of health outcomes. These analyses of risk–dollar trade-offs have relied in large part on market-based data.[2] For example, wage–risk trade-offs have been used to analyze the implicit value of fatalities and the average nonfatal job accident risk. Similarly, economists have analyzed the trade-offs implied by seat-belt usage decisions to infer a value of life.[3]

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[2]See [16] for a review of the market trade-off literature.

[3]See the analysis in [4] for an inventive use of seat-belt usage data to infer a value of life.

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Although studies using market data provide useful benchmarks for health risk valuation, they do not resolve the issue of how to attach benefit values to health outcomes for which we do not have good market data. This omission is particularly important for government agencies, such as the U.S. Environmental Protection Agency (EPA), which generally focus on policy contexts in which market forces are believed to not be fully effective. For these situations, no useful market trade-off data may be available. Nevertheless, economic analysts would like to select the efficient project mix, and some benefit measure is required to perform such an analysis. In recent years, numerous studies have addressed these benefit issues using nonmarket techniques, thus greatly expanding the range of benefit components that can be valued.[4]

This study makes two main contributions to the literature on nonmarket techniques for benefit valuation. First, we develop a methodology for measuring the benefits of reducing the risks from various types of morbidity effects. The methodology uses an iterative computer program to ascertain the points of indifference for consumers who are asked to trade off the reduced morbidity risk with increases in other attributes of a location decision, such as an area's cost of living and the risk of an automobile fatality.[5]

Second, we apply the methodology to an important health benefit valuation problem, that of estimating the value of marginal reductions in the risk from chronic bronchitis (CB), a central type of chronic obstructive pulmonary disease alleged to be a major adverse effect of ozone pollution exposure. Most previous studies of health valuation focus on acute health effects, such as accidental death, rather than chronic diseases, whose effects are more difficult to communicate to potential victims.[6]

Three aspects of our study are particularly noteworthy. First, the approach yields the entire distribution of consumer values for chronic bronchitis risk reduction, rather than just the mean valuations, which are usually derived from market-based approaches to the problem. This information is important for policymakers in situations where consumers place widely divergent values on reducing risk.

Second, because chronic disease effects are difficult to communicate to potential sufferers, it is important to use a methodology that adapts to whether subjects understand the valuation task being asked of them. By administering the questionnaires interactively on a computer, our approach allows us to build in several tests of task comprehension that, if failed, provide additional information before we proceed with the questionnaire.

Finally, our methodology produces values for morbidity risk reduction in terms of trade-offs with another metric besides money. In our chronic bronchitis application, we measure risk–risk trade-offs which balance morbidity against the risk of automobile fatalities, as well as risk–dollar trade-offs derived from changes in the cost of living. The calculation of risk–risk trade-offs has three important advantages. The first relates to the elicitation of correct values. Although not formally tested, there are several reasons to suspect that consumers may have fewer

[4]Survey studies of various health and environmental risks include the seminal work [1] as well as more recent studies often grouped under the designation "contingent valuation." These recent analyses include [5–9, 14, 17–19].

[5]We used Ci2 software from Sawtooth Software, Inc. (P.O. Box 3429, Ketchum, ID 83340) to create and manage the personal-computer-based interviews.

[6]For an important recent study of the valuation of health risks rather than mortality, see [3].

difficulties with the task of specifying rates of trade-off of one risk with another, as opposed to trading off a risk with a certain dollar amount. The risk–dollar trade-off task sometimes produces alarmist responses from subjects who cannot envision that they would voluntarily subject themselves to a higher risk of a serious morbidity effect for a finite amount of additional income.[7] Establishing a death risk metric for CB enables respondents to think in risk terms, avoiding the comparability problems that might be encountered if monetary attributes were introduced. Dollar valuation tasks are also difficult to design in ways that subjects will find analogous to real choice situations, and they may offer biased responses to questions that do not force them to pay for the risk reduction being valued. Further, risk–dollar trade-offs must be made with a budget constraint that is not binding on risk–risk trade-offs.

Risk–risk trade-offs have a second advantage when used in policy analysis. Many policymakers are hesitant to base decisions on benefits denominated in dollars, and they may be more willing to implicitly consider benefit values when measured in units of a common risk such as death. Converting all health outcomes into death–risk equivalents facilitates cost-effectiveness analysis by calculating the cost per statistical life equivalent saved, and it addresses concerns with respect to dollar pricing.

As indicated in [16], this cost-effectiveness index (in terms of the cost per statistical death prevented) will provide a comprehensive measure of the policy impact and also avoid the political sensitivities of placing dollar values on all health outcomes. Once a uniform health metric is established, one can then compare the cost per life equivalent saved with various value of life reference points and decide whether the policy should be pursued if one wishes to take a benefit–cost approach. Even if the morbidity valuations are elicited in terms of trade-offs between risks, they can still be converted into dollar values by using hedonic measures of the value of the comparison risk if that comparison risk is death (with the appropriate application of sensitivity analysis to the assumed values of life used to make the translation).

Finally, to the extent that consumers are equally averse to the uncertainty associated with different types of health risks, asking them to trade off one risk against another produces rates of trade-off which measure the relative value to them of the two risks without regard to the risk aversion, which enters in trading off an uncertain health risk with certain dollars. In this sense the risk–risk trade-offs provide values which are not as heavily influenced by the consumers' attitudes toward facing risks per se.

The outline of this paper is as follows. Section 2 provides an overview of the study design and the sample. Section 3 describes the risk–risk trade-offs whereby respondents put their chronic morbidity valuations into auto death equivalents. In Section 4 we describe the direct estimates of risk–dollar trade-offs for chronic bronchitis obtained by asking respondents to trade off chronic bronchitis risks with the area's cost of living. As a check of the validity of the approach, we provide evidence on auto fatality risk–dollar trade-offs in Section 5. These implicit value of life numbers are tested against those in the literature to assess the validity of the survey approach. In Section 5 we also convert all of our results for the value of chronic bronchitis to dollar equivalents. Section 6 concludes the paper.

[7] For example, see [19, pp. 477–478].

2. STUDY DESIGN AND SAMPLE DESCRIPTION

General Approach

We used a sample of 389 shoppers from a blue-collar mall in Greensboro, North Carolina to measure willingness to pay values for reducing the probability of contracting chronic bronchitis. The subjects made three series of pairwise comparisons of different locations where they could live with the locations differing in two attributes. In most of these comparisons, we varied the probability of contracting chronic bronchitis.

The first series of questions yielded a rate of trade-off between decreases in the risk of CB and increases in the risk of an automobile fatality, thus providing what we call a "risk–risk" trade-off. The second series of questions determined a "risk–dollar" trade-off, where the reduction in the risk of CB was achieved at the expense of a location with a higher cost of living.

Finally, in order to compare the CB risk–auto fatality trade-offs with the risk–dollar trade-offs, it was useful to obtain a dollar measure of the value of reducing the risk of automobile fatalities. This third series of questions provided a rate of trade-off between risk reduction in automobile fatalities and increases in a location's cost of living.

The results from these three series of questions allow us to address the following questions:

* What is the distribution of CB risk–auto death risk trade-offs?
* What is the distribution of CB risk–dollar trade-offs?
* What is the distribution of auto death risk–dollar trade-offs?
* How does the distribution of CB risk–dollar trade-offs compare with the distribution of CB risk–dollar trade-offs derived from combining the CB risk–auto death risk trade-offs with the auto death risk–dollar trade-offs?
* How does the distribution of CB risk–dollar trade-offs compare with the distribution of CB risk–dollar trade-offs derived from combining the CB risk–auto death risk trade-offs with the mean values of life derived from wage hedonic studies?[8]

It should be noted that the first question is the most important one because it addresses the use of an alternative metric to dollars for measuring morbidity risk willingness to pay values, that of another health risk, namely death. For cost-effectiveness purposes, it is not necessary to go beyond the death risk metric, as alternative policy initiatives can be compared on the basis of this metric rather than dollars. However, if the CB risk values measured in death risk units translate closely to the direct dollar valuations of reducing CB risks that we obtain, this triangulation permits policymakers to be more confident in the reasonableness of the risk–risk valuations.

In order to understand the empirical results that allow responses to the questions above, it is first necessary to carefully describe the design of the survey and the sample.

[8]Note that the latter distribution of risk–dollar values derived from combining two statistics reflects only the distribution of CB–death risk values and not the distribution of values of life.

TABLE I
Health Implications of Chronic Bronchitis

1.	Living with an uncomfortable shortness of breath for the rest of your life
2.	Being easily winded from climbing stairs
3.	Coughing and wheezing regularly
4.	Suffering more frequent deep chest infections and pneumonia
5.	Having to limit your recreational activities to activities such as golf, cards, and reading
6.	Experiencing periods of depression
7.	Being unable to do the active, physical parts of your job
8.	Being limited to a restricted diet
9.	Having to visit your doctor regularly and to take several medications
10.	Having to have your back mildly pounded to help remove fluids built up in your lungs
11.	Having to be periodically hospitalized
12.	Having to quit smoking
13.	Having to wear a small, portable oxygen tank

Methodology

The task of eliciting individuals' valuations of chronic bronchitis is not straightforward. The first problem is that few individuals fully understand the health effects of chronic bronchitis. Second, once given this information, they may not have sufficient experience in dealing directly with such trade-offs to give meaningful valuation responses. To accommodate these difficulties, we developed an interactive computer program that informs consumers as well as elicits trade-off information.

Two different questionnaires were used, but for concreteness let us initially focus on what we designate Questionnaire A. After acquainting the respondent with the computer, the program elicits information regarding the respondent's personal characteristics (e.g., age). A substantial portion of the questionnaire (about 40 questions) is then devoted to acquainting the respondent with the health implications of chronic bronchitis and the nature of the trade-offs that would be encountered. These questions elicit the respondent's familiarity with chronic bronchitis and information on smoking history and provide a detailed summary of the health implications of chronic bronchitis.

The 13 principal health implications of chronic bronchitis are summarized in Table I. The chronic bronchitis disease classification includes a variety of illnesses of differing severity. Our intent was *not* to value *each* possible combination of systems, but rather to establish a methodology that could be used to value this and other adverse health effects. Consequently, our valuation procedure pertains to the set of symptoms summarized in Table I, but the broader purpose of our analysis is to develop a methodological approach that is more generally applicable to other patterns of chronic bronchitis, as well as to different diseases such as cancer.

Chronic bronchitis takes many forms, and this study focused on its most severe chronic morbidity effects.[9] Thus, the survey's focus is on the adverse health

[9]See [13] for a discussion of the distinction between chronic bronchitis, the related disease emphysema, and the broader disease category called chronic obstructive pulmonary disease. The authors selected the type of chronic bronchitis described in Table I after consulting closely with two lung specialists at Duke University Medical Center and visiting the Medical Center rehabilitation program for patients with severe lung diseases.

outcomes at the extreme and of the cluster of diseases within the chronic bronchitis grouping. Because a quick overview of these effects may not be fully absorbed by respondents, subsequent questions ascertained their disutility ranking of each outcome in a linear 49-point scale. The purpose of these questions is not to establish attribute-based utilities, but to encourage respondents to think carefully about the health implications of chronic bronchitis and to reinforce their own view of the effect of this disease on their well-being.

At this point in the questionnaire, the respondents confront the first of two sets of trade-off questions. Individuals are presented with a choice of moving to one of two alternative hypothetical locations which differ in terms of their chronic bronchitis risk and automobile accident risk. To ensure that respondents would be willing to consider making such a move at all, they were told that these two locales posed a lower risk of both outcomes than their current place of residence.[10]

Since risk levels differ across individuals, the program elicits information regarding individual activities that are likely to influence their person-specific risks, such as smoking habits (for chronic bronchitis) and mileage driven per year (for auto accident deaths). The program then informs the respondents that the probabilities presented in subsequent questions are calculated on the basis of *their* responses to the earlier risk-related activity questions, even though the same risks are actually presented to all subjects.[11] This procedure increases the extent to which the stated risk levels are taken at face value, while facilitating the comparison of risk trade-offs across subjects because they all responded to the same risks.

To ensure that respondents understand the task before proceeding to questions in which one location is lower in one risk but higher in the other risk, they are first presented with a dominant choice situation. Let the notation (x, y) denote a locale where the chronic bronchitis probability is $x/100{,}000$ and the automobile death risk is $y/100{,}000$. The actual survey did not present the choices in such abstract terms, but this notation makes the exposition of the survey structure simpler.[12] To ascertain whether respondents understand the task, they are first asked whether they prefer Area A with (CB, auto death) risks per 100,000 population of (75, 15) or Area B with risks (55, 11). Since both Area B risks are lower, this alternative is dominant. Respondents who do not comprehend the task and incorrectly answer that they prefer Area A are given a series of questions that explain the structure of the choice in more detail.

The performance with respect to the dominance question was quite good. Over four-fifths of the sample gave a correct response to the dominance questions on their initial attempt. After being given additional information, fewer than 1% of them gave an incorrect answer, and these respondents were excluded from the sample since they did not understand the interview task.

The program then proceeds with a series of pairwise comparisons in which the attributes are altered on the basis of the previous responses until indifference is achieved. The computer program used descriptive summaries, but for expositional purposes we consider the abstract formulation of the trade-offs.

[10]The questionnaire did not indicate the source of the difference in chronic bronchitis risks across locations (e.g., air pollution), and subjects easily accepted this variation in risks.

[11]At the end of the interview, subjects were carefully debriefed about this use of average rather than person-specific risks.

[12]Our past studies suggest that presenting the risk in terms of the number of cases for a large base population is more comprehensible than giving risk levels such as 0.00075.

A Model of State-Dependent Utilities for Risk–Risk Trade-offs

Consider the following model of state-dependent utilities. Let subscript a denote Area A and subscript b denote Area B. Also, let $U(\mathrm{CB})$ be the utility of living with a case of chronic bronchitis, $U(D)$ equal the utility of death from an auto accident, and $U(H)$ equal the utility of being healthy (i.e., having neither CB nor an auto accident). To simplify this exposition, assume that contracting CB and dying from an automobile accident are mutually exclusive events. Also, let X_a denote the annual probability of contracting chronic bronchitis in Area A and Y_a denote the annual probability of dying from an automobile accident in Area A, and let X_b and Y_b be similarly defined. The survey continually modifies X_a and Y_b in the choice pairs until subjects are indifferent, where

$$X_a U(\mathrm{CB}) + Y_a U(D) + (1 - X_a - Y_a)U(H) = X_b U(\mathrm{CB}) + Y_b U(D) + (1 - X_b - Y_b)U(H). \quad (1)$$

Our general objective is to establish the death risk equivalent of chronic bronchitis. If we assume without loss of generality that $X_a > X_b$ and $Y_b > Y_a$, then

$$(X_a - X_b)U(\mathrm{CB}) = (Y_b - Y_a)U(D) + (X_a - X_b + Y_a - Y_b)U(H), \quad (2)$$

or

$$U(\mathrm{CB}) = \frac{Y_b - Y_a}{X_a - X_b}U(D) + \left(1 - \frac{Y_b - Y_a}{X_a - X_b}\right)U(H). \quad (3)$$

If we define the rate of trade-off between CB and D as t_1, so that

$$t_1 = \frac{Y_b - Y_a}{X_a - X_b}, \quad (4)$$

we obtain the result that

$$U(\mathrm{CB}) = t_1 U(D) + (1 - t_1)U(H). \quad (5)$$

The utility of CB cases has been transformed into an equivalent lottery on life with good health and death, for which we have a well-developed literature.

Survey Structure for Questionnaire A

Now consider the first set of paired comparison questions presented in Questionnaire A after the dominant choice question described above. In this case, respondents are given the choice between Area A with (CB, auto death) risks (75, 15) and Area B with risks (55, 19). Suppose that Area B is preferred in this example. Area B has the lower chronic bronchitis risk and higher auto accident risk; therefore, in subsequent questions the program raises the CB risk in the preferred Area B until indifference is achieved. If in the original choice the subject prefers Area A, in subsequent questions the program lowers the auto death risk in Area B until the point of indifference is reached.[13,14]

Suppose that after considering a series of such comparisons the subject reaches indifference where he views the risk (75, 15) as being equivalent to (65, 19). Using Eqs. (4) and (5) above, this would imply that

$$t_1 = \frac{19 - 15}{75 - 65} = 0.4$$

and

$$U(\mathrm{CB}) = 0.4U(D) + 0.6U(H).$$

The second set of paired comparison questions in Questionnaire A focuses on the more traditional risk–dollar trade-off involving CB and cost of living. Area A has the same cost of living as the respondent's present residence and a lower CB risk X_a, while Area B has an annual cost of living that is $\$Z$ higher, yet poses a CB risk X_b which is lower than the CB risk X_a. If in the initial question Area B is preferred, Area B's CB risk is increased until indifference is achieved. Similarly, if Area A is preferred, Area B's cost of living is reduced until the point of indifference is reached.

A Utility Model for Risk–Dollar Trade-offs

Consider a utility function with two arguments, health status, H or CB, and income net of living expenses, I or $I - Z$. Indifference between Areas A and B

[13]On the basis of the results of extensive pretesting, the initial set of paired comparison questions was carefully designed to present risk difference for the two risks between the two areas which lead to approximately half of the subjects preferring Area A and half of the subjects preferring Area B. This procedure minimizes the number of iterations needed to reach indifference for most subjects and thus minimizes the chance of a starting point bias created by the initial selection of the risk difference.

[14]There are several reasons for the selection of this particular procedure for adjusting the risks in subsequent questions. As a cognitive task, it is easier for subjects to focus on changes in the risks in Area B only, rather than being forced to compare the two possible risk changes across two different locations on each question. In addition, this adjustment procedure bounds the range of possible adjustments to the risks by the comparable risks in Area A. Since the computer program must define the range in advance of receiving any responses from subjects, this feature of the design guarantees that the range is never too small for a subject. Perhaps more important, by bounding the range of adjustment by the comparable risk in Area A, which was designed to be less than the risk in the subject's current location, we ensured that subjects would never be evaluating a move to a new location with a health risk which exceeded their risk in their current place of residence.

Risk increases are often valued differently than risk decreases (see, for example, [19]). In future research it would be useful to test the sensitivity of our results to alternative procedures for adjusting the risks in subsequent questions. It is important to note that the adjustment procedure we used has no effect upon the response to the *initial* question in the series. Thus, the only possible effect of the adjustment procedure chosen is on the *number of questions* answered before a subject reaches a question which presents him with locations for which he is indifferent. Since the adjustment procedure was designed to keep both the risks below the levels in the subject's current location, he (or she) is never forced to select a location which exposes the subject to an increase in risk relative to his (or her) current location. This design feature ought to significantly reduce any possible biases from using an adjustment procedure which raises the risk of chronic bronchitis in Area B for some subjects and lowers the risk of an auto death in Area B for others.

implies that

$$X_a U(\mathrm{CB}, I) + (1 - X_a)U(H, I) = X_b U(\mathrm{CB}, I - Z) + (1 - X_b)U(H, I - Z). \qquad (6)$$

If the utility function is additively separable in health and money, then

$$X_a U_1(\mathrm{CB}) + (1 - X_a)U_1(H) = X_b U_1(\mathrm{CB}) + (1 - X_b)U_1(H) + U_2(I - Z) - U_2(I), \qquad (7)$$

where $U_1(\cdot)$ now represents the utility function for health and $U_2(\cdot)$ is the utility function for money. This expression simplifies to

$$(X_a - X_b)U_1(\mathrm{CB}) = U_2(I - Z) - U_2(I) + (X_a - X_b)U_1(H), \qquad (8)$$

or

$$U_1(\mathrm{CB}) = \frac{U_2(I - Z) - U_2(I)}{(X_a - X_b)} + U_1(H). \qquad (9)$$

If we assume that utility is linear in money (with a coefficient equal to one) in establishing our health valuation scale, then we have

$$U_1(\mathrm{CB}) = -L + U_1(H); \qquad (10)$$

i.e., chronic bronchitis is equivalent to being healthy and suffering a financial loss tantamount to L dollars, where

$$L = \frac{Z}{X_a - X_b}. \qquad (11)$$

Consider a specific example. Suppose that a subject indicates indifference between Area A with a CB risk of 75/100,000 and Area B with a CB risk of 55/100,000 and a \$100 higher cost of living than that in Area A. Then the implied dollar value of chronic bronchitis is

$$L = \frac{\$100}{(75/100{,}000) - (55/100{,}000)} = \$500{,}000, \qquad (12)$$

and

$$U_1(\mathrm{CB}) = -\$500{,}000 + U_1(H). \qquad (13)$$

This procedure for establishing a risk–dollar trade-off rate involves two assumptions regarding the structure of utility functions. First, we assume additive separability with respect to money and health. Second, we assume that the dollar magnitudes treated are sufficiently small that utility is approximately linear in money. Since even risk-averse utility functions meet this test for small monetary changes,[15] we selected our health risk levels so that the dollar magnitudes involved would be small.

It should be noted that our results provide values for small reductions in the risk of chronic bronchitis and in the risk of an auto fatality. The results are likely to be somewhat different if the specific pairs of risk reductions presented differ from those in our questionnaire, especially if the changes in risk are large, i.e., nonmarginal. Thus, for example, respondents' willingness to pay for risk reduction would not necessarily double if the risk changes were doubled because of the nonlinearity of the relationship.

Survey Structure for Questionnaire B

As noted above, we used two different questionnaires. Questionnaire B repeats the first part of Questionnaire A, and these samples are pooled in the analysis below. The second set of questions addresses the more traditional death risk–dollar trade-off using auto deaths and cost of living trade-offs. The structure is similar to that of the second set of questions in Questionnaire A except that CB has been replaced by auto fatality risks so that respondents must reach the point that

$$U(D) = -L + U(H), \tag{14}$$

where

$$L = \frac{Z}{X_a - X_b}, \tag{15}$$

as before. This portion of the study provides a direct comparability test with the literature on market-based values of life. The fatality risk–dollar trade-offs are also used in conjunction with the chronic bronchitis–fatality risk trade-offs to establish a chronic bronchitis–dollar trade-off rate.

Sample Description

The interviews of the subjects were all done through an interactive computer program, thus avoiding problems of interviewer bias and promoting the honest revelation of preferences. Response rates to sensitive questions, such as income level, were much higher than those usually achieved with face-to-face interviews. In addition, subjects were not concerned with whether their responses impressed the interviewer. Use of a computer also made it possible to ask a sequence of questions to ascertain the appropriate marginal rates of substitution.

The sample was recruited for the study by a professional marketing firm at a mall intercept in Greensboro, North Carolina. This locale has a representative household mix and is used as a test marketing site for many national consumer brands. This firm and locale have been used successfully in two previous studies by the authors.[16]

[15] See [2].
[16] See [17, 19].

TABLE II
Summary of Sample Characteristics

Demographic variables	Means (standard deviations) Questionnaire A	Means (standard deviations) Questionnaire B
AGE, in years	33.74 (12.42)	33.07 (11.66)
MALE, sex dummy variable	0.50	0.51
EDUCATION, years of schooling	14.02 (2.23)	13.79 (2.66)
MARRIED, married dummy variable	0.49 (0.50)	0.49 (0.50)
KIDS, number of children under 18	0.56 (1.00)	0.65 (1.07)
HOUSEHOLD, number of people in household	2.71 (1.25)	2.80 (1.23)
INCOME, annual household income in dollars	35,386.60 (19,009.95)	37,153.85 (21,333.80)
Sample size	194	195

Table II provides a glossary of the variables and the associated sample statistics. As the last row of Table II indicates, each of the two samples had about 200 respondents, with combined sample for the study of 389.

Subjects were excluded from our sample if their responses indicated that they did not fully comprehend the valuation task, or if their responses could not be used to calculate a trade-off rate. Specifically, we excluded subjects who failed one of the following consistency checks:

(1) *Never Changed.* They started the series of paired comparison questions by preferring one area, say Area A, and as Area B was made more desirable in subsequent comparisons they continued to prefer Area A, even on the last question of the series in which Area B dominated Area A on both attributes.

(2) *Only Changed to Indifference.* Like inconsistency 1, they continued to prefer Area A in each comparison until the last one, in which Area B dominated Area A in both attributes; yet on this last question they indicated indifference between Area A and Area B.

(3) *Reversed Response.* They indicated preference for one area, say Area A, on the first and all subsequent questions in the series (including the last one, in which Area B dominated Area A); then when confronted with this inconsistency and asked to repeat the series of questions they chose Area B in the first question (despite have selected Area A the first time they were given this question).

(4) *Boundary Result.* They indicated preference for one area, say Area A, on all questions in the series except the last one in the series (in which Area B dominated Area A), but including the next-to-last question (for which Area B easily dominated Area A on one attribute and Area A just barely dominated Area B on the other attribute), thus making it impossible to interpolate between the trade-offs implied by the last two questions to obtain an indifference point (because the last question yields no rate of trade-off).

TABLE III

Consistency Checks and Dominance Test for Comparisons of Chronic Bronchitis (CB) Risk, Cost of Living (COL), and Auto Death (AD) Risk Changes

Consistency check	Number (percentage) of subjects failing test who answered		
	CB vs AD	CB vs COL	AD vs COL
Dominance test	77 (19.7)	41 (21.1)	36 (18.5)
1 (Never Changed)	22 (5.6)	11 (5.7)	9 (4.6)
2 (Only Changed to Indifference)	24 (6.1)	7 (3.6)	13 (6.7)
3 (Reversed Response)	9 (2.3)	10 (5.2)	5 (2.6)
4 (Boundary Result)	53 (13.6)	29 (14.9)	17 (8.7)
5 (All Indifferent)	3 (0.8)	7 (3.6)	2 (1.0)
N	389	194	195
Failed at least one consistency check	102 (26.2)	54 (27.8)	41 (21.0)
Failed at least one consistency check and also failed dominance test	18 (23.4)	15 (36.6)	8 (22.2)

(5) *All Indifferent*. They expressed indifference between *all* pairs of areas in the series of questions, despite wide variation in their attributes.
Individuals who failed one of these inconsistency checks either did not understand the choice task, were not responding honestly, have extreme values (Boundary Result), attached no value to one of the two attributes, or have nonmonotonic preferences for one of the attributes. We assume that neither of the last two preferences attributes are possessed by any subjects, thus implying that answers which fail any of the five inconsistency checks cannot be used to represent the subjects' true preferences.

The requirement that the response pattern to the series of paired comparisons be internally consistent leads to more meaningful estimates than if no such checks were imposed. About two-thirds of the sample in both questionnaires converged to an indifference situation and had consistent responses.[17]

Table III describes the number of subjects who failed each of the consistency checks, as well as the dominance test, for the comparisons of chronic bronchitis risk changes with auto death risk changes, chronic bronchitis risk changes with cost of living changes, and auto death risk changes with cost of living changes. From

[17]Probit analysis was used to identify personal characteristics that explain the division of subjects between those giving consistent and inconsistent responses. The only two significant variables in the equation are AGE and SMOKER, with older respondents less likely to give consistent responses and smokers more likely to respond consistently. These results may reflect the difficulty that older subjects have with the new interview technology (computers) and the greater thought that smokers have given to the implications of chronic bronchitis.

these statistics it is evident that the major inconsistency in subjects' responses came from checks 1 (Never Changed) and 2 (Only Changed to Indifference). By indicating a preference for one area on all the questions in a series (except the last one, in which some indicated indifference), these subjects revealed that they did not understand the choice task or did not wish to cooperate by responding in a manner consistent with their true preferences because in the last question the previously preferred area became dominated by the other area (in the sense that one risk was less and the second risk was equal). The relatively large number of subjects failing check 4 (Boundary Result) were not necessarily being inconsistent because they may have had extreme preferences that could not be measured by the preprogrammed set of questions.

The table also gives statistics on the numbers and percentages of subjects who failed at least one consistency check and who also failed the dominance test (in which they chose an area whose risks exceeded the risks in the other area) the first time it was posed to them. Those subjects failing the dominance test failed on the consistency checks about the same fraction of the time as the entire sample failed the consistency checks, indicating that the failure of the dominance test was not a good predictor of failing subsequent consistency checks.

These consistency checks distinguish our approach from the usual contingent valuation method, in which respondents' answers are taken at face value without such formal tests of whether the subjects understood the valuation task and displayed consistent choices. While the fraction of responses used in the analysis would have been higher without the consistency checks, these checks are an important check on subjects' understanding of the choice task. In contrast, the standard contingent valuation approach includes no such systematic checks of task comprehension on a question-by-question basis and, not surprisingly, allows researchers to use a larger fraction of subjects' responses in the analysis.

3. RISK-RISK TRADE-OFFS

Table IV displays the means and standard deviations of the trade-off rates implied by the indifference points of the subjects responses. To go beyond these summary statistics, consider first the set of trade-offs between CB and auto accident deaths. For this analysis the identical questions from Questionnaires A and B are pooled.

While market-based studies of the value of life usually do not calculate the entire distribution of willingness to pay responses, we report the entire distribution of the valuations since this more detailed information can be useful. Column (2) of Table V gives the deciles of the distribution for respondents who gave consistent answers that converged to a particular trade-off value.

In evaluating the distribution in Column (2) of Table V, first consider the respondent at the 10th percentile. This person viewed a change in the chronic bronchitis risk as being just as severe as a change in the risk of an auto accident that was 0.12 as great. Thus, this individual would view a change in his or her chronic bronchitis risk of 100/100,000 per year as being equivalent to a change in his or her annual chance of being involved in an auto accident of 12/100,000.

Now examine the respondent at the other end of the distribution. This individual views a chronic bronchitis risk change as being four times as severe as an

TABLE IV
Rates of Trade-off Implied by Indifference Points

	Means (standard deviations)	
	Questionnaire	
Trade-off Rates	A	B
CB–auto, auto deaths per CB case	0.68 (0.82)	0.70 (0.95)
CB–cost of living, dollar value per 1/100,000 CB risk	8.83 (12.50)	—
Auto–cost of living, dollar value per 1/100,000 reduced auto accident risk	—	81.84 (168.54)
Sample size	194	195

equivalent change in the risk of death, so that a 100/100,000 change in the risk of CB would be viewed as comparable to a 400/100,000 change in the risk of death. He or she gave consistent responses to the questions, but opted for the choice reflecting the highest CB valuation.

Many studies in the survey valuation literature exclude the tails of the distribution since they are tainted by extreme respondents such as this. Rather than discard such information altogether, we report the entire distribution, recognizing that the top and bottom deciles may be affected by a lack of complete understanding of the interview task. The reported distributions enable readers to assess how important outliers are within the context of the study and, by focusing primarily on the *median* responses rather than the *mean*, we avoid the distortion of our results by these outliers.

The response pattern in which CB was more highly valued than auto death risks was exhibited by the top two deciles for each questionnaire's response distribution. Two explanations can be offered for such a pattern. First, individuals might legitimately believe that a severe chronic illness is a worse outcome than death. The health outcomes described in Table I are quite serious and have substantial duration. Normal activities would be curtailed, medical interventions including hospitalization and reliance on a portable oxygen tank accompany severe cases of CB, other illnesses are more likely, and they are accompanied by periods of depression.

The second possible explanation is that the respondents were establishing equivalencies between different average risks in an area rather than between different risks to themselves. The CB risk was characterized as an involuntary risk not under their control except for smoking, whereas the auto accident risk differs depending on one's driving habits and skills. Other studies suggest that individuals may have overly optimistic assessments of risks influenced by their actions, such as auto death risks, as discussed in [17]. If this were the case, the perceived person-specific risk would be below the stated risk, causing an upward bias in the results in Table V.

TABLE V

Distribution of Trade-offs for Chronic Bronchitis and Auto Death, Chronic Bronchitis and Cost of Living, and Auto Death and Cost of Living

(1) Decile	(2) Auto death equivalents per CB case	(3) Dollar value per 1/100,000 reduced risk of CB	(4) Implicit dollar value per CB case	(5) Dollar value per 1/100,000 reduced AD risk	(6) Implicit dollar value of AD	(7) CB dollar value implied by CB–AD and AD–COL trade-offs
0.10	0.12	1.50	150,000	10.00	1,000,000	200,000
0.20	0.20	3.00	300,000	17.50	1,750,000	350,000
0.30	0.23	3.50	350,000	17.50	1,750,000	522,449
0.40	0.27	4.00	400,000	20.00	2,000,000	646,154
0.50 (Median)	0.32	4.57	457,000	22.86	2,286,000	800,000
0.60	0.40	5.33	533,000	26.67	2,667,000	1,066,667
0.70	0.80	6.40	640,000	40.00	4,000,000	2,133,333
0.80	1.00	8.00	800,000	80.00	8,000,000	3,555,556
0.90	1.33	20.00	2,000,000	177.78	17,778,000	12,800,000
1.00	4.00	80.00	8,000,000	800.00	80,000,000	320,000,000
Mean	0.68	8.83	883,000	81.84	8,184,000	6,962,364
(Standard Error of Mean)	(0.06)	(1.14)	(114,000)	(14.40)	(1,440,000)	(2,977,373)

The median CB valuation is equivalent to 0.32 auto deaths. Because of the skewed nature of the responses, the mean value of 0.68 is more than double the median response. Regression analyses of the CB–auto death trade-off rates indicate no significant variations across subjects with respect to either demographic factors, such as age, income, and education, or personal characteristics, such as smoking habits. This result is neither surprising nor disturbing. Most individual attributes, such as household income, should affect the CB valuation and the value of life similarly and thus be unrelated to variation in the CB–auto death trade-off rates across subjects. Because there are no systematic differences among individuals in their risk–risk trade-offs, we can aggregate them into meaningful summary measures such as medians and means without the risk of drawing misleading conclusions from an unrepresentative sample.

The general implications of these results are as follows. Most, but not all, people regard the risk of chronic bronchitis as a less severe outcome than the risk of death. However, the prospect of a sustained chronic illness is viewed as a very severe outcome. On the basis of the median response, the death risk equivalent of CB is 0.32, and on the basis of the mean response, it is 0.68. The general order of magnitude of both the median and the mean is the same and is just below 1, indicating that chronic bronchitis is valued less than death. As is indicated in Section 5, these statistics can be transformed into dollar valuation equivalents using established value of life statistics.

4. RISK-DOLLAR VALUATIONS OF CHRONIC BRONCHITIS

The second approach that we employed to value chronic bronchitis was to establish risk–dollar trade-offs by assessing the chronic bronchitis risk equivalent of a higher cost of living. Column (3) of Table V presents the distribution of increased dollar values of the annual cost of living that respondents were willing to incur per 1/100,000 reduction in the annual probability of chronic bronchitis. If we multiply the results in Column (3) by 100,000, we obtain the implicit dollar value per statistical case of chronic bronchitis in Column (4).

As in the case of the risk–risk results, the response pattern is skewed so that the upper tail of the responses generates a mean valuation estimate in excess of the median. The results indicate that the average dollar value of chronic bronchitis is $883,000, with an associated standard error of $114,000. The $457,000 median of the distribution is just over half of the mean. Each of these values is below the usual estimates of the implicit value of life, which are reviewed in [6]. These results follow the expected pattern, given the CB–auto death risk trade-off results reported above. The upper bound of the chronic bronchitis valuation estimates exceeds most estimates of the value of a fatality, as $8 million exceeds some but not all estimates of the value of life.[18]

[18]One would expect cross-sectional analysis of the risk–dollar trade-offs to yield some systematic variation of values across individuals; however, most of the variable coefficients were insignificant. We regressed the chronic bronchitis dollar values against variables measuring income, education, age, household size, marital status, number of children, sex, and whether the subject smoked. The best results came from equations in which the top 5% and bottom 5% of the distributions of values were deleted from the sample, and in these equations only the household size variable was statistically significant at a 5% level. While it may be that for small expenditures the income effect is unimportant, it is still surprising that the values did not reveal more systematic variation across subjects. In a

5. TRADE-OFFS BETWEEN AUTO DEATHS AND COST OF LIVING

A useful check on the survey methodology is to ascertain the implicit value of life using a direct fatality risk–dollar trade-off. This is done using the automobile accident risk–cost of living trade-offs in Questionnaire B2, and the results of this exploration are reported in Columns (5) and (6) of Table V.

The median response of $2,286,000 is quite reasonable in view of the similar (in 1987 dollars) market-based estimate by [4], but the mean value of $8,184,000 seems rather large. The high mean estimate was generated by a portion of the sample with value of life estimates as high as $80,000,000. Such implausible large estimates can occur because of the difficulty of the comparison task. Respondents are being asked to establish an equivalence between some annual change of chronic bronchitis $x/100{,}000$ that is equivalent to an $80 per year cost of living increase. This is a difficult comparison to make. In contrast, the risk–risk questions focused on chronic bronchitis–auto accident risk comparisons of $x/100{,}000$ and $y/100{,}000$, where most respondents did not believe that the severity of outcomes differed by more than an order of magnitude.

Consider two further checks on the consistency of the results. First, compare the ratio of the dollar value of a statistical CB case to the dollar value of a statistical life with the CB risk–auto death risk ratio found from the direct risk–risk trade-offs. Because of the inordinate importance of outliers in the calculation of mean values, we argued above that the most useful summary statistic is the median value. The median CB value is $457,000 (from Column (4) of Table V), which is 20% of the median auto death value of $2,286,000 (from Column (6) of Table V). In comparison, the median CB–auto death trade-off value is 32% (from Column (2) of Table V).

As a second consistency check on values derived for the risk–risk trade-off and the risk–dollar trade-offs for both chronic bronchitis and automobile fatalities, we calculate an implied value of auto death from dividing the cost of living–chronic bronchitis trade-off rate by the chronic bronchitis–auto death trade-off rate. Use of the median values gives an implied value of an auto fatality of $1,428,000, while the mean values yield a result of $1,299,000 per auto death. Again, these values are reasonably consistent with both the direct measures of the dollar value of auto fatality risk avoidance we derived and the value of life measures from the literature.

The implicit dollar value of CB can be obtained by chaining the responses to Questionnaire Part B1, which gives the CB–auto death trade-off, and Part B2, which gives the auto death–dollar trade-off. These results appear in Column (7) of Table V. The median dollar value of each chronic bronchitis case is $800,000. The mean is much greater because there is one outlier with a $320 million value. This individual expressed extreme responses on each component part, valuing each CB case at four times the amount of each death and having an implicit value of an auto fatality of $80 million. In each case, these were the highest values in the sample and the highest permitted by the program, which indicates that this individual probably did not understand the valuation task.

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subsequent study using our methodology [10], the authors found no significant cross-sectional variation in the risk–risk values, as in our study, but their risk–dollar values were positively related to income, children in the family, nonsmoking status, female sex, and the purchase of life insurance.

TABLE VI
Summary of Risk–Dollar Equivalents

Questionnaire part	Direct dollar valuation estimate	CB dollar estimate using $2 million value of life	CB dollar estimate using $3 million value of life	CB dollar estimate using $5 million value of life
		CB–auto		
A1 & B1 (Median)	—	640,000	960,000	1,600,000
A1 & B1 (Mean)	—	1,360,000	2,040,000	3,400,000
		CB–cost of living		
A2 (Median)	457,000	—	—	—
A2 (Mean)	883,000	—	—	—
	CB–dollars (derived from CB/auto fatality and auto/cost of living)			
B1 & B2 (Median)	800,000	—	—	—
B1 & B2 (Mean)	6,962,364	—	—	—
		Auto–cost of living		
B2 (Median)	2,286,000	—	—	—
B2 (Mean)	8,184,000	—	—	—

An instructive summary of the results is provided in Table VI. For the results creating CB–auto death risk equivalents, the numbers have been transformed into implicit value of life terms using three different reference points: a $2 million value of life, a $3 million value of life, and a $5 million value of life. The $2 million figure is comparable to the median auto death risk valuation within the survey, so this estimate provides an internal comparison of the results. The $3 million figure is included since the recent estimates in [11], using Bureau of Labor Statistics (BLS) data, indicate that the labor market value of life is in the $2 million to $3 million range, and this was the "best estimate" of the value of life in earlier work [15]. The $5 million reference point is the value of life figure obtained using new NIOSH data on job fatality risks, which the authors of [11] view to be superior to the BLS data.

The pattern displayed by the results is fairly similar. In each case mean valuations are at least double the value of the median. Although one would not expect symmetry in a distribution truncated at zero, the very high end responses observed appear to be due to response errors.

The most clearcut divergence from plausible patterns is the mean value of life of $8,184,000 for the auto death–cost of living trade-off. Whereas the mean CB–auto values were roughly double the median, the mean auto–cost of living values were almost four times the size of the median, indicating a much more skewed distribution. As noted in the discussion of Column (6) of Table V, this mean value was influenced in part by individuals with implied values of life as high as $80 million. These outliers suggest that for some people making meaningful trade-offs involving small cost of living differences and low risks of auto accident fatalities is a task they cannot handle effectively.

The valuation of chronic morbidity across the difference questionnaire approaches is quite similar for the case in which we use a $2 million value of life figure to transform the death equivalent statistics into meaningful dollar estimates.

The median value for the CB–auto death risk trade-offs is $640,000, as compared with a median value of $457,000 for the CB–cost of living trade-off. These results are similar to the $800,000 median CB value that was obtained by chaining the CB–auto and auto–cost of living responses. Even with a higher value of life of $3 million, the CB–auto median of $960,000 is not out of line with the CB–cost of living results. Given all the possible sources of error in this first application of the methodology, we view the closeness of all these chronic bronchitis risk valuations to be supportive of the reasonableness of the values derived from the approach.

Once we move to the case where a $5 million value of life is used, the median dollar valuation of each CB case prevented is greatly increased to $1,600,000. If EPA were to rely on, for example, the CB–cost of living results to value CB and then use a value of life of $5 million without also using an appropriately adjusted CB value, this procedure could potentially understate the value of the CB cases prevented by a factor of 3. By converting all outcomes to a health risk equivalence scale using a death risk metric, EPA avoids any distortion in the mix of targeted illnesses that might otherwise occur if the value of life number selected was incorrect.

6. CONCLUSION

Although market evidence remains our most reliable guideline for assessing the shape of individual preferences, such evidence is unavailable for many outcomes that are either not traded explicitly in markets or traded implicitly but in a market for which available data are not rich enough to identify the pertinent trade-off rates. Analysis of risk–risk and risk–dollar trade-offs using various types of simulated market choices provides a useful mechanism for establishing such values.

This study has developed a methodology for deriving morbidity risk valuation estimates on the basis of the trade-off with another well-known risk, rather than forcing individuals to express trade-off rates between morbidity rate reductions and dollars, a more difficult task. We presented several conceptual reasons why consumers should be able to more accurately convey risk–risk trade-offs than risk–dollar trade-offs. In addition, the applications of our methodology to the valuation of reductions in the risk of chronic bronchitis indicate that most individuals can make risk–risk trade-offs, even with a disease as complicated and unfamiliar to healthy people as chronic bronchitis. Although for the purpose of cost-effectiveness analysis there is no need to measure risk reduction value in terms of dollars, when we translated our risk–risk estimates into risk–dollar estimates using either survey results on auto accident risk reduction values or published value of life estimates, the distributions compared favorably, thus providing additional confidence in the reasonableness of the results derived from our methodology. These favorable results suggest that the methodology may be more widely applicable to other morbidity risks, such as various forms of cancer.

While the results of the application of our new morbidity valuation methodology to chronic bronchitis are encouraging, much further research is needed before applying the methodology to give estimates precise enough to be used in regulatory analyses. Several types of sensitivity analyses need to be explored. The authors of [10] have started the process of studying potential biases caused by our approach. They have examined how the values derived from our methodology are affected by the degree of familiarly subjects have with the health benefit being valued. They compared the responses of subjects with and without relatives having chronic respiratory disease. Other potentially valuable sensitivity analysis studies could address the thoroughness and vividness with which the disease characteristics are described to subjects, possible biases created by the starting point, the specific choice situation (that of a locational choice), the severity of the illness whose risk is being valued, and other characteristics of the risk such as involuntariness, immediacy, and dread. While we provided several conceptual reasons why we expect subjects to more easily respond to risk–risk trade-offs than risk–dollar trade-offs and our application to chronic bronchitis yielded values consistent with those derived from the risk–dollar trade-off approach, subsequent studies need to more precisely test this conjecture and evaluate its veracity in different health risk domains.

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