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Willingness to pay for mortality risk reductions: Does latency matter?

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Abstract Using results from two contingent valuation surveys conducted in Canada and the U.S., we explore the effect of a latency period on willingness to pay (WTP) for reduced mortality risk using a structural model. We find that delaying the time at which the risk reduction occurs by 10 to 30 years reduces WTP by more than 60% for respondents in both samples aged 40 to 60 years. The implicit discount rates are equal to 3.0–8.6% for Canada and 1.3–5.6% for the U.S.

Keywords Value of a statistical life · Mortality risks · Benefit-cost analysis

JEL Classification Q51· Q58

For many environmental policies, such as those that seek to reduce exposure to carcinogens, the reduction in the risk of dying occurs many years after the initial investment in pollution reduction. To value the benefits of such policies it is necessary to ask people how much they would be willing to pay now for a reduction in risk that takes place in the future. Economic

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theory suggests that willingness to pay (WTP) for a future risk reduction should be less than WTP for an immediate risk reduction of the same size. This occurs for two reasons: (1) the individual may not be alive to enjoy the risk reduction and (2) if the individual is willing to substitute consumption for risk, the risk reduction should be discounted at the consumption rate of discount. A key question for policy is exactly how much WTP is reduced by a gap between the initiation of a program and the time at which the risk reduction is delivered.

In a recent contingent valuation survey administered in Canada (Krupnick et al., 2002) and the U.S. (Alberini et al., 2004), we asked individual respondents how much they would be willing to pay today for a reduction in their risk of dying at age 70. In this paper, we use the responses to such payment questions to obtain estimates of mean and median willingness to pay for the future risk reduction. Specifically, we present a structural model that produces three sets of results: (1) the relationship between WTP for a risk reduction and respondent age, income, health status, other individual characteristics, and the time when the risk reduction is experienced; (2) the discount rate implicit in the WTP responses; and (3) a comparison of WTP for the future risk reduction with WTP for a risk reduction of the same size that occurs today. Our structural model assumes (as predicted by the life-cycle model) that WTP today for a risk reduction at age 70 equals what the individual would pay for a current risk reduction at age 70 discounted to the present.

We estimate the average discount rate at 3.0–8.6% for our Canada sample and 1.3–5.6% for our U.S. sample. These estimates are in line with those in Moore and Viscusi (1990) (1–14%), Horowitz and Carson (1990) (4.5%), and Johannesson and Johansson (1996) (0.3 and 1.3%). Most importantly for policy, we find that WTP today for a risk reduction at age 70 is, for persons aged 40–60 years, less than half of WTP for a current risk reduction.

The remainder of this paper is organized as follows. Section 1 presents the life-cycle model with uncertain lifetime and reviews its implications for willingness to pay for a reduction in the conditional probability of dying at any age. It also outlines our plan of analysis. Section 2 discusses the administration and structure of our survey. Section 3 presents our econometric models and Section 4 our results. We summarize our findings in Section 5.

1. Theoretical framework and plan of analysis

1.1. The value of mortality risk changes in the life-cycle model

To provide a framework for our empirical work, in this section we derive WTP for a change in the conditional probability of dying (at any age) in the context of the life-cycle model with uncertain lifetime. The derivation follows Cropper and Sussman (1990) and Cropper and Freeman (1991). The model assumes that at age j the individual chooses his future consumption stream to maximize expected lifetime utility,

$$V_j = \sum_{t=j}^{T} q_{j,t}(1+\delta)^{j-t} U_t(C_t) \tag{1}$$

where V_j is the present value of expected utility of lifetime consumption, $U_t(C_t)$ is utility of consumption at age t, $q_{j,t}$ is the probability that the individual survives to age t, given that he is alive at age j, and δ is the subjective rate of time preference. The individual has wealth W_j and an earnings stream $y_j, y_{j+1}, \ldots, y_T$. We assume that (1) is maximized subject to a budget constraint that allows the individual to invest in annuities and to borrow via life-insured loans (Yaari, 1965).

If actuarially fair annuities are available, an individual who invests \$1 at the beginning of his jth year will receive $(1 + R_j)$ at the end of the year with probability $1 - D_j$ and nothing with probability D_j, where D_j is the conditional probability of dying at age j.[1] For the annuity to be fair, it must have an expected payout of $1 + r$, where r is the riskless rate of interest. R_j must satisfy

$$(1 + R_j)(1 - D_j) = 1 + r. \tag{2}$$

Since $R_j > r$, an individual will prefer to save via fair annuities; we assume that he must borrow at the actuarial rate of interest to guarantee that he does not die with loans outstanding. To prevent unlimited borrowing, the present value of the individual's borrowing, discounted at the actuarial rate of interest, must equal his initial wealth,

$$\sum_{t=j}^{T}\left[\prod_{i=j}^{t-1}(1 + R_i)^{-1}\right](C_t - y_t) = W_j.$$

This is equivalent to assuming that the present value of expected consumption equals the present value of expected earnings plus initial wealth,

$$\sum_{t=j}^{T} q_{j,t}(1 + r)^{j-t}C_t = \sum_{t=j}^{T} q_{j,t}(1 + r)^{j-t}y_t + W_j. \tag{3}$$

The individual's lifetime consumption path is chosen to maximize

$$L_j = \sum_{t=j}^{T} q_{j,t}(1 + \delta)^{j-t}U_t(C_t) + \lambda_j \sum_{t=j}^{T} q_{j,t}(1 + r)^{j-t}(y_t - C_t) + W_j. \tag{4}$$

Now consider a program that alters the conditional probability of dying at age k, D_k. Since $q_{j,t} = (1 - D_j)(1 - D_{j+1})\ldots(1 - D_{t-1})$, any program that alters D_k will necessarily alter the probability of surviving to all future ages. For small changes in D_k, willingness to pay may be written as the product of the rate at which the individual is willing to trade wealth W_j for a change in D_k, which we term $VSL_{j,k}$, times the size of the change in D_k,

$$WTP_{j,k} = -\frac{dV_j/dD_k}{dV_j/dW_j}dD_k \equiv VSL_{j,k}dD_k.^2 \tag{5}$$

[1] D_j is the probability that the individual dies between his jth and $j + 1$st birthdays, given that he is alive on his jth birthday.

[2] Equation (4) can be used to define the amount of money that can be taken away from the individual while varying D_k and keep his expected utility constant. We are approximating WTP for a small change in D_k by the slope of this function multiplied by the size of the risk reduction.

Applying the Envelope Theorem to (4),[3] the rate at which the individual substitutes current wealth for D_k may be written (Cropper and Sussman, 1990) as:

$$VSL_{j,k} = \frac{1}{1 - D_k} \sum_{t=k+1}^{T} q_{j,t}\left[(1+\delta)^{j-t} U_t(C_t)\lambda_j^{-1} + (1+r)^{j-t}(y_t - C_t)\right]. \tag{6}$$

Equation (6) says that the value of a change in the probability of dying at age k equals the loss in expected utility from age $k+1$ onward, converted to dollars by dividing by the marginal utility of income (λ_j). Added to this is the effect of a change in D_k on the budget constraint. Cropper and Sussman (1990) show that, by substituting first-order conditions for utility maximization into (6),

$$VSL_{j,k} = \frac{1}{1 - D_k} \sum_{t=k+1}^{T} q_{j,t}(1+r)^{j-t}[U_t(C_t)/U_t'(C_t) + (y_t - C_t)].$$

To show that $WTP_{j,k}$ is $WTP_{k,k}$ discounted to age j we use the fact that $q_{j+1,t} = q_{j,t}/(1 - D_j)$ to write

$$WTP_{j,k} = WTP_{j+1,k}/(1 + R_j). \tag{7}$$

Repeated use of (2) and (7) implies that WTP at age j for a risk reduction at age k equals WTP for a current risk reduction at age k multiplied by the probability of surviving to age k and discounted to the present at the monetary rate of discount,

$$WTP_{j,k} = q_{j,k}(1+r)^{j-k} WTP_{k,k}.^4 \tag{8}$$

Equation (8) suggests that $WTP_{j,70}$ should be lower the lower is the probability of surviving to age 70 ($q_{j,70}$) and should increase with current age (j), holding $q_{j,70}$ constant.

1.2. Plan of the analysis

Our empirical work focuses on Eq. (8), which we use to estimate respondent discount rates (r). Given the respondent's estimate of $q_{j,70}$, we estimate a log-linear version of (8), where $(1+r)^{j-70}$ has been approximated by $\exp[r(j-70)]$ to obtain an estimate of the interest rate facing respondents:

$$\ln WTP_{j,70} = \ln WTP_{70,70} + \ln q_{j,70} + r \cdot (j - 70). \tag{9}$$

On appending an error term Eq. (9) becomes a regression model where the discount rate can be estimated as the coefficient on (j – 70), the time until the risk reduction takes place, as long as the latter varies across respondents.

Because we elicit future WTP only of people of ages 60 and younger, we do not have information about what the respondent's WTP would be for an immediate risk reduction if he were 70 (which appears on the right-hand side of Eq. (9)). However, since our survey also

[3] The Envelope Theorem implies that $(dV_j/dD_k)/(dV_j/dW_j) = (\partial L_j/\partial D_k)/(\partial L_j/\partial W_j)$.

[4] Equation (8) of course holds for $VSL_{j,k}$ and $VSL_{k,k}$ as well.

elicits WTP for a current risk reduction (for persons of different ages), we can substitute an additional equation that predicts WTP for an immediate risk reduction at a given age into the right-hand side of (9), and thus replace ln $WTP_{70,70}$ with its expected value, plus an error term.

This approach also allows us to estimate $WTP_{j,k}/WTP_{j,j}$—i.e., to see by how much WTP is reduced when the risk valued occurs in the future. Equation (8) does not necessarily imply that $WTP_{j,j} > WTP_{j,k}$; however, if $WTP_{j,j} \geq WTP_{k,k}$—if WTP for a given risk reduction is no larger at age 70 than between ages 40 and 60—Eq. (8) indeed implies that $WTP_{j,j} > WTP_{j,k}$. The question of interest for policy is exactly what the ratio of $WTP_{j,k}/WTP_{j,j}$ is.

2. Survey administration and structure

Our survey instrument was administered in Canada in 1999 and in the U.S. in 2000.[5] In the Canada study, the questionnaire was self-administered by respondents using a computer at a centralized facility in Hamilton, Ontario. Study participants were recruited through random digit dialing. In the U.S., we drew a national sample from the panel of individuals maintained by Knowledge Networks. The sample received and filled out the questionnaire via Web-TV.

The questionnaire began by asking the respondent to provide information about his or her self, including age, gender, and health status. It also queried the respondent about the health status of family members (parents and siblings), and about the age of his or her parents. This was followed by a simple tutorial on probability, at the end of which respondents were introduced to the concept of risk of dying. To show risk and risk changes, we used a grid of 1,000 squares. White squares represented survival, while red squares represented death.

Respondents were subsequently told about their risk of dying over the next 10 years as well as the most common causes of death for a person of their age and gender (and shown this risk on the grid of squares). They were asked to think of this risk as their own. When eliciting WTP for a risk reduction, it is important that respondents understand that it is possible to reduce risk through a number of actions (both medical and non-medical), but that doing so costs money. We described to the respondents common risk-reducing actions (such as exercise and medical screening or diagnostic tests); but, to avoid anchoring respondents to specific dollar figures, we simply told them whether these actions were "expensive," "inexpensive," or "moderately priced."

Respondents were asked to report information about their WTP for each of three risk reductions: (i) 5 in 1000 over the next 10 years, (ii) 1 in 1000 over the next 10 years, and (iii) 5 in 1000, but beginning at age 70 and taking place over the subsequent 10 years.[6] The latter question was asked only of respondents aged 60 and younger. We used the dichotomous choice approach ("Would you purchase a product that would deliver the risk reduction in question at a stated price?") with a follow-up question. (see Table A.1 in the Appendix for the bid values used.)

[5] The survey instruments we used in our Canada and U.S. studies were almost identical, except for currency and baseline risk adjustments, and the fact that U.S. respondents were asked more detailed questions about their own health status, and the health status and ages of family members. For more information, see Alberini et al. (2004).

[6] People were randomly assigned to one of two subsamples, "wave 1" and "wave 2." The two subsamples received identical questionnaires, except for the order in which the risk reductions to be valued were presented to the respondents. In wave 2, the order of (i) and (ii) was reversed, but the future risk reduction was the third commodity to be valued in both subsamples.

Respondents were also asked to report their subjectively assessed life expectancy and probability of surviving until age 70. The latter question was asked just before the questions about their WTP for the risk reduction that begins at age 70. It is the subjective probability of living until age 70 that is used in the equation for the WTP for the future risk reduction in the structural model of this paper. The survey ended with socio-demographic questions, debriefing questions, and questions from Short Form 36 (SF-36), a questionnaire widely used to assess health status and functionality in the medical literature.[7]

A total of 930 and 1135 respondents completed the survey in Canada and in the U.S., respectively. The WTP questions about the future risk reductions were answered by 650 persons in Canada and 699 in the US.[8] We exclude from the usable samples respondents who failed simple probability questions, which results in 638 respondents for the Canada study, and all 699 for the U.S. study.[9,10] Of these, 427 and 353, respectively, are from the wave I subsamples.

3. Econometric model

To obtain an estimable econometric model, we begin by appending an error term to equation (9), which we denote as ε. This yields

$$\ln WTP_{j,70} = \ln WTP_{70,70} + \ln q_{j,70} + r \cdot (j - 70) + \varepsilon. \tag{10}$$

Next, we specify a regression equation relating $\ln WTP_{j,j}$, the logarithmic transformation of WTP for an immediate risk reduction at age j, to the individual characteristics of the respondent, including age, j. Formally,

$$\ln WTP_{j,j} = E(\ln WTP_{j,j}) + \eta = \mathbf{x}_j\boldsymbol{\beta} + j \cdot \gamma + \eta, \tag{11}$$

which implies that

$$\ln WTP_{70,70} = E(\ln WTP_{70,70}) + \eta = \mathbf{x}_{70}\boldsymbol{\beta} + 70 \cdot \gamma + \eta. \tag{12}$$

[7] The SF-36 questions were given to respondents in a pencil-and-paper questionnaire in the Canada study, but were included in the Web-TV questionnaire in the US study. The SF-36 questions were asked at the end of both surveys.

[8] Note that the questions about WTP for the future risk reduction were asked of individuals up to 60 years of age.

[9] Following the probability tutorial, respondents were asked to identify which of two grids represented the individual with the higher risk and which of the two they personally would rather be. Individuals who answered these questions incorrectly were deleted from the sample used in this paper.

[10] A comparison of the Hamilton sample with the population of Hamilton and that of Ontario suggests that the sample is representative of both for health status. Respondents are slightly wealthier and better educated than the average Hamilton resident, but are similar to the average Ontario resident (see Krupnick et al. (2002)). The U.S. sample was drawn by Knowledge Networks from a panel recruited through random digit dialing to be representative of the U.S. in terms of age, gender, race and income. We compared those who filled out the survey with those who were invited to do so but declined, finding that the former were slightly less wealthy than the latter, but that there were no major differences across the two groups in all other respects. See www.knowledgenetworks.com for more information on panel representativeness. Comparisons of the Canada and U.S. samples in terms of socio-demographics, health status and baseline risks are provided in Alberini et al. (2004).

Equation (12) can now be substituted into Eq. (10) to obtain

$$\ln WTP_{j,70} = \mathbf{x}_{70}\boldsymbol{\beta} + 70 \cdot \gamma + \ln q_{j,70} + r \cdot (j - 70) + (\varepsilon + \eta). \tag{13}$$

Equations (11) and (13) make up a system of equations with cross-equation restrictions on the coefficients. Inspection of these two equations shows that (i) it is the cross-equation restriction on γ that allows us to disentangle the effect of age from the intercept in the second equation, and (ii) the discount rate, which is assumed here to be constant across individuals, is the coefficient on $(j-70)$, i.e., the latency period. Finally, (iii), an additional restriction is that the coefficient on $\ln q_{j,70}$, the probability of surviving until age 70, which is reported directly by the respondent in our survey, is equal to one.

We assume that ε and η are independently normally distributed, which means that the error terms in Eqs. (11) and (13), ε and $(\varepsilon + \eta)$, respectively, are normal and are correlated with one another. We do not observe the respondent's WTP amounts for the immediate and the future risk reduction, but intervals around them can be formed by combining the responses to the initial and follow-up dichotomous choice questions in the survey. The double-bounded interval-data contribution for an individual of age j to the likelihood function is thus:

$$\begin{aligned}
&\Phi\big(\ln WTP_j^H/\sigma_1 - \mathbf{w}_j\boldsymbol{\theta}_1/\sigma_1, \ln WTP_{70}^H/\sigma_2 - \mathbf{w}_{70}\boldsymbol{\theta}_2/\sigma_2, \rho\big)\\
&-\Phi\big(\ln WTP_j^L/\sigma_1 - \mathbf{w}_j\boldsymbol{\theta}_1/\sigma_1, \ln WTP_{70}^H/\sigma_2 - \mathbf{w}_{70}\boldsymbol{\theta}_2/\sigma_2, \rho\big)\\
&-\Phi\big(\ln WTP_j^H/\sigma_1 - \mathbf{w}_j\boldsymbol{\theta}_1/\sigma_1, \ln WTP_{70}^L/\sigma_2 - \mathbf{w}_{70}\boldsymbol{\theta}_2/\sigma_2, \rho\big)\\
&+\Phi\big(\ln WTP_j^L/\sigma_1 - \mathbf{w}_j\boldsymbol{\theta}_1/\sigma_1, \ln WTP_{70}^L/\sigma_2 - \mathbf{w}_{70}\boldsymbol{\theta}_2/\sigma_2, \rho\big)
\end{aligned} \tag{14}$$

where $\Phi(\cdot)$ is the cdf of the bivariate standard normal distribution, WTP_j^H and WTP_j^L denote the lower and upper bound of the interval around the WTP for the risk reduction starting at age j, and WTP_{70}^H and WTP_{70}^L are the lower and upper bound of the interval around the WTP for the risk reduction that begins at age 70. The symbols $\mathbf{w}_j$ and $\mathbf{w}_{70}$ are the vectors of right-hand side variables in Eqs. (11) and (13) ($\mathbf{w}_j = [\mathbf{x}_j,\ j\,]$; $\mathbf{w}_{70} = [\mathbf{x}_{70},\ 70,\ \ln q_{j,70},\ (j-70)]$), and $\boldsymbol{\theta}_1 = [\boldsymbol{\beta},\ \gamma]$ and $\boldsymbol{\theta}_2 = [\boldsymbol{\beta},\ \gamma,\ 1,\ r]$ are their regression coefficients. Finally, $\sigma_1^2$and σ_2^2 are the error variances, and ρ is the correlation coefficient between the error terms of Eqs. (11) and (13). The coefficients are estimated by the method of maximum likelihood.

In our empirical work, we replace j, age measured in years, with three age-group dummies.[11] The vector of regressors $\mathbf{x}$ includes a gender dummy, a low-income dummy, education expressed in years of schooling and dummies capturing the health status of the respondent.

[11] The relationship between willingness to pay for a mortality risk reduction and, hence, the VSL, and age is very important for policy purposes, since epidemiological evidence (e.g., Pope et al., 1995) suggests that the majority of the lives saved by environmental policies are those of the elderly. In a theoretical exercise, Shepard and Zeckhauser (1982) assume an isoelastic utility function, C^{β}, with $\beta = 0.2$, and show that under certain conditions the VSL is a quadratic function of age that peaks when the individual is about 50 years old. Subsequent contingent valuation surveys by Jones-Lee et al. (1985) and Johannesson et al. (1997), and compensating wage studies by Aldy and Viscusi (2003) and Viscusi et al. (2006) find empirical evidence of an inverted U-shaped relationship between the VSL and age, the highest VSL being observed when the individual is 40–50 years old. Accordingly, we experimented with including age and age squared in the right-hand side of the WTP equation, but the coefficients of these terms were never significant. This specification was abandoned in favor of the one with age-group dummies. Finally, we wish to remind the reader that our sample includes only persons of ages 40 and older. This may have prevented us from capturing an inverted-U-shaped relationship between age and WTP.

Ideally, we would have liked to include income and health status at age 70 in $\mathbf{x}_{70}$, but do not have information on current wealth or expected income at that age. We are therefore forced to proxy future income with current income. To account for the respondent's health status when he experiences the risk reduction, we use a dummy variable based on the respondent's own assessment of whether his or her health will be worse at age 75—in the middle of the decade when the future risk reduction is expected to occur—than it is now (Health Worse at 75).

Clearly, this approach assumes that the interest rate r is constant over time and across individuals. In subsequent runs, we relax this assumption by allowing individuals with different characteristics to have different discount rates. Specifically, we posit that $r_i = \exp(\mathbf{z}_i \lambda)$, where $\mathbf{z}_i$ is a $1 \times k$ vector of individual characteristics. Data limitations do not allow us to discriminate between a linear discount rate or a hyperbolic one, but we do check whether the discount rate is affected by the time horizon over which the discounting takes place by including a dummy variable that takes on a value of one for respondents in the age group from 50 to 60 years.

4. Results

Descriptive statistics for our Canada and U.S. samples are reported in Table 1. Briefly, the two samples are roughly comparable in terms of age, education, and some of the health status variables, but differ somewhat in terms of their respective cardiovascular illness and cancer rates.[12]

Our first order of business is to check whether the responses to the WTP questions always imply that future WTP is less than WTP for the immediate risk reduction. We found that only 12 out of 427 respondents in the Canada study and 12 out of 353 respondents in the U.S. sample gave responses to the WTP questions that clearly implied that their WTP for the future risk reduction was greater than that for the immediate risk reduction. These respondents were excluded from the samples we used for the analyses reported below.

We estimate model (ii) using only respondents in wave 1.[13] Because individuals of all ages contribute observations on WTP for the immediate risk reduction, but only individuals aged less than 60 years contribute observations on future WTP, our total sample sizes are 589 for the Canada study and 403 for the U.S. study.[14]

Assuming that the discount rate is constant for all respondents and all ages, we estimate the discount rate to be 3.0−8.6% in the Canada study and 1.3−5.6% in the U.S. study. Results are sensitive to the inclusion of covariates and age-group dummies on the right-hand side of the two WTP equations.

[12] The difference between the rates of cardiovascular illnesses in the two samples could be due to the slightly different phrasing of the question about such illnesses, while the difference in cancer rates could be due to the more aggressive diagnostic testing for cancer in the U.S. (James Wilson, personal communication). See Alberini et al. (2004).

[13] We choose to do so because our procedure relies on predicting willingness to pay for a 5 in 1000 risk reduction at age 70 for respondents who are currently between 40 and 60 years old. But willingness to pay for an immediate risk reduction is sensitive to the order in which the risk reductions were valued by the respondents in the survey. To be conservative, when we estimate models of willingness to pay for the 5 in 1000 risk change, we restrict attention to those respondents who valued the 5 in 1000 risk reduction first.

[14] Individuals of ages 60 and higher contribute only one observation to the sample used to fit model (14), and respondents of younger ages contribute two (the WTP responses for the immediate and the future risk reductions). Hence, the sample size for this estimation exercise is greater than the number of respondents.

Table 1 Descriptive statistics of the Canada and U.S. samples. cleaned samples,wave I only

Variable	Description	U.S. study Mean	U.S. study Standard deviation	Canada study Mean	Canada study Standard deviation
Age	Age in years	55.2258	11.2849	54.0187	10.295
Male	Dummy	0.5112	0.5005	0.4754	0.4998
Education	Education in years of schooling	13.1464	2.3236	13.7708	2.9537
Bottom 25%	Dummy equal to 1 if respondent's income is bottom 25% of the sample	0.2705	0.4448	0.253	0.4351
Cardiovascular	Has chronic cardiovascular illness (dummy)	0.0149	0.1213	0.1053	0.3072
Lungs	Has chronic respiratory illness (dummy)	0.1613	0.3683	0.2003	0.4006
Pressure	Has high blood pressure (dummy)	0.3275	0.4699	0.1952	0.3967
Cancer	Has or has had cancer of any type (dummy)	0.0993	0.2994	0.0441	0.2056
Chronic	Any of CARDIO, LUNGS or PRESSURE	0.4342	0.4963	0.3905	0.4883
Log Chance	Log chance of surviving to age 70	−0.2459	0.3442	−0.2293	0.3411
Black	African American (dummy)	0.0769	0.2668	0	0
Age 50–59	Age group 50 to 59 (dummy)	0.2382	0.4265	0.2615	0.4398
Age 60–69	Age group 60 to 69 (dummy)	0.2109	0.4085	0.202	0.4019
Age 70+	Age group 70 and older (dummy)	0.1439	0.3514	0.1104	0.3136
Health Worse at 75	Age at age 75 is expected to be worse than it is now (dummy)	0.5136	0.5007	0.4199	0.4940

Table 2 Estimates of the Discount Rate. (assumed constant across individuals and over time). Standard errors in parentheses

Specification	Canada	U.S.
No **x** covariates, $\gamma = 0$	0.0862	0.0559
	(0.002)	(0.005)
No **x** covariates, $\gamma \neq 0$	0.0320	0.0168
	(0.01)	(0.011)
x covariates included in the model, $\gamma \neq 0$	0.0299	0.0130
	(0.010)	(not available)

This is clearly shown in Table 2, where we report the estimates of the discount rate, r, for three models. The first model suppresses all individual characteristics and the age group dummies, the second drops the former but not the latter, and the third is a full model with both individual characteristics and age-group dummies.[15] The estimated discount rates are largest in the model with no covariates and no age-group dummies (8.6% for Canada and 5.6% for the U.S.), and smallest in the full model (3.0% for Canada and 1.3% for the U.S.). The discount rates are systematically larger in the Canada study than they are in the U.S. study.

[15] All three approaches retain ln q_{j70} and $(j - 70)$ on the right-hand side of the equation for WTP for the future risk reduction.

Table 3 Structural form estimation of WTP for current and future risk reduction. Joint lognormal interval-data model.Discount rate expresed as $r_i = \exp(\mathbf{z}_i \boldsymbol{\lambda})$

	Specification I		Specification II	
Variable	Coefficient	T statistic	Coefficient	T statistic
Intercept	6.1207	29.662	6.1267	20.399
β coefficients				
Canada	−0.1739	−1.449	−0.1077	−0.768
Male	−0.2794	−2.509	−0.2915	−2.415
Black	0.7702	2.245	0.6961	1.888
Education	−0.0182	−1.181	−0.0162	−0.753
Bottom 25%	−0.1308	−0.974	−0.2524	−1.755
Chronic	0.1472	1.251	0.1081	0.856
Cancer	–	–	0.4059	1.451
Health Worse at 75	–	–	−0.5074	−1.234
γ coefficients				
Age 50–59	0.2113	1.766	0.128	0.885
Age 60–69	0.0368	0.199	0.091	0.505
Age 70+	−0.4143	−2.278	−0.3522	−1.37
λ coefficients (*determinants of the discount rate*)				
Intercept	−3.7704	−11.335	−3.6898	−5.941
Canada	–	–	0.6873	1.714
Age 50–59	–	–	0.1938	0.715
Bottom 25%	–	–	−0.6564	−1.448
Male	–	–	−0.2803	−1.187
Sigma 1	1.5777	25.918	1.5708	24.657
Sigma 2	1.7443	18.203	1.9902	18.677
Rho	0.8039	32.186	0.8015	32.134
Sample size	992		877	
Log Likelihood	−1729.56		−1609.75	

Results for two specifications of the structural-form model with covariates are displayed in Table 3. In specification I the discount rate is constant, while in specification II it is individual-specific (specification II also adds two health status variables). Here, we pool the data from the two studies to increase the sample size, but make sure that we account for potential differences across the two studies by including a dummy equal to one for the Canada study among the covariates and among the determinants of the discount rate.

In both specifications, WTP for an immediate risk reduction is about one-third lower among males, and about twice as large among African-Americans. We do not find evidence of a significant association between education and WTP, but note that the negative sign on the low-income dummy agrees with expectations. The coefficient on the latter dummy, however, is not statistically significant in specification I, and is significant only at the 10% level in specification II.

We are particularly interested in the coefficients on the health status variables. These coefficients are often large, and so are the standard errors, implying that results should be interpreted with caution. The coefficients on the chronic illness dummy are relatively small and insignificant in both specifications. However, specification II would suggest that persons with cancer are willing to pay 50% more, and persons who believe their health at age 75 will be worse than it is now are willing to pay 40% less, than the other respondents. The respective coefficients, however, are not statistically significant.

Specification I finds that the oldest individuals in the sample—those aged 70 and older—are willing to pay about one-third less than younger respondents. This effect is significant at the 5% level. The magnitude of the effect implied by specification II is similar, but the coefficient on the age70-and-older dummy is no longer significant.[16,17]

At the same time, specification II results in a discount rate for low-income respondents that is 48% *lower* than that of the other respondents, but this effect is not statistically significant. Older respondents have higher discount rates: those in the 50–59 age group have a discount rate that is 21% greater than that of younger respondents, but the p-value of the coefficient is about 0.23. Male respondents report 25% lower discount rates, but, once again, this effect is not statistically significant. The only coefficient that is statistically significant (at the 10% level) in specification II is that on the Canada dummy, which implies that, all else the same, our Canadian respondents hold discount rates that are roughly twice as large as those of our U.S. respondents.

Our models indicate that, assuming household income is above the bottom 25% of the sample, a Canadian male will have a discount rate of 3.75% (s.e. 1.84%) if he belongs to the 40–49 age group, and 4.55% (s.e. 2.78%) if he belongs to the 50–59 age group. His U.S. counterpart is predicted to have a discount rate of 1.89% (s.e. 1.62%) and 2.29% (s.e. 2.20), respectively. Should the 40–49 year-old now be in the lower-income group, his discount rate would be 1.94% (s.e. 1.70%) if Canadian and 1% if a U.S. citizen (s.e. 0.73%). Clearly, these figures are aligned with those shown in the third row of Table 2, which refers to comparable statistical models estimated separately for the two countries.

We attempted to estimate a function where the discount rate is a linear function of age (and hence of the time until the discounting takes place, which is 70 minus current age), but this model behaved poorly, as did the model with hyperbolic discounting.

We end by comparing mean and median WTP for a future risk reduction, estimated using all respondents but with no covariates nor age-group dummies,[18] with mean and median

[16] To test the robustness of our results, we re-estimated both specifications after relaxing the constraints that the coefficients on the **x** covariates are equal across the two WTP equations. Unfortunately, our maximum lilkelihood estimation routines were unable to produce the standard errors of the estimates. The likelihood ratio statistic of the null that the β coefficients are equal across the two equations is equal to 15.07, with a p-value of 0.0577. We also re-estimated our model assuming that the two WTP variables are independent Weibull. The results are very similar to those reported in this paper for correlated lognormal. The Weibull distribution agrees with the lognormal distribution in its prediction for median WTP, but typically results in lower mean WTP values than the lognormal distribution.

[17] The structural-form estimation approach of this paper can be compared with a reduced-form approach in which we regress WTP for a risk reduction at age 70 directly on variables thought to influence it, such as the respondent's age, gender, education and income, current and future health status, and the respondent's self-assessed chance of surviving until age 70. From Eq. (8), we expect the coefficients on $q_{j,70}$ and age to be positive. To the extent that current income is correlated with wealth, it should increase $WTP_{j,70}$, and so, presumably, should a more optimistic estimate of the respondent's health status at age 75. Double-bounded interval-data regressions for the Canada and US samples, respectively, as well as for the pooled data, show that in this reduced form model individual characteristics like age, race, education, and income are generally not important predictors of a person's WTP for the future risk reduction. The coefficient on income, while not statistically significant, has a sign that is consistent with expectations. The only significant predictors are current health status, future health status, and the subjective probability of living until age 70. Individuals are willing to pay more if their health is currently impaired, and less if they expect that health in the future to be worse than now. WTP is positively associated with the self-assessed probability of living until age 70.

[18] The log of the self-assessed probability of surviving to age 70, and $(j - 70)$ are retained in the equation for the future risk reduction.

Table 4 Mean and Median WTP for future vs. immediate risk reductions. All figures in 2000 U.S. dollars (PPP conversion from the Canadian dollar) Cleaned samples

	Canada study			U.S. study		
	Future	Immediate	Ratio	Future	Immediate	Ratio
Median WTP	36.60	289.20	0.13	82.20	354.53	0.23
	(4.98)	(20.19)	(0.11)	(11.45)	(41.19)	(0.02)
Mean WTP	364.6	987.03	0.41	543.16	1589.46	0.34
	(100.72)	(62.62)	(0.11)	(168.05)	(184.67)	(0.10)

Notes: Joint lognormal interval-data model with no individual-specific covariates on the right-hand side of WTP_{JJ}, 70% probability of surviving to age 70, and current age equal to 50 years.

WTP for a current reduction, estimated using the same respondents. Specifically, we restrict γ in Eqs. (11) and (14) to be equal to zero, suppress all regressors in **x**, and let β_0 denote the intercept of the model. The ratio between the mean WTP figures is:

$$\frac{E(WTP_{j,70})}{E(WTP_{j,j})} = \frac{\exp\left(\beta_0 + \ln q_{j,70} + r\cdot(j-70) + 0.5\sigma_2^2\right)}{\exp\left(\beta_0 + 0.5\sigma_1^2\right)} = \frac{\exp\left(\ln q_{j,70} + r\cdot(j-70) + 0.5\sigma_2^2\right)}{\exp\left(0.5\sigma_1^2\right)}, \tag{15}$$

while that of the two median WTP figures is:

$$\frac{\text{Median } WTP_{j,70}}{\text{Median } WTP_{j,j}} = \frac{\exp(\beta_0 + \ln q_{j,70} + r\cdot(j-70))}{\exp(\beta_0)} = \exp(\ln q_{j,70} + r\cdot(j-70)) \tag{16}$$

Standard errors around the ratios of the estimates are computed using the delta method.[19]

These results appear in Table 4, where all calculations assume that $j = 50$ and $q_{j,70} = 0.70$ (the sample averages). As expected, WTP for a future risk reduction *is* less than WTP for a risk reduction that starts immediately.[20] The ratio of mean $WTP_{j,k}$ to mean $WTP_{j,j}$ for $40 \le j \le 60$ and $k = 70$ is 0.41 in the Canadian sample and 0.34 in the U.S. sample. This suggests that a latency period of 10 to 30 years, experienced late in life, significantly reduces WTP for a reduction in risk of dying.

The WTP estimates displayed in Table 4 can be translated into VSL estimates by dividing the WTP by 5/10,000 (the annual risk reduction valued by our respondents). The VSLs derived from the mean WTP estimates for the future risk reductions for this 40–60 age group range from \$730,800 for Canada to \$1,086,000 for the U.S. As is generally the case with estimates from contingent valuation surveys, the median VSLs are lower still. By contrast,

[19] Eqs. (15) and (16) presume that age does not affect WTP. As shown in Table 3, this is indeed the case among individuals aged 40–60.

[20] We remind the reader that we have excluded from the usable samples a total of 24 respondents for whom the WTP for the future risk reduction unambiguously exceeds that for the immediate risk reduction.

the VSL derived from the mean WTP for an *immediate* risk reduction is \$1.974 million (Canada) or \$3.179 million (for the U.S.).[21]

5. Conclusions

This paper reports the results of a contingent valuation survey that elicits WTP for current and future mortality risk reductions. The survey questionnaire was self-administered by respondents in Canada and the U.S. using a computerized format.

We examine the responses to the payment questions for the future risk reduction using a structural form approach that results in a system of related equations with cross-equation restrictions. We estimate the implicit discount rates to be 3.0–8.6% in Canada and 1.3–5.6% in the U.S. The discount rate appears to depend on age and health status, but inference should be made with caution, because the estimated coefficients are large, as are their standard errors. For comparison, earlier estimates of the discount rate in risk reduction tradeoffs range from 0.3% (Johannesson and Johansson, 1996) to as high as 14% (Moore and Viscusi, 1990).[22]

Finally, we note that for respondents aged 40 to 60, WTP today for a risk reduction occurring at age 70 is less than half of WTP for a current risk reduction of the same size. Delaying the time at which the risk reduction occurs significantly reduces WTP, at least for respondents in the 40 to 60 age group.

What are the policy implications of this finding? In its primary analysis of the benefits of reducing the maximum contaminant level (MCL) of arsenic in drinking water from 50 ppb to 10 ppb, the USEPA (2000) did not discount the value of a statistical life used to value the reduction in lung and bladder cancers that were predicted to occur as a result of the rule, even though there is likely to be a cessation lag between the reduction in exposure and the reduction in cancers.[23] The study estimated that there would be between 21 and 30 fewer cancers per year from the reduction in exposure, starting immediately, and used a VSL of \$6.1 million (1999 USD) to value each case. The resulting mortality benefits (\$128–\$183 million) accounted for over 90% of the monetized benefits of the rule. Total annual costs were estimated to be \$205.6 million, implying that the upper bound estimate of benefits was approximately equal to costs.

Adjusting the \$6.1 million VSL to reflect an average gap of 20 years between reduction in exposure and reduction in cancer would, according to the results reported above, cause the benefit-cost ratio to fall below one-half.[24] Using the VSLs estimated in our study for this

[21] These contemporaneous VSL estimates are higher than those reported in Alberini et al. (2004) for two reasons. First, for ease of computation, we assume here that WTP is lognormally distributed, while in Alberini et al. we used the better performing Weibull distribution. The two distributions tend to produce similar estimates of the median WTP, but the estimates of mean WTP based on the lognormal are generally higher than those resulting from the Weibull distribution. Second, here we restrict the sample to those 40–60 years old. In Alberini et al., we also included older people, who tend to have a lower WTP.

[22] These figures are in sharp contrast with estimates of the discount rate for money based on surveys and laboratory experiments. For example, Harrison et al. (2002) estimate the discount rate for money to be 28% in a field experiment in Denmark, while Warner and Pleeter (2001) peg the individual discount rates for U.S. military personnel that were offered voluntary separation options between 10 and 19% for officers, and between 35 and 54% for enlistees.

[23] In evaluating the health benefits of a reduction in exposure to a carcinogen, the *cessation-lag* matters, i.e., the time between cessation of exposure and the reduction in risk.

[24] We obtain benefit figures that are less than 50% if we multiply the VSL (\$6.1 million) by $\exp(-20 \cdot \delta)$, where δ is a discount rate between 1.3 and 5.6 percent, our estimates for the U.S., and further multiply the result by about 0.70, the average respondent-estimated probability of surviving until age 70.

valuation exercise would have even more dramatic effects in lowering benefits, as our VSL for the U.S. ($3.2 million) is about half that used by EPA.

The decision to reduce the MCL for arsenic is, of course, more complicated than the previous paragraph would suggest.[25,26] Our purpose in citing this example is to show that allowing for a gap between reduction in exposure and reduction in risk can indeed make a difference in a policy context.

Appendix

Table A1. Bid design by country

	Initial bid	If yes	If no
U.S.	70	150	30
(2000 U.S. dollars)	150	500	70
	500	725	150
	725	1000	500
Canada	100	225	50
(1999 Canadian	225	750	100
dollars)	750	1100	225
	1100	1500	750

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[25] The USEPA Science Advisory Board (USEPA, 2001) criticized the benefits analysis for assuming a zero cessation lag, but also noted that no attempt was made to quantify other health benefits, in spite of a rich epidemiological literature.

[26] A referee pointed out that altruism may place a role in determining people's WTP to reduce arsenic in drinking water. This is a valid point; however, even in the presence of altruism the lag between exposure and effect should also affect WTP.

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