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To Be, or Not to Be, That Is the Question: An Empirical Study of the WTP for an Increased Life Expectancy at an Advanced Age

MAGNUS JOHANNESSON
Department of Economics. Stockholm School of Economics, S-113 83 Stockholm, Sweden

PER-OLOV JOHANSSON
Department of Economics, Stockholm School of Economics, S-113 83 Stockholm, Sweden

Abstract

This study reports an attempt to measure the value of an increased survival probability at advanced ages. It turns out that the average willingness to pay for a program which would increase the expected length of life by one year, conditional on having survived to the age of 75 years, is lower than $1,500. The willingness to pay increases with a person's age, but at a low and seemingly constant rate (1–4 percent per year).

Key words: expected length of life; time preference; contingent valuation; willingness to pay

JEL Classification: J17

Introduction

Many western societies faces the combination of an aging population and rapid development of medical technology. This provides a challenge to decision makers in that the cost of providing frontier care to more and more and older and older people tends to increase rapidly. There is also the difficult and painful question as to whether we are prepared to pay for increasingly sophisticated and expensive life-extending treatments.

Cropper et al. (1994) touch upon this question by letting people choose among programs which would save lives in different age groups. It turns out that the average respondent strongly favors programs which save the lives of young people rather than programs which save old people. Similar results have been obtained for Sweden in a study by Johannesson and Johansson (1995a). These studies thus seem to indicate that people would like to allocate more health care resources to young people and fewer to old people. However, these studies provide no guidance as to the question of whether we are willing to pay the costs for new technologies aimed at increasing our own survival probability once we become older people. There are studies on observed wage-risk trade-offs of workers in the labor market (see, e.g., Viscusi and Moore, 1989; Moore and Viscusi, 1988, 1990), but it is not obvious that their results can be generalized to the general population and to death risks faced by old people.

This article addresses this valuation question by asking a random sample of adult Swedes about their current willingness to pay for a new medical program or technology which would extend the expected remaining duration of their lives, conditional on having survived until the age of 75. There are three different issues on which the study sheds light. First, we get an estimate of the average willingness to pay (WTP), as well as the proportion of the population willing to pay at all for a shift in the survival probability at advanced ages. Second, we can examine if this WTP increases smoothly with age or if there is a dramatic increase in the WTP when people become older. Third, we can obtain a rough estimate of the marginal rate of time preference and check if its magnitude is age-dependent.

The article is structured as follows. In section 1, the basic model is presented and used to define a willingness to pay measure as well as to show how our data can be used to estimate a marginal rate of time preference. We then turn to a presentation of our empirical data and to the methods used to analyze the data. Section 3 presents the results of the empirical study, and the study ends with a few concluding remarks.

1. A simple model of the value of changes in life expectancy

Let us consider an individual who consumes a single commodity, which, following Rosen (1988), can be interpreted as representing quality of life. The individual also values the length of life. The present value utility at his current age, denoted T_0, attained from surviving with certainty another $t - T_0$ "years," is written as follows:

$$U(t; T_0) = \int_{T_0}^{t} u[c(s); T_0; s]\alpha(s; T_0)ds, \tag{1}$$

where $u[c(s); T_0; s]$ is a twice continuously differentiable instantaneous utility function on $(0, \infty)$, $c(s)$ is consumption at time s, $\partial u[.]/\partial c(s) = u_c[c(s); T_0; s] > 0$, $\partial^2 u[.]/\partial c(s)^2 = u_{cc}[c(s); T_0; s] < 0$ for $c \in [0, \infty)$, and $\alpha(s; T_0)$ is a strictly positive and continuously differentiable discount factor on $[0, \infty)$, in (1) discounting back utility to time T_0; i.e., $\alpha(s; T_0) = \alpha(s)/\alpha(T_0)$. The instantaneous utility $u(.)$ derived from consuming $c(s)$ units of the commodity at time s may depend on the individual's age at that time, as is indicated by T_0 and s in the instantaneous utility functions. Unless otherwise stated, we assume that present value utility $U(.)$ is increasing in t, and that $U(.)$ may be "age-dependent" also through a time-dependent marginal time preference $-[d\alpha(s; T_0)/ds]/\alpha(s; T_0) = \theta(s)$.

The survivor function of the individual is defined as follows:

$$\mu(t) = 1 - F(t) \tag{2}$$

where $\mu(0) = 1$ and $\lim_{T\to\infty} \mu(T) = 0$. This function yields the probability that the individual survives for at least t periods/years, i.e., $F(t)$ in (2) yields the probability that the individual survives at most until time t. The probability density of living for exactly t

"years" is $F_t(t) = -\mu_t(t)$, where the subscript t refers to a derivative with respect to time, and $F_t(t) \geq 0$ for $t \in [0, \infty)$.

Conditional on having survived until time T_0, the individual's remaining expected present value utility can be written as follows:

$$E(u_{T_0}) = \int_{T_0}^{\infty} \frac{U(t; T_0)F_t(t)}{\mu(T_0)} dt = \int_{T_0}^{\infty} u[c(t); T_0; t]\alpha(t; T_0)\mu(t; T_0)]dt \tag{3}$$

where $\mu(t; T_0) = \mu(t)/\mu(T_0)$ is the probability of surviving at least to time t conditional on having survived until time T_0. The final equality in (3) is obtained by integration by parts; note that $F_t(t) = -\mu_t(t)$ in (3). The middle expression in (3) yields the present value utility at time T_0, conditional on having survived that long, of living for exactly t periods multiplied by the probability of living that long, i.e., $F_t(t)$, summed (integrated) from $t = T_0$ to $t = \infty$. The right-hand side expression in (3) yields the present value at time T_0 of instantaneous utility at time t multiplied by the probability of surviving for at least $t - T_0$ periods beyond T_0 summed (integrated) over the entire time horizon.

The considered individual faces a budget constraint, which can be written as follows:

$$\dot{k}(t) = rk(t) + y(t) - c(t)\,; \qquad k(T_0) = k_0 \tag{4}$$

where a dot denotes a time derivative, $k(t)$ is wealth at time t, r is the, for simplicity, constant rate of interest, $y(t)$ is a fixed income at time t, $c(t)$ is consumption at time t, and k_0 is a constant.

The individual maximizes his expected present value utility subject to the dynamic budget constraint in (4); there is also a transversality condition, see (A.4) in the appendix, which prevents unlimited borrowing.

The expected present value Hamiltonian corresponding to this maximization problem is:

$$H(t) = u[c(t); T_0; t]\alpha(t; T_0)\mu(t; T_0) + \lambda^p(t)[rk(t) + y(t) - c(t)] \tag{5}$$

where $\lambda^p(t) = \lambda(t)[\alpha(T_0)\mu(T_0)]^{-1}$ is an expected present value costate variable. Necessary conditions for an optimal solution to the individual's decision problem are stated in the appendix.

Assume that the individual has solved the above maximization problem. His expected remaining present value utility at time T_0, conditional on having survived to time T_0, is defined as follows:

$$V(T_0) = \int_{T_0}^{\infty} u[c^*(t); T_0; t]\alpha(t; T_0)\mu(t; T_0)dt \tag{6}$$

where $V(T_0)$ denotes the value function, i.e., the solution of the maximization problem in (3)–(4), conditional on having survived until age T_0, and an asterisk refers to an optimal value. The reader is referred to Caputo (1990), Johansson and Löfgren (1994), LaFrance and Barney (1991) and Seierstad and Sydsaeter (1987) for details (in particular on how to use the value function in comparative dynamics).

In order to arrive at an expression for the value of changes in survival probabilities which can be estimated from empirical data, we proceed as follows. Let us write the survivor function as $\mu(t) = \mu[t, \beta(t)]$, where $\beta(t)$ is a shift variable whose initial value is equal to zero for all t. We use $d\beta(t)$ to redistribute probability mass in a time interval $[T, T + \epsilon)$, where ϵ is an arbitrary positive number, and $T > T_0$. We will assume that β is changed so as to marginally increase the individual's life expectancy (and sometimes use β, for short, when we refer to $\beta(t)$).

Next, differentiate the Hamiltonian along the optimal path with respect to $\beta(t)$ (evaluated at $\beta(t) = 0$). One obtains:

$$dV(T_0) = (\partial V(T_0)/\partial\beta)d\beta = \int_{T_0}^{\infty} [\partial H(t)/\partial\beta(t)]d\beta(t) = \int_{T}^{T+\epsilon} [\partial H(t)/\partial\beta(t)]d\beta(t)$$

$$= [\alpha(T_0)\mu(T_0)]^{-1} \int_{T}^{T+\epsilon} u[c^*(t); T_0; t]\alpha(t; 0)\mu_\beta[t, \beta(t)]d\beta(t) \tag{7}$$

where a subscript β refers to a partial derivative with respect to $\beta(t)$, $\alpha(t; 0)$ discounts time t values to time 0, and $[\alpha(T_0)]^{-1}$ shifts present values from time zero to time T_0. Thus, the integral in (7) yields the change in expected present value utility (at time 0) over the time interval T to $T + \epsilon$. This value is discounted to time T_0, through $[\alpha(T_0)]^{-1}$, and adjusted, through $[\mu(T_0)]^{-1}$, for the fact that the individual has survived until time T_0.

Let us next assume that the individual makes a payment $dCV(T_0)$ at time T_0 in exchange for a change in the parameter β. We model this by defining fixed income at time T_0 as $y(T_0) = Y(T_0) + CV(T_0; \beta)$, where $Y(.)$ is a fixed income, $CV(.) = 0$ for $\beta = 0$, and $dCV(T_0) = [\partial CV(.)/\partial\beta]d\beta$. The payment $dCV(T_0)$ is such as to keep the individual at his initial level of expected present value utility following a change in the individual's survivor function. Proceeding in the same way, as in (7), one arrives at the following expression:

$$(\partial V(T_0)/\partial\beta)d\beta = [\alpha(T_0)\mu(T_0)]^{-1} \int_{T}^{T+\epsilon} u[c^*(t); T_0; t]\alpha(t; 0)\mu_\beta[t, \beta(t)]d\beta(t) -$$

$$\lambda^{c*}(T_0)dCV(T_0) = 0, \tag{8}$$

where $\lambda^{c*}(T_0) = \lambda^{p*}(T_0)$ can be interpreted as the current value marginal utility of income (wealth) at time T_0 conditional on having survived that long. Dividing through (8) by $\lambda^{c*}(T_0)$ converts the expression from units of utility to monetary units. Thus, by estimating $dCV(T_0)$, we get an estimate of the conditional WTP for a small change in the survival probability over the time interval T to $T + \epsilon$.

Let us next define the ratio of the individual's WTP at time T_1 and time T_0. In so doing, let us assume that on $[T, T + \epsilon)$ both the instantaneous utility functions and the pure discount functions are independent of the individual's *current* age, i.e., T_0 and T_1. That is, whether the individual is 40 years or 50 years of age, say, has no impact on the present value utility he will derive in the age interval 75–80 years. Moreover, assume that the current value marginal utility of wealth $\lambda^{c*}(.)$ is constant over time. Given these assumptions, one obtains the following neat expression:

$$dCV(T_1) = \frac{\alpha(T_0)\mu(T_0)}{\alpha(T_1)\mu(T_1)} dCV(T_0) \tag{9}$$

The general expression corresponding to (9) can be found in (A.5) in the appendix.

Equation (9) provides us with a possibility of estimating the marginal rate of time preference, assuming here that θ is independent of the individual's age. The ratio of survival probabilities in (9) can be calculated from population survival data. Then, by comparing the WTP of people of age T_0 years and age T_1 years, respectively, one can calculate the marginal rate of time preference θ from the equality: $dCV(T_1) = dCV(T_0)e^{\theta\Delta t}\mu(T_0)/\mu(T_1)$, where $\Delta t = T_1 - T_0$. We use an exponential distribution, since θ is a constant, by assumption, and our basic model is a continuous-time model. Since data for more than two age groups are available, we can also test the hypothesis that θ is constant over (different parts of) an individual's lifespan.

Alternatively, (9) can be rewritten so as to provide an estimate of the individual's expected (real net of tax) interest rate; see (A.5). Provided that the expected interest rate does not vary with the individual's age, one can test the hypothesis that the individual's current age affects his valuation of the considered change in his survival probability. That is, one can check if the WTP grows at an increasing or decreasing rate with a person's age. Such an increasing or decreasing rate is an indication of an age dependency of the value of increased longevity.

It should be noted, however, that an individual may find that the opportunity costs of prolonging life may exceed the benefits of a longer life. Thus, as has been shown by Erlich and Chuma (1990), the WTP for an extension of life is not necessarily strictly positive. This is, however, a testable hypothesis, since WTP should be equal to zero for a person who finds T to be optimal or even too large.

2. Methods

A binary willingness to pay question was administered in a random sample of individuals in the age 18–69 age group. The survey was carried out in June 1995 by a professional survey firm (Scandinavian Opinion AB), and telephone interviews were used. In total, 2013 individuals were interviewed; 82% of the 2455 contacted individuals agreed to be interviewed. The willingness to pay question was worded in the following way:

"The chance for a man/woman of your age to become at least 75 years old is x percent. On average, A 75-year-old lives for another ten years. Assume that if you survive to the age of 75 years you are given the possibility to undergo a medical treatment. The treatment is expected to increase your expected remaining length of life to 11 years.

Would you choose to buy this treatment if it costs SEK C and has to be paid for this year?

☐ Yes

☐ No"

The following six bids, C, were used in SEK (Swedish Crowns; \$1 ≈ SEK 7.25 in August 1995): 100, 500, 1000, 5000, 15000, and 50000. The probability of surviving until the age of 75 years (i.e., x) was also varied, depending on the age and sex of the respondent, according to the average survival probabilities in Sweden. The following probabilities for men/women were used: 0.6/0.75 (18–39 years), 0.65/0.80 (40–59 years) and 0.7/0.85 (60–69 years).

The NOAA expert panel on the validity of the contingent valuation method concluded that the existing evidence indicates that hypothetical willingness to pay overestimates real willingness to pay (National Oceanic and Atmospheric Administration, 1993). For this reason, in a follow-up question, we asked the respondents if they were totally sure whether they would pay or not. The idea is that only those individuals that are certain of their yes response would actually pay in a real decision situation. This approach allows a more conservative estimation of willingness to pay where only the respondents that are certain of their yes response are interpreted as truly accepting the bid. Ready et al. (1995) found that replacing the pure yes/no alternatives by a number of yes/no alternatives (yes, certain; yes, uncertain, etc.) may affect the overall proportion of yes answers. Our approach, where we ask a pure yes/no question and then inquire whether a yes answer is certain or uncertain, avoids this complication. We analyzed our data both in accordance with the standard interpretation of the yes responses and the more conservative interpretation of the yes responses. Sex, age, education, and income data were also collected within the survey in order to investigate the relationship between willingness to pay and these socioeconomic characteristics.

Using a linear approximation of the utility function, see, for example, Johansson (1995) and assuming a logistic model, the log of the odds that the bid is accepted is equal to:

$$\ln[P/(1 - P)] = \beta_0 + \beta_1 C, \tag{10}$$

where P is the probability of accepting the bid C, β_0, and β_1 are coefficients to be estimated. Since a medical treatment is a private commodity, which you are free to accept or reject to "buy," we rule out a negative WTP in the estimation of the mean WTP. Thus, in the estimation of the mean WTP, the WTP is set equal to zero for the proportion of respondents, which the logit regression predicts to have a non-positive WTP (an assumption which rules out a logarithmic specification). In the case where the WTP is nonnegative, but the probability of a zero WTP is strictly positive, the mean willingness to pay is equal to (Johansson, 1995):

$$dCV = \int_0^{\infty} [1/(1 + e^{-(\beta_0+\beta_1 C)})]dC = -(1/\beta_1)\ln[1 + e^{\beta_0}]. \tag{11}$$

The mean willingness to pay was also estimated with a nonparametric method reported in Kriström (1990), which makes no assumption about the distribution of the willingness to pay in the population. Using the proportion of individuals accepting the bid at different bid levels, a curve is constructed that shows the proportion of acceptance as a function of the bid. The mean willingness to pay is equal to the area below this curve. If the proportion of acceptance was positive at the highest bid level used in the study (SEK 50,000), the maximum willingness to pay was assumed to be equal to this bid in our nonparametric estimation.

3. Results

Of the 2013 respondents interviewed, 28% answered yes to the binary willingness to pay question, 71% answered no, and 1% were unable to answer the question. Of the yes responses, 47% were certain of their yes response. Overall, 53% accepted the lowest bid of SEK 100 in the study, and 9% accepted the highest bid of SEK 50,000 in the study. If only the individuals that are certain of the yes response are interpreted as accepting the bid, the proportion of acceptance goes down to 29% at the lowest bid and 4% at the highest bid. The low proportion of acceptance at the lowest bid of SEK 100, suggests that many individuals have a zero willingness to pay.

The results of the regression analysis for the probability of accepting the bid (standard estimation) and the probability of accepting the bid with certainty (conservative estimation) are shown in Table 1.[1] The bid is highly significant with the expected sign in both regressions. Age is also statistically significant with the expected positive sign in both regressions, consistent with the hypothesis of a positive θ (discount rate). Income has the expected positive sign in both regressions, but is only statistically significant in the conservative estimation. The education variable has a positive sign and is statistically significant at the 5% level in the standard estimation and at the 10% level in the conservative estimation, indicating that the willingness to pay increases with higher education. Sex has a positive sign in both regressions, but is not statistically significant.[2] According to the likelihood ratio index, the fit of the two regressions is about the same, whereas the proportion of correctly predicted responses is higher for the conservative interpretation of the willingness to pay data (see Amemiya, 1981, for details on these statistical measures).

In order to estimate the discount rate, i.e., θ, the population was divided into three age groups of equal size (18–34 years, 35–51 years, and 52–69 years); this is the most neutral way of grouping our, unfortunately, scarce number of observations. The mean willingness to pay was estimated for each of these age groups based on separate logistic regression

Table 1. Results of the logistic regression analysis for the probability of accepting the bid (standard estimation) and the probability of accepting the bid with certainty (conservative estimation), *t*-ratio within parentheses.

Regressor variable	Standard estimation	Conservative estimation
Intercept	−1.32***	−2.79***
	(−5.47)	(−8.69)
Bid	−0.000049***	−0.000050***
	(−9.80)	(−6.58)
Age	0.010**	0.018***
	(2.48)	(3.37)
Income[a]	0.0000073	0.000019***
	(1.28)	(3.02)
Education[b]	0.31**	0.30*
	(2.39)	(1.78)
Sex[c]	0.053	0.026
	(0.69)	(0.29)
Number of observations	1925	1925
Log-likelihood	−1063.23	−713.55
Goodness of fit:		
Individual prediction (%)	71.64	86.44
Likelihood ratio index	0.07	0.07

***, **, * = Significant at 1%, 5%, and 10% levels (two-tail test).
[a]: SEK/month (pretax);
[b]: 1 = ≥ high school, 0 = otherwise;
[c]: 1 = man, 0 = woman.

equations for each age group. In table 2, the estimated mean willingness to pay is shown for the three age groups for the standard and the conservative willingness-to-pay estimations based on both the logistic regression analysis and the nonparametric method.

The estimated willingness to pay with the nonparametric method is somewhat lower than the willingness to pay based on the logistic regression equations. The reason for this outcome is the fact that the former approach ignores or truncates the right-hand side tail. In total, the willingness is about SEK 10,000 with the standard estimation and SEK 4,000 in the conservative estimations based on the logistic regression equations. The willingness to pay increases with age, a result which is consistent with the regression results presented in table 1. The implied discount rate is between 0.3% and 1.3% based on the standard

Table 2. Estimated mean willingness To pay (WTP) in SEK. The implied marginal rate of time preference within parentheses.

	Standard WTP estimyation		Conservative WTP estimation	
Age group	Regression	Nonparametric	Regression	Nonparametric
18–34 years	8113	6632	2180	1755
	(1.3%)	(0.3%)	(2.9%)	(3.2%)
35–51 years	10208	7151	3594	3071
	(0.4%)	(0.3%)	(3.4%)	(1.6%)
52–69 years	11707	8146	7097	4389
All	9787	7283	3922	2952

willingness to pay estimation and between 1.6% and 3.4% based on the conservative willingness to pay estimation (see the discussion following (9) for the formula used for these computations). There is no obvious age dependency for the discount rate. We also carried out an estimation of the mean willingness to pay in the three different age groups, controlling for differences in the socioeconomic variables of income, education, and sex between the age groups. However, the results are similar to those presented in table 2.

4. Concluding remarks

The willingness to pay for an increased life expectancy is surprisingly low in this study. The considered "project" increases the expected length of life by one year, provided that the individual survives to the age of 75 years. The average WTP for this conditional increase in the expected length of life is \$400 to \$1,500. According to a rough estimate, the value of a statistical life in our study is in the range \$30,000 to \$110,000. These numbers are in the lower tail of the values reported in the survey of valuation studies of Viscusi (1992). There is an age dependency in our data in the sense that the WTP increases with age, but we cannot detect a dramatic shift in preferences as people become older.

In terms of a discount rate, our results are reasonable. The estimated discount rate is in the same range as the expected real aftertax interest rate in Sweden (1–4%). There is no obvious age pattern to the discount rate. Our results rather suggest that people use the same discount rate independently of their age. The discount rates reported here are consistent with those reported by Moore and Viscusi (1990). Using wage-risk trade-offs of workers in the labor market, they estimate the discount rate for life years at 1–11%, depending on the model used.

The fact that the WTP for the considered increase in life expectancy is quite low is in accordance with results reported by Cropper et al. (1994). They find that respondents strongly prefer to devote resources to "life-saving" programs directed towards young people rather than to programs aimed at older people. We interpret the saving of a life as meaning avoiding one fatality during a year. For example, on average, saving 11 60-year-olds is judged equivalent to saving one 30-year-old. The same pattern is found in Swedish data reported in Johannesson and Johansson (1995a).

One reason for these results may be that people think that old people have already had a chance to live a long life. However, it might also be the case that people feel that the quality of life is very low at advanced ages. Johannesson and Johansson (1995b) report an attempt to use a rating scale to measure the expected quality of an extra life year at an advanced age from a random sample of about 3000 adult Swedes between the ages of 18 and 69 years. In comparison to studies attempting to measure the *actual* quality of life, it seems that the average *expected* quality of life at an advanced age is quite low. The average relative expected quality of life is about 0.45 (or 5 on a scale between 1 and 10). Brooks et al. (1991) find that the average quality of life in Sweden (for ages 16 years+) is about 0.85 on a scale between 0 and 1. For ages older than 75 years, the average is about 0.75, i.e., far higher than what is expected by Swedes between the ages of 18 and 69 years.

Thus, Swedes on average are quite pessimistic about what they expect when they have attained an advanced age. It should be noted that age does not have a statistically significant influence on the perceived quality of life at an advanced age. Thus, the way in which one views the quality of life as an old person does not seem to change as one's actual age increases. We find it likely that the low expected quality of life at an advanced age is an important reason for the low WTP for an increased life expectancy, as well as for the low implied value of a statistical life reported above. In relation to the costs of medical treatments at advanced ages, not the least of which are hospital treatments, the reported average WTP is negligible.

Appendix

Necessary conditions for optimality (assuming the optimal plan is time consistent) include:

$$\partial H(t)/\partial c(t) = u_c[c(t); T_0; t]\alpha(t)\mu(t) - \lambda(t) = 0 \tag{A.1}$$

$$\partial H(t)/\partial k(t) = r(t)\lambda(t) = -\dot{\lambda}(t) \tag{A.2}$$

$$\dot{k}(t) = r(t)k(t) + y(t) - c(t) = -k(T_0) = k_0 \tag{A.3}$$

$$\lim_{t\to\infty} \lambda(t) = 0 \tag{A.4}$$

where k_0 is a constant and the term $[\alpha(T_0)\mu(T_0)]$ is ignored. The transversality condition (A.4) requires that certain growth conditions are satisfied. See Theorem 3.16 in Seierstad and Sydsaeter (1987). Note that $H_{cc}(t) = u_{cc}(.)\alpha(t; T_0)\mu(t; T_0) < 0$ for all $c(t)$ and $t \in [0, \infty)$, and that $H(t)$ is linear in $k(t)$, implying that the necessary conditions are also sufficient for optimality (see Theorems 3.16 and 3.17 in Seierstad and Sydsaeter, 1987). The above conditions ensure that (the optimal) $c(t)$ and $\lambda(t)$ are continuous and that $c(t)$ is continuously differentiable. Taking the time derivative of $\lambda^c(t) = \lambda(t)[\alpha(t)\mu(t)]^{-1}$, using (A.2), which shows that $\lambda(t) = ae^{-rt}$, where a is a constant, one finds that $d\lambda^c(t)/dt = -\lambda^c(t)[r - \theta(t) - \delta(t)]$, where $\theta(t) = -[d\alpha(t)/dt]/\alpha(t)$ and $\delta(t) = -[d\mu(t)/dt]/\mu(t)$. The term $\delta(t)$ is the hazard rate yielding the probability that an individual will die in a short time interval $(t, t + dt)$, conditional on having survived until time t. Thus, we can write $\lambda^c(t) = ae^{-rt}[\alpha(t)\mu(t)]^{-1}$, and $\lambda^c(t)$ is constant over time if $r = \theta(t) + \delta(t)$.

The general expression corresponding to (9) is as follows:

$$dCV(T_1)\frac{e^{-rT_1}\alpha(T_0)\mu(T_0)}{e^{-rT_0}\alpha(T_1)\mu(T_1)} = dCV(T_1)\frac{\lambda^{c*}(T_1)}{\lambda^{c*}(T_0)}$$

$$= \frac{\alpha(T_0)\mu(T_0)}{\alpha(T_1)\mu(T_1)}\int_T^{T+\epsilon}\frac{u[c^*(t); T_1; t]\alpha(t; 0)\mu_\beta[t, \beta(t)]d\beta(t)}{u[c^*(t); T_0; t]\alpha(t; 0)\mu_\beta[t, \beta(t)]d\beta(t)}\,dCV(T_0). \tag{A.5}$$

If instantaneous utility and the marginal rate of time preference for $t \in [T, T + \epsilon]$ both are independent of the individual's current age, the magnitude of the integrals in (A.5) are independent of the individual's current age, i.e., their ratio is equal to unity. In this case, we can estimate the marginal rate of time preference in the way specified below (9), provided $\lambda^{c*}(.)$ is constant over time. This holds if the sum of the marginal rate of time preference plus the hazard rate is equal to the interest rate at each point in time, as was shown above. If this condition does not hold in the kind of models used here (see, e.g., Leung, 1994, equation 15), consumption will go to either infinity or zero as time approaches infinity. The sign of $dc(t)/dt$ is governed by the sum of the hazard rate plus the marginal rate of time preference less the interest rate. Alternatively, we can net out $\alpha(.)$ and $\mu(.)$ from (A.5) and obtain an estimate of r and also test the hypothesis that the instantaneous utility functions are age-dependent.

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Notes

1. Due to the 4% nonresponse on the income question, the number of observations is 1925 in the regressions reported here. However, dropping the income variable so that the regressions are run with all the respondents on the willingness to pay question (2013 observations) does not significantly change the results and conclusions of the article.
2. Some of the socioeconomic variables are correlated. A commonly used rule compares the simple correlation coefficients to R^2 of the model. This is problematic in this article, since the usual R^2 cannot be calculated. However, if we compare the correlation coefficients with the likelihood ratio index, we find that the collinearity seems to be rather high between education, income, sex, and age (the highest correlations are between age and education (-0.38) and sex and income (-0.20)). This is also indicated by the internal R^2, i.e., when each regressor variable is regressed against the remaining four regressor variables (the internal R^2 is highest for age (0.18) and education (0.18)).

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