WHO CAN PREDICT THEIR OWN DEMISE? HETEROGENEITY IN THE ACCURACY OF LONGEVITY EXPECTATIONS

TERESA BAGO D' UVA[a,b], ESEN ERDOGAN-CIFTCI[c], OWEN O'DONNELL[a,b,d] and EDDY VAN DOORSLAER[a,b]

a Erasmus School of Economics, Erasmus University Rotterdam, The Netherlands.
b Tinbergen Institute, The Netherlands
c Novartis, Turkey
d School of Economics and Area Studies, University of Macedonia, Greece

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Abstract

Biased longevity expectations will lead to suboptimal decisions regarding saving, retirement, annuitization and health, with consequences for wellbeing in old age. Analysis of the US Health and Retirement Study reveals that individuals with lower education and cognitive functioning report survival probabilities that are less accurate in predicting actual survival. Conditional on objective mortality risks – health indicators, smoking and parental longevity – the least educated can process no further information that is useful in predicting longevity, while the better educated can make use of private information. Systematic differences in the accuracy of longevity expectations may partly explain documented differences in economic behavior by education and cognitive functioning.

Keywords: Expectations, Mortality, Longevity, Health, Cognition, Education

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1. INTRODUCTION

To form an accurate expectation of longevity, an individual must acquire health knowledge, perceive mortality risks and process information. These are cognitive skills that may be improved through education. Variation in ability to forecast the lifetime horizon over which finances are planned may contribute to observed differences by education and cognition in saving, retirement and wealth management (Fang et al. 2008, Banks and Oldfield 2007, Banks et al. 2010, Christelis et al. 2010, Smith et al. 2010, Behrman et al. 2012, Agarwal and Mazumder 2013). It may also be partly responsible for differences in health behavior and, consequently, the education gradient in health (Kenkel 1991, Cutler and Lleras-Muney 2010).

This paper tests whether the accuracy of longevity expectations varies by education and cognitive functioning. Using eight waves of the Health and Retirement Study (HRS) of older Americans, we find that even high school dropouts and the least cognitively able report survival probabilities that predict actual survival. However, these groups hold less accurate expectations than their more educated and cognitively able contemporaries.

Differences in the accuracy of expectations are marked. A marginal increase in the survival probability reported by a high school dropout is around half as strongly correlated with reduced mortality risk as is the same report made by a college graduate. After conditioning on objective mortality risks – health indicators, smoking and parental longevity – the least educated can process no further information that is useful in predicting longevity, while the better educated can. The latter possess and can process more private information that is relevant to decisions about life insurance and the annuitization of wealth. These findings are relevant not only to explanation of differences in economic and health behaviour but also to normative evaluation of inequality in the resulting outcomes.

We find that the accuracy of expectations varies more by education than by cognition, suggesting that low education is associated with a knowledge deficit, and possibly also a deprivation of experience, that hampers the evaluation of survival chances. Differences in the veracity of expectations by numeracy are even stronger than those by education. Individuals with poor numerical skills either formulate the least accurate longevity beliefs or have the greatest difficulty in expressing their beliefs in a probability. This is consistent with evidence of poor numeracy impeding both the understanding of probabilities (Bruine de Bruin et al. 2000, Peters 2008) and the comprehension of medical advice about treatment survival rates (Schwartz et al. 1997, Reyna and Brainerd 2007, Zikmund-Fisher et al. 2007).

Limited ability to think probabilistically about longevity, and possibly other prospects, potentially explains the strong correlation between cognitive functioning and the quality of decision-making (Choi et al. 2014). It may also explain the difficulty that individuals with low education and numeracy skills have in valuing an annuity (Brown et al. 2016). Heimer et al (2015) show that pessimism about survival chances at younger ages and optimism at older ages respectively explain under-saving before retirement and sub-optimal depletion of assets after retirement. They find that the deviation from the optimal consumption path induced by biased mortality beliefs is greater at lower levels of education. We do not examine the consequences of biased expectations for behavior, but add to Heimer et al by demonstrating variation by education, and

by cognition, in the extent to which an individual's expectation is consistent with her own longevity, rather than merely assess the deviation of subjective from life-table probabilities,

Previous analyses of the HRS and other representative surveys have established that reported survival probabilities do predict longevity (Van Doorn and Kasl 1998, Smith et al. 2001, Hurd and McGarry 2002, Siegel et al. 2003, Hurd 2009). We extend the literature by documenting heterogeneity in the accuracy of longevity expectations by education and cognition. In doing so, we move beyond the question of whether a representative agent possesses and can process information on her longevity prospects that are instrumental to solving lifecycle planning problems. Rather, we address a question that has a distributional motivation: Which individuals are more likely to hold inaccurate expectations and, consequently, make suboptimal decisions?

Elder (2013) challenges the claim that the positive correlation between reported survival probabilities and actual survival indicates that the former provide useful information on longevity. He demonstrates that life table survival probabilities do a better job of predicting mortality within the HRS, and that the perceived deviation of survival chance from the life table average accounts for little more than a third of the variation across individuals in reported probabilities. This suggests that there is a great deal of noise in reported survival probabilities. We demonstrate that the signal-to-noise ratio is lowest for the least educated and cognitively able.

Delavande and Rohwedder (2011) are considerably more optimistic regarding the information content of subjective survival probabilities. They show that the wealth gradient in reported survival probabilities is remarkably similar to the gradient in actual survival in the HRS. However, the gradient in reported probabilities by education is markedly shallower than that in actual survival (see Delavande and Rohwedder 2011, online Appendix). This is consistent with our more direct demonstration that individuals with lower educational attainment are less accurate in predicting their longevity.

2. DATA AND DESCRIPTIVES

2.1 SAMPLE

We use data mostly from the original cohort of the US Health and Retirement Study (HRS), which is a nationally representative sample of individuals born between 1931 and 1941, who were aged 50-62 years in 1992 and have been interviewed every two years since. We include spouses of the original HRS cohort and of other HRS cohorts only if they were born between 1931 and 1941.[1] We analyse a sample of individuals who were all born within this decade.

We took all variables from the RAND HRS data files (St. Clair et al. 2009), except for data on numeracy, which was taken from original HRS files. We use data from wave three (1996), from which point consistent measures of cognitive functioning are available, until wave ten (2010), at which point the cohort was aged 68-80. Some individuals belonging to the 1931-41 birth cohort

[1] Direct members of the AHEAD (born<1924), CODA (1924-30), War Babies (WB) (1942-47) and Early Baby Boomers (EBB) (1948-53) cohorts are not included since they were not born between 1931 and 1941. Our estimation sample consists of 32,437 individual×wave observations from the HRS original cohort (core members & spouses), 154 from the AHEAD/HRS overlap, 85 spouses from AHEAD, 24 spouses from CODA, 130 spouses from WB and 2 spouses from EBB.

enter our sample after wave 3 either because of missing covariates in that wave or because they are new spouses or spouses of cohorts added to the survey in later waves. The analyses are based on 32,437 individual×wave observations for which there is complete information on subjective survival probabilities, vital status, education, cognition and covariates.

2.2 LONGEVITY EXPECTATIONS

The HRS asks the respondent to report the chance that s/he will live to a specified target age on a scale of 0-100, with the instruction that 0 indicates absolutely no chance of survival and 100 corresponds to absolute certainty. The target age depends on the respondent's current age. All those aged 65 and younger are asked to report the percentage chance of living to at least the age of 75. In the first four waves, those aged 75 or less (including those <66) were asked to evaluate their chances of living to at least the age of 85. From the fifth wave, instead of the target age being fixed at 85 for those older than 65, it varied with the respondent's age. The target ages used in the analysis by wave and age are identified in Appendix A Table A1.

We deal with differences in the target age by analyzing the deviation of the reported probability from the life table probability of survival to the specified target given the respondent's age and gender.[2] A positive value of this deviation does not necessarily imply that the respondent is overly optimistic. Given health, lifestyle and family medical history, his or her survival chances may very well be objectively above the actuarial average based only on age and gender. The reason for the transformation is simply to overcome the differences in the questions and so maximise the number of observations and waves from which information can be used. In addition, taking the deviation from the life table probability eliminates the difference in longevity expectations that is implicit when the same probability of survival to a given target age is reported by individuals who differ in age and sex.

The mean reported survival probability in our estimation sample is five percentage points less than the corresponding life table probability, although the median is closer (Table 1). On average, the sample is pessimistic. There is a great deal of variation in the deviation of reported from life table probability: the standard deviation (29.5) is about five times the mean. At least in part, this reflects the variation in actual mortality risks around the life table average.

About 4% of observations (across all waves) do not answer the survival probability question (Table 1).[3] This may reflect difficulty in completing the abstract task of formulating and reporting a probability. Focal answers of 0, 50 and 100 percent may be given by individuals who have trouble performing the exercise. Around one-quarter of respondents report a value of 50 percent. Such bunching has been attributed to an extreme form of rounding (Gan et al. 2005, Manski and Molinari 2010, Kleinjans and Van Soest 2014), epistemic uncertainty (50%='I haven't a clue') (Fischhoff and Bruine De Bruin 1999, Bruine de Bruin and Carman 2012) and extreme ambiguity (50%='I am very unsure') (Hill et al. 2004, Hudomiet and Willis 2013). About

[2] The probability of survival to age T is calculated as the number of a (sex specific) birth cohort surviving to that age divided by the number of the same cohort surviving to the respondent's age at the time of the survey. The life table produced by the National Center for Health Statistics) for each survey year is used.

[3] In modelling mortality, we exclude these observations. Including them reveals that non-response is correlated with a higher risk of death in the subsequent period.

5% of the sample give an answer of 0 percent to the survival expectations question, while three times that fraction answer 100 percent.

Table 1: Difference between reported and life table survival probability by education, cognition and numeracy

	Mean	Median	% reporting probability of 0	50	100	Non-response (%)	N
Total	-5.38	-2.20	5.14	25.80	15.75	4.09	32437
Education							
High school dropout & GED	-13.28	-13.45	11.28	26.77	17.84	9.04	6966
High school graduate	-6.24	-4.72	4.47	28.30	16.23	3.03	11175
Some College	-2.77	0.63	3.42	24.93	17.20	2.65	7132
College	1.04	4.69	1.91	21.83	11.46	1.79	7164
Equality across groups: p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Cognitive functioning							
Lowest quartile group	-9.20	-6.72	8.38	25.26	18.93	7.79	8223
2nd lowest	-7.01	-4.91	5.69	27.36	14.58	3.57	8209
2nd highest	-4.31	-1.25	3.31	26.87	13.98	2.61	7967
Highest quartile group	-0.87	2.83	3.07	23.70	15.39	2.34	8038
Equality across groups: p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Numeracy							
Lowest quartile group	-7.09	-6.48	8.02	25.42	15.88	7.88	4477
2nd lowest	-3.85	-2.48	5.37	26.87	12.77	3.59	4324
2nd highest	-1.52	-0.78	4.35	28.63	10.90	2.72	4118
Highest quartile group	-1.57	2.15	4.01	26.06	9.37	2.39	4044
Equality across groups: p-value	<0.001	<0.001	<0.001	0.006	<0.001	<0.001	

Notes: Reported probability is the stated percentage chance of surviving to a specified target age. Life table probability is that percentage implied by the Vital Statistics life tables given current age and gender. Data from HRS waves 3-9 (total, education & cognition) and waves 6-9 (numeracy). Sample size (N) and all statistics are with respect to the estimation sample except for percentage non-response. Cognition/numeracy categories are quartile groups of age-sex standardized total cognition/numeracy score. 'Equality across groups' gives p-value for null of equal means/medians/proportions. For mean, it is a Wald test that allows for unequal variances across groups. For the median, it is implemented by the joint significance of the group indicators in a least absolute deviation regression in which those indicators are the only regressors. For proportions, it is the Pearson chi-square test.

2.3 EDUCATION AND COGNITIVE FUNCTIONING

Education groups are formed from years of schooling and highest qualification obtained: i) high school drop outs and General Educational Development (GED) (0-11 years of schooling and no qualification other than GED)[4]; ii) high school graduate (12 years of schooling and high school diploma); iii) some college (more than 12 years of schooling and high school diploma or GED); and, iv) college and above (bachelor degree or higher).

There is a pronounced education gradient in longevity expectations that is in the same direction as actual differences in mortality risks.[5] On average, high school dropouts report a survival probability about 13 percentage points below the actuarial average, while college graduates report a mean probability one point above the life table average (Table 1).

The least educated appear to have the greatest difficulty in providing subjective survival probabilities. Across all waves, around 9% of high school dropouts do not answer the question, compared with less than 2% of college graduates (Table 1). When they do answer, the lesser

[4] We categorise GED with high school dropouts since the purpose of the classification is to demarcate levels of educational experience (Heckman et al. 2014). Cognition is identified separately.

[5] Population vital statistics indicate that in 2007 the mortality rate of high school dropouts aged 55-64 was 2.4 times higher than that of individuals with at least some college education in the same age range (Xu et al. 2010) (Table 26).

educated are significantly more likely to give a focal response of 0, 50 or 100 percent. Kleinjans and Van Soest (2014) find, using the HRS, that modelling non-response and focal responses makes little difference to the estimated education gradient in longevity expectations. Nonetheless, we examine whether estimates of education-related differences in the accuracy of longevity expectations are robust to dropping observations giving focal responses.

In addition to higher non-response and focal response rates, the less educated have been found to be more prone to give answers to subjective probability questions that violate monotonicity and adding up (Dominitz and Manski 1997, Dominitz and Manski 2006, Delavande and Rohwedder 2008, Van Santen et al. 2012). On the whole, it seems likely that there is more noise in the subjective probabilities reported by the least educated.

The HRS contains measures of cognitive functioning in several domains based on validated tests (Ofstedal et al. 2005, Fisher et al. 2012). We restrict attention to the measures that are directed at respondents of all ages and have been fielded in a consistent format since wave 3. These measures relate to *episodic memory* and *intact mental status* and are described in Appendix B. Following Ofstedal et al. (2005), we aggregate the measures in the two domains into a total score increasing in cognitive functioning.

Our aim is not to identify the extent to which expectations become biased as individuals age and cognitive functioning declines (Anderson and Craik 2000). Rather, we wish to assess whether individuals who enter middle age with relatively low cognitive ability hold less accurate expectations of their length of life. If this is the case, it may lead to suboptimal decisions that result in lower wellbeing at older ages. Consistent with this objective, we test whether there is heterogeneity in the accuracy of survival expectations by cognition measured when an individual enters our sample.[6] We standardize these first-entry cognition scores for age and sex, and examine heterogeneity across quartile groups of these standardized scores.[7]

Cognitive functioning is also positively correlated with subjective survival chances (Table 1, middle panel), although not as strongly as is education.[8] Reporting the probability of survival to a specific age is a task that involves cognitive processes, including abstraction, concentration, retrieval and processing of information from health experiences, comprehension of the concept of probability, and calculation. One would expect ability to accomplish this task to be related to cognitive functioning. This appears to be evident in the data. The percentage of the lowest cognition group that does not report a survival probability is more than three times that of the highest functioning group.

Previous analyses of the HRS reveal that respondents who score poorly on cognition tests are less likely to respond to a variety of subjective probability questions and those who do are more likely to give focal responses of 0, 50 or 100 percent (Hurd and McGarry 1995, Kleinjans and Van Soest 2014, Binswanger and Salm. 2014). This is evident in Table 1, although the

[6] We do allow mortality risk to vary with time varying cognitive functioning.

[7] The standardised score is the residual from a linear regression of the score on a full set of sex-specific age-year dummies. We form gender specific quartile groups.

[8] The correlation coefficient between years of education and the total cognition score is 0.426 (p-value<0.001).

relationship between cognition and the likelihood of reporting a probability of 50 percent is neither monotonic nor as strong as that between education and this response.

Numeracy is measured in every second wave from wave 6 (2002) and at entry to the panel after that wave. A numeracy score is given by the sum of correct answers to three questions involving calculation of a percentage, division and compound interest (see Appendix B). This score is age-sex standardized as for cognition and quartile groups are formed using the first measure taken for each individual.

As for education and cognition, low numeracy is strongly associated with lower subjective survival probability, higher non-response and a greater tendency to report survival probabilities of 0 and 100 percent (Table 1, bottom panel).[9]

2.4 MORTALITY

The death of a HRS cohort member is reported by a relative contacted by an interviewer. A sample participant is presumed to be alive if s/he cannot be contacted but there is information obtained from a relative or another source that the person is alive. If no information is available, possibly because the respondent has dropped out of the HRS when alive and refused to participate further in the survey, then vital status is classified as unknown. We trace the vital status of each respondent from wave 3 (or the wave in which s/he first appears in our sample) until wave 10, which corresponds to a period of 14 years (1996-2010). Of the 6816 individuals who appear in our sample at some time, 1347 (19.8%) die by wave 10 and the vital status is unknown for 256 (3.8%).

In Table 2 we present the 14 year mortality rates for all respondents in the estimation sample who are observed in wave 3 (N=5210). There is a clear gradient in mortality by both education and cognitive functioning. The mortality rate among high school dropouts is around twice that of college graduates. The rate for those in the bottom quartile group of cognition is slightly less than three quarters greater than that of those in the top quartile group.

Mortality is also strongly correlated with longevity expectations. Of the 312 individuals who report a zero probability of survival to the age of 75 in 1996, 142 (45%) do not survive to 2010. The mortality rate falls steadily as the reported survival probability rises until reaching the top of the distribution. The mortality rate among the one fifth of respondents who report a 100 percent chance of surviving to 75 is around 20%, which is substantially greater than the rate for those reporting a probability between 51 and 99 percent. While a reported probability of zero does appear to contain information on mortality risk, the accuracy of a focal response of 100 is particularly low.[10]

[9] The correlation coefficient between years of education and the numeracy score is 0.4522 (p-value<0.001).

[10] The mortality rate of those not responding to the survival probability question in wave 3 is 28.9% compared with 23.5% among those who do. The mortality rate of those missing on covariates is also slightly higher. Gradients by education, cognition and longevity expectations are affected little by this selection. See Appendix, Table A2.

Table 2: Percentage of individuals who die between 1996 and 2010 by education, cognition and subjective probability of survival to 75

	Percent	N
Education		
High school dropout & GED	30.57	1184
High school graduate	19.98	1802
Some College	19.91	1130
College	15.45	1094
Test equal proportions, p-value	<0.001	
Cognitive functioning		
Lowest quartile group	28.52	1413
2nd lowest	21.34	1326
2nd highest	18.26	1243
Highest quartile group	16.53	1228
Test equal proportions, p-value	<0.001	
Subjective survival probability to 75		
0	45.51	312
1-49	28.71	498
50	23.96	1327
51-99	14.86	1918
100	19.74	1155
Test equal proportions, p-value	<0.001	
Total	21.42	5210

Notes: Sample includes respondents used in estimation of mortality models who are observed alive in wave 3 (1996). Cognition groups defined as in notes to Table 1. Subjective survival probability is the value reported in wave 3. Test of equal proportions is the Pearson Chi-square test.

The relationship of longevity expectations to mortality risk by education and cognition is shown in Figures 2a and 2b respectively. Those who reported a zero chance of survival in wave 3 experienced an elevated mortality rate at all levels of education. The fall in the death rate as the reported probability of survival turns positive is steepest for those with a college degree. This is consistent with the hypothesis that (low) longevity expectations of the most highly educated are most accurate. However, one should be careful of reading too much into the variation at the bottom of the distribution since only 20 individuals (2%) in the highest education group report a zero probability of survival to 75 (see Appendix A, Table A3). In contrast, 14% of high school dropouts report a zero survival chance. A distinct kink in the death rate at a reported survival chance of 50 percent is evident only for college graduates, while the rate turns upwards at a response of 100 percent for all groups. On the whole, it is not immediately evident from this simple analysis that longevity expectations reported by the more highly educated are more accurate. Likewise, Figure 2b does not support the hypothesis that the more cognitively able report more accurate expectations.

a) by education **b) by cognitive functioning**

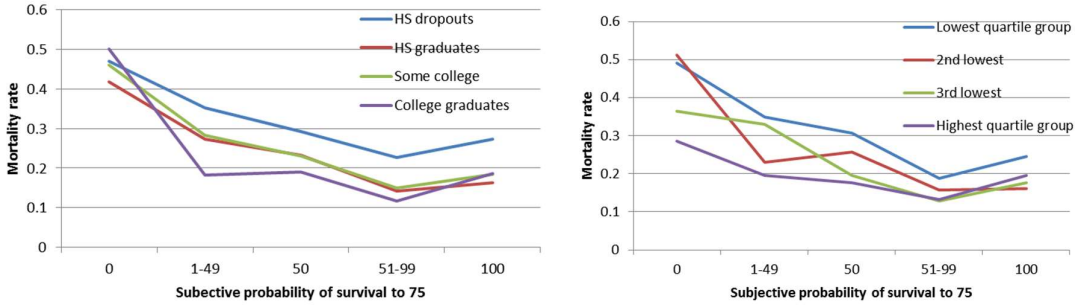


Figure 1: Proportion of individuals who die between 1996 and 2010 by subjective probability of survival to 75

3. METHODS

We examine heterogeneity in the accuracy of longevity expectations more rigorously by using all observations and conditioning on covariates. Accuracy is assessed by the extent to which the expectations predicts death within the period of observation.

3.1 MODELLING LONGEVITY

We observe a sample of individuals who were alive and aged between 54 and 65 at the time HRS wave 3 was conducted. We observe whether each individual is dead by each subsequent wave (4-10). Using these data, we model the probability of death at each age by specifying a discrete time hazard. This can be implemented by pooling the data over all waves from the third until the tenth, or until the wave in which the individual is recorded as being dead, and estimating a binary model of vital status at each wave (Jenkins 1995).

Let τ_i indicate the age of individual i when she is first observed. Each individual is observed until the wave in which her death is recorded or wave 10 if she survives.[11] Let $t = \tau_i + s_i$ be an index of age at which a spell is completed, such that s_i represents the years from first observation until either death or the end of the observation period. The duration elapsed until the age at death is modelled via the probability of a spell ending at each potential value of t given survival to that age, which is the discrete time hazard rate (Jenkins 1995),

$$h_{it} = P\left(T_i = t \middle| T_i \geq t; X_{it}\right) \quad (1)$$

where T_i is a discrete random variable representing the age at which a spell ends, and $\boldsymbol{X}_{it}$ is a vector of covariates that may vary with time and which will be described below.[12] These hazards map into probabilities of varying lengths of survival.

If unobservable heterogeneity in the probability of survival to the age at first observation is ignored, then the log-likelihood for the discrete time duration model is equivalent to that for a

[11] A few individuals drop out of the sample without their vital status being established. Such individuals are used in the estimation until the wave in which they drop out, after which they become right-censored observations.

[12] We do not use the precise age at death but rather whether an individual dies between waves that are separated by approximately two years. We assume that the underlying survival time is continuous and that deaths occur at a uniform rate within each two year period (Jones et al. 2012) (pp.182-218).

binary model for vital status at each wave (Jenkins 1995). Let y_{it} be an indicator of the occurrence of death at age *t*. For those who are still alive in wave 10, $y_{it}=0$ at all observed ages. For those who die during the observation period, $y_{it}=0$ at all ages except that in the wave in which death is recorded, when $y_{it}=1$. The log-likelihood of observing the vital status history of the sample can be written as

$$Log\,L=\sum_{i=1}^{n}\sum_{t=\tau_i}^{\tau_i+s_i} y_{it}\log h_{it}+\left(1-y_{it}\right)\log\left(1-h_{it}\right). \tag{2}$$

3.2 EMPIRICAL SPECIFICATION

We specify the hazard rate as a complementary log-log function, which provides a discrete-time counterpart of the hazard for an underlying continuous-time proportional hazards model (Prentice and Gloeckler 1978, Jenkins 1995). We estimate hazards of the form

$$h_{it}=1-\exp\left[\exp\left(\beta\left(E_i,C_i,N_i\right)S_{it-2}+\mathbf{Z_{it\text{-}2}}\boldsymbol{\gamma}+\theta_g\left(t\right)\right)\right] \tag{3}$$

where S_{it-2} is the measure of longevity expectation, i.e. the difference between the reported and life table probability of survival to a target age, at the previous wave, which is two years before the time at which vital status is established. Initially, we restrict the model such that the expectation variable is not interacted with any factor and a single expectations parameter β is estimated. This specification tests whether expectations predict length of life in the full sample. We then test for variation in predictive accuracy by interacting the expectation measure with education (*E*), cognition (*C*) and numeracy (*N*) such that β is allowed to vary with one or more of these characteristics, each of which is measured at first observation.[13]

The function $\theta_g(t)$ represents the baseline hazard of death at each age for a given gender (g), which we specify as piecewise-constant by including a dummy for each gender-age combination giving a semi-parametric specification of the discrete-time duration model (Jones et al. 2012). Initially, we condition only on the baseline hazard. The purpose of this specification is to test whether individuals are able to use all available information, including that correlated with characteristics observable in the data, to formulate and report survival probabilities that predict longevity. We then condition on socioeconomic characteristics by introducing the vector $\mathbf{Z}_{it-2}$ and specifying it to include income, wealth, employment status, race and marital status, in addition to education (see Appendix A, Table A4 for variable descriptions). Any decline in the predictive power of longevity expectations at this stage indicates the extent to which individuals are knowledgeable of variation in mortality risks with these factors and incorporate this information into their expectations.

Measures of health, lifestyle and parental longevity are initially left out of $\mathbf{Z}_{it-2}$ in order observe, when they are added, the degree to which any predictive power of longevity expectations comes from utilizing information contained in these objective and observable indicators of mortality risks. If expectations continue to predict longevity in this general specification, then we can

[13] An interaction between longevity expectations and gender is never significant and its inclusion does not alter the gradient in the predictive accuracy of expectations by education or cognition.

conclude that respondents are able to draw on private information on mortality risks that are not measured or proxied in the survey data.

The health measures include indicators of the previous existence and recent onset of eight diseases or risk factors: lung disease, cancer, diabetes, heart disease, stroke, psychiatric illness, high blood pressure and arthritis. Additionally, we include measures of current cognitive functioning and control for psychological distress (depression and anxiety) through a shortened version of the CES-D scale (Steffick 2000).[14] We measure functional status by three Activities of Daily Living (ADL) – Instrumental ADL indices following Wallace and Herzog (1995) using only the ADL-IADL questions asked consistently across waves. We also include indicators of mobility and large muscle problems, as well as fine motor skills. Finally, we control for hospitalization in the previous two years, body mass index (BMI) and being a current or former smoker. We condition not only on current but also on lagged measures of psychological distress, functional limitations, hospitalization and BMI. The complete list and their definitions are given in Appendix A, Table A4.

Parental longevity is measured using indicators of whether the respondent's mother and father are deceased, the age/age-at-death of each parent and an interaction between the indicator of vital status and age-at-death.

4. RESULTS

4.1 ACCURACY OF EXPECTATIONS ON AVERAGE

Table 3 shows the coefficient on the longevity expectations variable in mortality hazard models that do not allow for heterogeneity by education, cognition or numeracy. Taking the exponent of the significant coefficient of -0.0168 in the model with no covariates other than age and sex gives an estimated hazard ratio of 0.9833 with respect to a percentage point increase in the deviation of the subjective probability above the life table probability. That is, the hazard rate of death is 1.67% lower for each unit increase in the longevity expectations variable. Since the magnitude of the coefficient is reasonably small, it approximates this relative change in the hazard rate, which provides a convenient interpretation of all the coefficients in the table.[15]

As anticipated, controlling for socioeconomic covariates that are correlated with mortality risks reduces the magnitude of the longevity expectations coefficient. But it remains highly significant indicating that people utilize other available information on mortality risks – most obviously that obtained from observing their own health – to predict their longevity with some accuracy. The estimate from this model implies that the hazard ratio for a standard deviation increase in the longevity expectation measure is 0.6833, which is very close to that for a standard deviation increase in wealth (0.6572). The relationship between actual and expected longevity is as strong as that between mortality and wealth.

[14] In the models that allow for heterogeneity in expectations accuracy by initial cognitive functioning, the quartile groups of the (initial) total cognition score are included in addition to the current cognition measures.

[15] Using $\exp(b) - b \approx 1$ for small b .

When control is made for health indicators, smoking and parental longevity in addition to socioeconomic characteristics (right-hand column), the coefficient falls substantially but remains strongly significant. A percentage point rise in the deviation of the subjective from the life table probability is associated with an approximately 0.5% decrease in the hazard rate, which is 27% of the estimate obtained with age-sex controls only (and 36% of the estimate with only socioeconomic controls). Most of the predictive power of the subjective survival probability derives from the incorporation of information on mortality risks that are associated with measured health indicators, smoking and parental longevity. Once these factors are controlled for, individuals apparently possess further information that is useful in predicting their longevity.

Table 3: Longevity expectations coefficient in mortality hazard models

		Controlling for:		
		Age-sex	Age-sex + socioeconomics	Age-sex + socioeconomics + mortality risks
Full sample		-0.0168***	-0.0129***	-0.0046***
		[0.0012]	[0.0012]	[0.0012]
Log likelihood		-3944.918	-3808.477	-3368.997
	N	32437	32437	32437
Drop if report survival probability:				
0		-0.0131***	-0.0102***	-0.0035**
		[0.0015]	[0.0015]	[0.0015]
	N	30770	30770	30770
50		-0.0166***	-0.0130***	-0.0048***
		[0.0012]	[0.0013]	[0.0013]
	N	24068	24068	24068
100		-0.0204***	-0.0159***	-0.0063***
		[0.0014]	[0.0015]	[0.0015]
	N	27332	27332	27332

Notes: Coefficients on difference between the subjective and life table probability of survival to a target age (*longevity expectation*) from complementary log-log hazard models of mortality. *Mortality risks* in third column refer to indicators of health, smoking and parental longevity. Full estimates from the most general specification are given in Appendix Table A5. Standard errors adjusted for clustering at individual level in parentheses. *, ** and *** indicate significance at 10%, 5% and 1% respectively.

4.2 ACCURACY OF EXPECTATIONS BY EDUCATION AND COGNITION

In Table 4, we present estimates from models that allow the association of longevity expectations with the mortality hazard to differ across categories of education and cognitive functioning. The table gives the coefficient on the longevity expectation variable for each education/cognition category, i.e. the expectations coefficient for the reference category plus the coefficient for the category-specific interaction with expectations. This approximates the relative effect on the hazard rate of a marginal change in longevity expectations for each group.

Consider the estimates by education reported in the left-hand panel. The point estimate of the expectations parameter is increasing with education in all three specifications. The expectations of the better educated are more closely associated with their longevity. Controlling only for age and sex, longevity expectations are a significant predictor of mortality for all education groups. While there is a clear education gradient in the expectations coefficient, it should not be overlooked that even high school dropouts report expectations that, at least to some extent,

predict longevity. A unit increase in the survival probability reported by a high school dropout (in excess of the life table probability) is associated with a decrease in the mortality hazard rate of 1.2%. For college graduates, the equivalent estimate is 2.1%. Individuals with at least some college education are significantly better at predicting their longevity than high school dropouts.

Controlling for socioeconomic characteristics reduces the coefficients but leaves expectations as a significant predictor of mortality for all education groups and does not diminish the education gradient in the accuracy of expectations. Once control is made for the full set of covariates, the expectations reported by high school dropouts no longer significantly predict their longevity, while the expectations variable remains significant for the other education groups. Even after conditioning on a large battery of health indicators, smoking behavior and parental longevity, individuals who have at least graduated from high school are able to incorporate information in their reported expectations that predicts their longevity. The exploitation of this additional, unmeasured information, and not only differential incorporation of information contained in the observables appears to give the better educated an advantage in predicting their own demise, although the differences across groups are no longer significant with the complete set of covariates.

In the middle panel, the accuracy of expectations is allowed to differ by cognition, but not education. Controlling only for age and gender, longevity expectations are significant predictors of mortality at all levels of cognitive functioning. Even individuals with a cognition score below the first quartile report survival probabilities that predict longevity. The association between expectations and realisations rises with cognition but not monotonically. The accuracy of expectations for the third quartile group is not significantly different from that of the first quartile group. The significant difference between the top and bottom cognition groups is roughly similar to that between the top and bottom education groups.

Controlling for socioeconomic factors leaves the expectations variable as a significant predictor of mortality for all cognition groups. The gradient in the accuracy of expectations is affected little by adding these controls, although only the top group is significantly different from the bottom. Conditioning on mortality risk factors reduces the coefficient for all groups but leaves expectations as a significant predictor of longevity for three of the four groups. Individuals with the lowest level of cognitive functioning, unlike high school dropouts, appear to form survival expectations on the basis of information on mortality risks that is not captured by the rich battery of health indicators included. While the point estimates suggest that expectations remain more accurate for the highest compared with the lowest cognition group, there is no significant difference. All told, differences in the accuracy of longevity expectations by cognitive functioning are not quite as strong as those by education.

The right-hand column of Table 4 shows estimates from models in which the predictive power of subjective probabilities is permitted to vary with both education and cognition. At each level of education (cognition), we show the effect of the longevity expectations variable for the lowest cognition (education) group. Controlling only for age and sex, survival probabilities reported by all education-cognition groups predict mortality. Within the first quartile of cognitive functioning, the expectations coefficient rises with education but only the difference between college graduates and high school dropouts is significant (at 10%). Among college graduates with

the lowest cognitive functioning, a unit increase in expectations is associated with an approximately 1.8% decrease in the hazard rate, compared with a fall of 1.1% for high school dropouts with the same (broad) level of functioning. Among high school dropouts, the estimates suggest a rise in the accuracy of expectations with cognitive functioning that is neither monotonic nor significant. Although it is not apparent in the table, the estimates imply that a percentage point increase (above the life table probability) in the survival probability reported by a college graduate in the top cognition group is associated with a 2.3% decrease in the hazard rate, compared with a 1.1% decrease associated with a marginal change in the survival chance reported by a high school dropout in the lowest cognition group.

Controlling for socioeconomic factors has little impact. After controlling for health, smoking and parental longevity, the residual information in the subjective probabilities reported by high school dropouts in the bottom cognition group no longer significantly predicts longevity. Holding cognition constant, the point estimates suggest a strengthening relationship with rising levels of education, but the difference is only marginally significant (10%) for high school graduates and those with some college education. Differences by cognition are weaker, although the point estimate for the top cognition group is almost three times the magnitude of that for low cognition high school dropouts. The lack of significance of the education and cognition differences in this specification could very well arise from a lack of power given the strong overlap between the two characteristics.

Table 4: Longevity expectations coefficients in mortality hazard models with heterogeneity by education and cognition

	Education, with controls for:			Cognition, with controls for:			Education & Cognition, with controls for:		
	Age-sex	Age-sex + socio-economics	Age-sex + socio-economics+ mortality risks	Age-sex	Age-sex + socio-economics	Age-sex + socio-economics + mortality risks	Age-sex	Age-sex + socio-economics	Age-sex + socio-economics + mortality risks
Education									
High school dropout	-0.0121***	-0.0094***	-0.0023				-0.0107***	-0.0083***	-0.0020
	[0.0019]	[0.0019]	[0.0019]				[0.0021]	[0.0020]	[0.0020]
High school graduate	-0.0160***	-0.0131***	-0.0050**				-0.0134***	-0.0109***	-0.0043*
	[0.0022]	[0.0021]	[0.0021]				[0.0027]	[0.0026]	[0.0025]
Some College	**-0.0188***	**-0.0156***	-0.0063***				-0.0159***	-0.0130***	-0.0053*
	[0.0026]	**[0.0025]**	[0.0024]				[0.0032]	[0.0031]	[0.0030]
College graduate	**-0.0210***	**-0.0176***	-0.0072**				**-0.0178***	**-0.0148***	-0.0062
	[0.0033]	**[0.0032]**	[0.0030]				**[0.0041]**	**[0.0039]**	[0.0038]
Cognitive functioning									
Lowest quartile group				-0.0127***	-0.0099***	-0.0032*	-0.0107***	-0.0083***	-0.0020
				[0.0018]	[0.0017]	[0.0018]	[0.0021]	[0.0020]	[0.0020]
2nd lowest group				-0.0178***	-0.0143***	-0.0049**	-0.0142***	-0.0114***	-0.0027
				[0.0024]	[0.0023]	[0.0023]	[0.0030]	[0.0029]	[0.0029]
2nd highest group				-0.0164***	-0.0128***	-0.0039	-0.0123***	-0.0093***	-0.0014
				[0.0027]	[0.0027]	[0.0026]	[0.0034]	[0.0033]	[0.0033]
Highest quartile group				**-0.0203***	**-0.0175***	-0.0082***	-0.0157***	-0.0135***	-0.0055
				[0.0029]	**[0.0028]**	[0.0027]	[0.0037]	[0.0036]	[0.0034]
Homog. $\chi^2(k-1)$ (p-value)	7.64 (0.0540)	7.16 (0.0670)	2.98 (0.3943)	6.28 (0.0987)	6.27 (0.0990)	2.76 (0.4304)	10.12 (0.1198)	9.93 (0.1278)	4.40 (0.6226)
Log likelihood	-3931.5119	-3804.487	-3367.3963	-3926.5436	-3802.6306	-3367.3553	-3920.2381	-3800.5753	-3366.4387
N	32437	32437	32437	32437	32437	32437	32437	32437	32437

Notes: As Table 3, with the following additions. This table gives estimates from models that include interactions between the longevity expectation variable and education and/or cognition categories. The coefficient on the longevity expectation variable for each education/cognition category is presented (i.e. coefficient for reference category plus coefficient on category-specific interaction). These approximate the relative effect on the hazard rate of a marginal change in longevity expectations for each category. For the model allowing heterogeneity by education and cognition (right-hand panel), the effects by education are for the lowest quartile group of cognition and the effects by cognition are for high school dropouts. Standard errors in parentheses are estimated by the delta method with adjustment for clustering at the individual level. Bold indicates that the coefficient differs at least at 10% from that for the lowest education/cognition group. Homog. indicates a Wald test of the null that the variation in the hazard with longevity expectations does not differ by education/cognition. k is the number of education and/or cognition groups.

4.3 ROLE OF FOCAL RESPONSES

Individuals with lower educational attainment and cognitive functioning are more likely to report survival chances of 0, 50 and 100 percent (see section 2.3). If these focal responses reflect difficulty in comprehending the task of reporting probabilities, are due to a high degree of rounding or reflect a good deal of ambiguity over longevity, then they should contain less information on mortality risks. Their higher prevalence among the responses of the less educated and cognitively able potentially explains why these groups are less successful in predicting their longevity. To assess the validity of this interpretation of the results, we examine whether they are robust to dropping observations giving a focal response.

The bottom panel of Table 3 shows the impact on the longevity expectations coefficient of dropping focal responses from models that do not permit heterogeneity by education and cognition. Dropping responses of a 50:50 chance of survival has little or no impact on the estimate. This is consistent with Figure 1, which shows little sign of a kink in the relationship between the mortality rate and the subjective survival probability at a response of 50. Dropping these responses also has little or no impact on the education and cognition gradients in the predictive power of reported survival chances (Table 5).[16]

As would be anticipated from Figure 1, dropping responses of 0 reduces the extent to which expectations predict actual longevity, on average, while dropping those reporting a 100 percent chance of reaching the target age raises the predictive power of expectations (Table 3). On average, a response of 'no chance of survival' is indeed informative of a higher probability of death but so too is a response of '100% chance of survival' (Delavande and Rohwedder 2008, Hurd 2009).

Dropping responses of 100 raises the predictive power of the reported survival probability for all groups but has little impact on the education and cognition differences (Table 5). If anything, they widen. Leaving out observations reporting a survival chance of 0 reduces the magnitudes of the point estimates of the differences by education and cognition and renders them insignificant.[17] At least part of the reason the survival chances reported by individuals with low education and cognition are less accurate in predicting longevity is that the difference in mortality risk associated with a zero and a positive reported probability is smaller for these individuals than it is for high education and cognition groups. A zero probability reported by the highly educated and cognitively able is more likely to indicate a greatly inflated mortality risk that is correctly perceived. Those with low education or cognitive functioning are more likely to be overly pessimistic when they report a zero chance of survival.[18]

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[16] Table 5 demonstrates robustness of heterogeneity in the accuracy of expectations to dropping focal responses for the model with socioeconomic covariates. The impact on the estimates obtained from the other specifications follow similar patterns. The omitted results are available on request.

[17] With age-sex controls only, the education differences remain significant (10%) when zero responses are dropped.

[18] If observations reporting any one of the three focal responses are dropped, then the education gradient in the accuracy of expectations remains: the coefficient for college graduates is twice the magnitude and significantly different from that of high school dropouts. These results are available on request.

Table 5: Longevity expectations coefficients in mortality hazard models – robustness to dropping focal responses

	Dropping subjective survival probability responses of:					
	0		50		100	
	Education	Cognition	Education	Cognition	Education	Cognition
Lowest group	-0.0078***	-0.0086***	-0.0092***	-0.0100***	-0.0118***	-0.0119***
	[0.0023]	[0.0021]	[0.0019]	[0.0017]	[0.0023]	[0.0021]
2nd lowest group	-0.0085***	-0.0097***	-0.0132***	-0.0144***	-0.0157***	-0.0161***
	[0.0025]	[0.0027]	[0.0020]	[0.0024]	[0.0025]	[0.0027]
2nd highest group	-0.0131***	-0.0115***	**-0.0155*** **	-0.0136***	**-0.0181*** **	-0.0161***
	[0.0029]	[0.0032]	[0.0026]	[0.0026]	[0.0029]	[0.0030]
Highest group	-0.0147***	-0.0128***	**-0.0190*** **	**-0.0171*** **	**-0.0214*** **	**-0.0225*** **
	[0.0036]	[0.0033]	[0.0032]	[0.0028]	[0.0033]	[0.0030]
Homog. $\chi^2(k-1)$ (p-value)	4.11(0.2502)	1.38(0.7095)	8.70(0.0336)	5.71(0.1268)	6.87(0.0760)	8.91(0.0304)
Log likelihood	-3296.6838	-3296.4852	-2831.0412	-2831.3772	-3330.7778	-3326.9095
N	30770	30770	24068	24068	27332	27332

Notes: as Table 4. Estimates correspond to those from models including age-sex and socioeconomic controls reported in Table 4 with observations reporting subjective survival probabilities of 0, 50 and 100 percent dropped from the sample. Lowest group is high school dropouts for education and lowest quartile group for cognition. Highest group is college graduates for education and highest quartile group for cognition. Intermediate groups as in Table 4. Homogeneity test as in Table 4. Bold indicates that the group coefficient is significantly different from that of the lowest group at 10% level or less.

4.4 ACCURACY OF EXPECTATIONS BY NUMERACY

The most numerate individuals are likely to be most comfortable with the concept of probability and most successful in expressing a longevity belief in a survival probability. In Table 6 we present estimates of the longevity coefficients for education and numeracy quartile groups in mortality hazard models estimated using data from wave 6 onwards and including age-sex and socioeconomic controls only.[19]

With heterogeneity only by education, expectations predict longevity significantly for all groups and the point estimates indicate a gradient in the same direction as that obtained using data from wave 3 onwards. However, the education gradient in the accuracy of expectations is not significant. This is likely attributable to the substantially smaller sample size and the much fewer number of deaths observed over an eight, as opposed to fourteen, year period. Despite this reduced power, there are significant differences in the accuracy of expectations by numeracy skills. The coefficient for the top numeracy quartile group is more than twice the magnitude of that of the bottom quartile group. This significant difference is maintained when the accuracy of expectations is allowed to vary by both numeracy and education. The expectations coefficient of the most numerate high school dropouts is double the magnitude of the coefficient of the least numerate dropouts.

Numeracy skills appear to be particularly pertinent to the formation and reporting of accurate survival probabilities. This is not necessarily inconsistent with the early observation that, if

[19] The expectations coefficients are larger with control only for age-sex and smaller with the full set of controls. These results are available on request.

anything, the accuracy of expectations varies more with education than it does with overall cognitive functioning. Numeracy is not cognition. It is a skill that can be taught.

Table 6: Longevity expectations coefficients in mortality hazard models with heterogeneity by education and numeracy

	Education	Numeracy	Education & Numeracy
Education			
High school dropout	-0.0122***		-0.0099***
	[0.0025]		[0.0028]
High school graduate	-0.0125***		-0.0082
	[0.0027]		[0.0031]
Some College	-0.0161***		-0.0110
	[0.0033]		[0.0040]
College graduate	-0.0178***		-0.0115
	[0.0036]		[0.0046]
Numeracy			
Lowest quartile group		-0.0096***	-0.0099***
		[0.0023]	[0.0028]
2nd lowest group		-0.0144***	-0.0099***
		[0.0032]	[0.0038]
2nd highest group		-0.0155***	-0.0146***
		[0.0030]	[0.0040]
Highest quartile group		**-0.0206*** **	**-0.0153*** **
		[0.0035]	[0.0045]
Homog. $\chi^2(k-1)$ (p-value)	2.38 (0.4980)	7.87 (0.0488)	8.76 (0.1875)
Log likelihood	-2340.65	-2335.537	-2335.138
N	16963	16963	16963

Notes: As Table 4. Estimates obtained from models estimated using data from wave 6 onwards including age-sex and socioeconomic controls only. Numeracy categories are quartile groups formed from age-sex standardised numeracy score. Bold indicates significant difference from lowest group at 5% level or less.

5. CONCLUSION

Our analysis confirms that older US citizens can, at least to some extent, predict their own demise. This is reassuring for researchers utilizing models that presume agents hold longevity expectations that are based on actual mortality risks. The fact that subjective survival probabilities predict longevity even after conditioning on a battery of health measures, smoking behavior and parental longevity, suggests that the average individual is able to process information on personal mortality risks that is unlikely to be observable to providers of insurance and annuities. Markets for these products are vulnerable to adverse selection (Hendren 2013).

We find that even the least educated individuals with low cognitive ability can formulate and report survival expectations that are accurate in the sense of predicting their own longevity. But higher educated and more cognitively able individuals are significantly and substantially better at predicting their survival chances. This is not only because they are better at utilizing longevity-relevant information that is observable in measures of health and other covariates, it is also because they hold more private information on their mortality risks. Adverse selection in the purchase of financial products may work to the advantage of the better educated.

Heterogeneity in accuracy of survival expectations could possibly result from differences in ability to exploit information made available by the experience of ill-health. We have assessed the plausibility of this explanation by testing for heterogeneity by education and cognition in the

updating of longevity expectations in response to the onset of serious health conditions, such as cancer and lung disease. While this reveals little support for the hypothesis, it does show that the longevity expectations reported by high school dropouts and the least cognitively able are less stable and display greater unexplained variability (see Bago d'Uva et al. 2015). These groups appear to find it more difficult to predict their longevity: their estimates fluctuate more over time, are explained less by objective risk factors and are weaker predictors of actual mortality.

These difficulties potentially result in sub-optimal decisions concerning household finances and health behavior. We have not tested whether there are behavioral consequences of mistaken longevity expectations. Heimer et al (2015) simulate the consequences for savings and there is evidence that behavior is correlated with longevity expectations (Hurd et al. 1998, Hurd et al. 2004, Salm 2010, Spaenjers and Spira 2015). One might suggest that advice regarding complex financial decisions be targeted on the least educated and cognitively able, and that it include help in predicting longevity and so the appropriate planning horizon.

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ONLINE APPENDICES

NOT FOR PUBLICATION

Appendix A: Additional Tables

Table A1: Target ages used in subjective probability of survival question

	Respondent's current age:				
Wave	**< 65**	**65**	**66-69**	**70-74**	**75-79**
3 (cohort aged 54-65)	75	75	-	-	-
4 (cohort aged 56-67)	75	75	-[a]	-	-
5 (cohort aged 58-69)	75[b]	80[c]	80	-	-
6 (cohort aged 60-71)	75[b]	80[c]	80	85	-
7 (cohort aged 62-73)	75[b]	80[c]	80	85	-
8 (cohort aged 64-75)	75[b]	80[c]	80	85	90
9 (cohort aged 66-77)	-	-	80	85	90

Notes: a. In wave 4, HRS documentation indicates that the question was to be skipped if the respondent was older than 75. But from the data it appears that the question was skipped if older than 65. This means that there is no information on survival expectations for individuals aged 66 and 67 in our sample in wave 4. b. Also asked to report the chance of living to age 80 (85 in wave 8). c. Also asked to report the chance of living to age 75. We opted to use the age 80 target because there are many missing observations for target age of 75 in wave 8, and also to maintain greater consistency across waves.

Table A2: Table 2 for sample including observations missing on subjective survival probability and covariates

	As Table 2 + missing on covariates		As Table 2 + missing on covariates & subjective survival probability	
Education	Percent	N	Percent	N
High school dropout & GED	32.78	2004	32.68	2240
High school graduate	21.02	2374	21.04	2472
Some College	21.05	1425	21.2	1462
College	16.39	1287	16.74	1314
Test equal proportions, p-value	<0.001	7090	<0.001	7488
Cognitive functioning				
Lowest quartile group	33.93	1677	34.09	1889
2nd lowest	24.13	1832	24.09	1914
2nd highest	18.66	1801	18.59	1861
Highest quartile group	17.98	1780	18.15	1824
Test equal proportions, p-value	<0.001	7090	<0.001	7488
Subjective survival probability to 75				
0	48.28	495		
1-49	31.28	729		
50	25.15	1793		
51-99	16.51	2435		
100	21.18	1638		
Test equal proportions, p-value	<0.001	7090		
Total	23.51	7090	23.80	7488

Notes: As Table 2 in text.

Table A3: Table corresponding to Figure 1 - Percentage of individuals who die between 1996 and 2010 by subjective probability of survival to 75, education and cognition

	Subjective probability of survival to 75					
	0	1-49	50	51-99	100	Test equality
Education						p-value
High school drop out	46.95	35.22	29.28	22.71	27.34	<0.001
N	164	159	321	273	267	
High school graduate	41.76	27.22	23.19	14.26	16.36	<0.001
N	91	169	526	582	434	
Some college	45.95	28.28	23.05	15.01	18.38	<0.001
N	37	99	269	453	272	
College graduate	50.00	18.31	18.96	11.80	18.68	<0.001
N	20	71	211	610	182	
Cognitive functioning						
Lowest quartile group	49.02	34.86	30.71	18.78	24.48	<0.001
	153	175	368	378	339	
2nd lowest	51.25	23.08	25.76	15.78	16.07	<0.001
	80	117	361	488	280	
2nd highest	36.36	33.03	19.58	12.80	17.62	<0.001
	44	109	337	492	261	
Highest quartile group	28.57	19.59	17.62	13.21	19.64	<0.001
	35	97	261	560	275	

Notes: As Table 2 and Figure 1.

Table A4: Definitions of socioeconomic, health, health behaviour and parental longevity covariates used in models of mortality

Variable	Description
Education	In categories: high school drop outs and General Educational Development (GED) (0-11 years of schooling and no qualification other than GED); high school graduate (12 years of schooling and high school diploma); some college (more than 12 years of schooling and high school diploma or GED); college and above (bachelor degree or higher).
Education parents	Number of education years of mother and of father.
Income	Logarithm of total household income.
Wealth	Logarithm of total wealth (excluding secondary residence) and indicator of positive wealth (0,1).
Employment	Indicator of whether currently working for pay (0,1).
Race	Categories White/Caucasian, Black/African American and other (reference category).
Marital status	Indicator of whether married/partnered (1) or widowed, divorced or never married (0).
Lung disease Cancer Diabetes Stroke Psychiatric illness Heart disease Hypertension Arthritis	Respondent has ever been told by a doctor that he/she has the condition. Mortality models include an indicator of whether condition reported in the previous wave (0,1) and another of whether did not report condition in last wave but did in present wave (*X since last wave* (0,1)). Expectations updating model includes the latter only in lagged dependent variable specification and fixed effects model includes indicator of currently having the condition.
Cognition – recall	Age-sex standardized total score on immediate and delayed word recall tests in current wave
Cognition – count	Age-sex standardized total score on the serial 7's and backwards counting tests.
CES-D score	Score (0-8) is the sum of five "negative" indicators minus two "positive" indicators. Negative indicators correspond to reports that all or most of the time experience: depression, feeling that everything is an effort, restless sleep, loneliness, sadness, and feeling that could not get going. Positive indicators are whether the respondent felt happy and enjoyed life all or most of the time. We include the current and the lagged score.
Mobility index	Current and lagged score (0-5) that is the sum of indicators of some difficulty with: walking several blocks, walking one block, walking across the room, climbing several flights of stairs and climbing one flight of stairs. We include the current and the lagged score.
Large muscle index	Current and lagged score (0-4) that is the sum of indicators of some difficulty with: sitting for two hours, getting up from a chair, stooping or kneeling or crouching, and pushing or pulling a large object.
ADL index	Current and lagged score (0-5) that sums indicators of difficulty with the activities of daily living: bathing, eating, dressing, and getting in or out of bed. Difficulty walking across a room excluded because it is included in the mobility index.
Fine motor skills indicator	Current and lagged indicator (0,1) of whether individual has some difficulty picking up a dime. Difficulty with eating and dressing excluded because these are included in the ADL index.
iADL index	Current and lagged score (0-3) that is sum of indicators of some difficult with the instrumental activities of daily living: taking medication, using a telephone and handling money.
Hospitalization	Indicator (0,1) of whether the respondent reports any overnight hospital stay since the last interview, or the last 2 years for new interviewees. We also include the lag of this indicator.
BMI	Current and lagged body mass index - weight in kilograms divided by the square of height in meters.
Smoker	Whether current smoker, former smoker or never smoked (reference).
Parental longevity	Separately for father and mother: age of the parent (currently or at death, if already deceased); indicator of whether parent is deceased; and interaction between age (-at-death) and vital status.

Table A5: Mortality hazard coefficients from model with all controls and without heterogeneity in longevity coefficient by education and cognition (Table 3, right-hand column)

Longevity expectation	-0.0046***	[0.0012]			
White	0.0303	[0.1996]	Heart disease at last wave	0.1661**	[0.0842]
Black	0.0432	[0.2116]	Heart disease since last wave	0.1732	[0.1551]
Married or partnered	-0.2136***	[0.0820]	Stroke at last wave	-0.0244	[0.1264]
High school graduate	0.1666*	[0.0934]	Stroke since last wave	-0.0016	[0.2299]
Some college	0.2974***	[0.1079]	Psychiatric illness at last wave	0.0209	[0.1055]
College graduate	0.3207**	[0.1267]	Psychiatric illness since last wave	0.1134	[0.2206]
Education years mother	-0.0073	[0.0131]	Arthritis at last wave	-0.1491*	[0.0810]
Education years father	-0.0014	[0.0117]	Arthritis since last wave	-0.0522	[0.1773]
Currently working for pay	-0.4930***	[0.0948]	Lagged mobility index	0.0864**	[0.0377]
Ln(Income)	0.0159	[0.0301]	Current mobility index	0.2859***	[0.0356]
Ln(Wealth)	-0.0427**	[0.0200]	Lagged large muscle index	-0.1029**	[0.0409]]
Has positive wealth	0.2157	[0.2288]	Current large muscle index	-0.0494	[0.0399]
Cognition – recall	-0.1306***	[0.0389]	Lagged ADL index	-0.0098	[0.0609]
Cognition – count	-0.0636*	[0.0354]	Current ADL index	0.069	[0.0552]
Age father	-0.0311	[0.0326]	Lagged fine motor skills	-0.0556	[0.1385]
Age mother	-0.0162	[0.0161]	Current fine motor skills	-0.0657	[0.1337]
Father died	-2.6021	[2.8120]	Lagged iADL index	-0.0227	[0.1049]
Mother died	-1.2449	[1.3989]	Current iADL index	0.0308	[0.0944]
Father died x father's age-at-death	0.0285	[0.0327]	Lagged CES-D score	-0.0764***	[0.0229]
Mother died x mother's age-at-death	0.0145	[0.0162]	Current CES-D score	0.0338	[0.0206]
High blood pressure at last wave	0.0786	[0.0775]	Lagged hospitalization	0.3340***	[0.0771]
High blood pressure since last wave	-0.0031	[0.1651]	Current hospitalization	0.4798***	[0.0806]
Diabetes at last wave	0.5997***	[0.0816]	Lagged BMI	0.0664***	[0.0125]
Diabetes since last wave	0.2019	[0.1870]	Current BMI	-0.1055***	[0.0136]
Cancer at last wave	0.6125***	[0.0916]	Former smoker)	0.3601***	[0.0880]
Cancer since last wave	1.4437***	[0.1183]	Current smoker	0.7490***	[0.1074]
Lung disease at last wave	0.3078***	[0.0933]	Constant	0.4916	[3.1287]
Lung disease since last wave	0.5908***	[0.1627]			
N	32437		Log likelihood	0.4916	

Notes: Table shows coefficients from the complementary log-log hazard models of mortality corresponding to right-hand column of Table 3. Model also includes gender specific age-year dummy variables. Standard errors allowing for clustering at the individual level in parentheses. *, ** and *** indicate significance at 10%, 5% and 1% respectively.

Appendix B: Cognition and numeracy scores

Following Ofstedal et al. (2005), we use a cognition score based on measures of *episodic memory* and *mental status*. The former enables recollection of experiences and specific events from the past (Tulving 1972). It may be required for reasoning (Smith et al. 2010). In the HRS it is assessed through two word recall tasks. The interviewer reads a list of ten common nouns (e.g., book, child, hotel) and the respondent is asked immediately to recall as many as possible in any order.[20] After five minutes or so, during which other questions are answered, the respondent is again requested to recall the words. The total recall score is the sum of the number of words recalled in these immediate and delayed recall tests (ranging from 0 to 20).

Mental status refers to the intactness of the neuro-cognitive system essential to communication and learning (Smith et al. 2010). It is measured through parts of the Telephone Interview for Cognitive Status (TICS) (Brandt et al. 1988). One dimension of mental status is *executive functioning*, which refers to the cognitive processes that facilitate the use of past experience in current action (National Center for Learning Disabilities,. 2012). These processes are used in planning, organization and management and are likely to be of considerable importance in relation to decisions taken concerning pensions, saving, health insurance, retirement and health behaviour. The cognitive processes relevant to the tasks we use from the HRS are working memory, attention and problem solving. Working memory refers to the ability to store and process information simultaneously (Baddeley and Hitch 1974). It, and the other two processes referred to, is assessed by asking respondents to subtract 7 from 100 and continue subtracting 7 from the answer for a total of five subtractions. The test score is the number of correct subtractions (0-5). This serial 7's test is part of the Mini-Mental State Examination (Folstein et al. 1975), in which it assesses the attention and calculation dimensions of mental status. A second test, which additionally assesses processing speed, asks the respondents to count backwards as quickly as possible, starting from 20 for 10 continuous numbers. Respondents are allowed two trials for this exercise. Scores are recorded as 0 if incorrect or "don't know/unable to do" on both tries, 1 if incorrect on the first try but correct on the second try, and 2 if correct on the first try. Three additional elements of mental status are assessed by orientation in time, ability to name objects and to recall the names of the President and Vice-President.[21] The total mental status score sums those of the serial 7's, backwards counting, date/object/president naming tests and ranges from 0 to 15.

The total cognition score is the sum of the total recall score and the total mental status score. It ranges from 0 to 35.

The numeracy score is derived from the following questions: 1) If the chance of getting a disease is 10 percent, how many people out of 1,000 would be expected to get the disease? 2) If 5 people all have the winning numbers in the lottery and the prize is two million dollars, how much will each of them get? 3) Let's say you have $200 in a savings account. The account earns 10 percent

[20] To avoid respondents acquiring familiarity with the words, they are asked to recall from a different list in each successive wave.

[21] Orientation in time is tested by asking the date and the day of the week. Object naming asks questions such as: "What do you usually use to cut paper?". The score of each test is the sum the number of correct answers and ranges from 0 to 4 (date), and 0 to 2 (object and President, Vice-President). These questions are asked of all respondents in wave 3 but only of new entrants and those aged 65 and above from wave 4 onwards.

interest per year. How much would you have in the account at the end of two years?. Respondents who answer 1) and 2) incorrectly are not asked 3). The numeracy score (0-3) is the sum of correct answers to the three questions. 'Don't know' responses and refusals are treated as incorrect.

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