Gains in life expectancy associated with higher education in men

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ABSTRACT

Background: Many studies show large differences in life expectancy across the range of education, intelligence, and socio-economic background but some natural experiments in education suggest that the direct effect of education on mortality may be limited. As educational attainment, intelligence, and social background are highly interrelated, appropriate methods are required to disentangle their separate effects. We here present novel methods to estimate gains in life expectancy associated with increased education in men in the Netherlands followed from ages 18-66 years, taking intelligence, education, and paternal occupation status at age 18 into account.

Methods: Our analysis is based on a structural model with education level and IQ at age 18 and mortality between from ages 18-66 years by education level all depend on a latent cognitive ability. The model allows for selective educational choices based on observed factors and on an unobserved factor capturing cognitive ability. The data used are from selected health examinations of military conscripts born in 1944-1947 in The Netherlands (n=39,798).

Results: Men with higher education show lower mortality. Compared to men at the lowest education level, the mortality ratio among men with lower vocational, higher vocational, and higher education is 0.76 (95% CI 0.71 to 0.82), 0.73 (95% CI: 0.67 to 0.79), and 0.58 (95% CI: 0.52 to 0.64) respectively based on Cox models. Using structural models to account for education choice, the gain in life expectancy for men moving from primary to lower vocational, from lower vocational to higher vocational, and from higher vocational to higher education is estimated to be 2.0 years (95% CI: 1.0 to 2.9), 0.3 years (95% CI: -0.4 to 1.0), and 1.9 years (95% CI: 0.9 to 2.9) respectively. Focusing on the difference in average years lived from 18 till 66, the observed age window, reveals that the gain in months lived for men moving from primary to lower vocational, from lower vocational to higher vocational, and from higher vocational to higher education is estimated to be 5.7 months (95% CI: 4.2 to 7.2), -1.2 months (95% CI: -2.1 to -0.2), and 1.4 months (95% CI: 0.2 to 2.7) respectively. The selection effect is positive and amounts to one to two additional months. This selection effect can be further decomposed into a selection on observed factors and selection on (latent) cognitive ability. The latter effect is predominant moving up one level of education and amounts to 1.0 (primary to lower vocational), 1.7 (lower vocational to lower secondary) or 1.3 (lower vocational to higher) additional months lived.

Conclusion: Our findings confirm a strong selection into education based on socio-economic background and cognitive ability. Higher education levels are still associated with higher life expectancy however after taking education choice into account. Based on our estimates, it is plausible that increases in education will lead to increases in life expectancy.

Keywords: Intelligence, education, mortality, structural models

Introduction

Early life family characteristics including education and socio-economic position are important predictors of adult health and mortality.(Preston, Hill et al. 1998; Hayward and Gorman 2004; Strand and Kunst 2007)

The mortality differences by education hold across many populations. Among a million deaths in eight western European populations, lower education was associated with higher mortality from all causes and from cardiovascular diseases, neoplasms, and external causes.(Huisman, Kunst et al. 2005) Even in an egalitarian country such as the Netherlands, the difference in life expectancy between individuals with no formal education beyond primary school and those with a university education is more than five years.(Bruggink 2009) The background of these inequalities is not fully understood.

The association between mortality and education may partly be explained by confounding factors such as cognitive ability, intelligence, and parental background that affect both education choices and mortality.(Deary 2008) Lower cognitive ability as measured by standardized IQ tests is related to increased mortality (Batty and Deary 2004; Batty, Deary et al. 2007; Calvin, Deary et al. 2011). Because educational attainment and cognitive ability are strongly correlated, it is difficult to separate their effects on mortality.(Deary and Johnson 2010)

Studies based on natural experiments in education including changes in compulsory schooling laws may to some extent overcome the difficulty of separating true education effects from these confounding factors. Recent analyses of such natural experiments suggest that the direct effects of education on mortality may be limited or even absent. (Lleras-Muney 2005; Kippersluis van, O'Donnell et al. 2011; Meghir, Palme et al. 2012; Clark and Royer 2013) It is possible therefore that the strong association between education and mortality is mainly due to the incomplete control of confounding factors.

The effects of cognitive ability on mortality could be operating in several ways. Indirect effects can be expected if higher intelligence drives better education and improvements in SES in later life.(Huisman, Kunst et al. 2005) Direct effects are likely if more intelligent individuals do better in managing their diseases and in seeking appropriate treatment where necessary.(Batty and Deary 2004) As an example of the latter, men in the British birth cohort of 1946 with lower cognitive ability at age 8 years showed higher mortality through age 54 and adjustment for childhood SES only had a small effect on the relation.(Kuh, Richards et al. 2004) Education and cognitive ability may also operate in tandem and be mutually reinforcing. A better understanding of these relations is needed to establish potential direct benefits of improvements in education on mortality.

To examine the separate and joint contributions of education, cognitive ability and socio-economic background on mortality we use a structural model developed by Bijwaard et al (Bijwaard, van Kippersluis et al. 2013). This model is applied to a cohort of 18-year old men examined for military service in the Netherlands and followed through age 66. The model is an extension of the approach taken by Conti and Heckman (Conti and Heckman 2010; Conti, Heckman et al. 2010) to include a survival model and ordered education choice.

Methods

Study population

Using anonymized extracts from examinations for military service in the Netherlands between 1961-1965, we followed 45,037 men selected from the national birth cohorts 1944-1947 (Ekamper, van Poppel et al. 2013). These examinations are based on yearly listings of all Dutch male citizens aged 18 years in the national population registers. The study was reviewed by the Institutional Review Board of the Columbia University Medical Center in New York, NY. The Board determined that studies on this study population do not meet the DHSS definition of 'human subjects research' and are exempt from IRB approval. In the Netherlands, the study does not need approval by Ethical Review Boards or by the National Data Protection Authority (College Bescherming Persoonsgegevens) as all study procedures are in compliance with Dutch privacy legislation and do not need the consent of the data subjects concerned or of their relatives. The study is based on population wide administrative records and not on patient records.

Examination records

The examination records contain a standardized recording of demographic and socioeconomic characteristics, including education, father's occupation, birth order, typology of place of birth, and a standardized psychometric test battery with several measures of cognitive ability.

The principal cognition measure is the Raven Progressive Matrices, a nonverbal untimed test that requires inductive reasoning about perceptual patterns (Neisser, Boodoo et al. 1996). Because the test does not depend on reading, writing, or language skills and is easily administered and interpreted it is widely used to test military conscripts across the world. We used separate tests for Arithmetic and Language performance. Scores for all tests were grouped in six levels from 1 (highest) to 6 (lowest). The test scores are highly correlated with Pearson's r values in the range of .63 to .76.

Conscripts' education was classified in four levels (Doornbos and Kromhout 1990): primary school (six years of schooling); lower vocational education (eight years of schooling); lower secondary education (ten years of schooling); and intermediate or higher vocational or academic education (twelve or more years of schooling).[1] Because conscripts were age 18 at examination the highest education group includes men who had just started university but this group is too small for further subdivisions. Men who did not complete primary school or who received special education for the physically or mentally handicapped (6.2%, see Results) were excluded from analysis.

[1] Education in the Netherlands is characterized by education years and by school level. There are two parallel streams in the educational system– general academic and vocational. Streaming choices are made at the end of primary school. Students in the vocational stream cannot directly enter university. Students with more than twelve years of education will nearly always be in the academic stream (Schröder and Ganzeboom, 2014; Vrooman and Dronkers, 1986).

Father's occupation was classified into five categories: professional and managerial workers; clerical, self-employed and skilled workers; farmers; semi-skilled workers including operators, process workers and shop assistants; and laborers and miners. Fathers with unknown occupations were classified separately. Birth order was recorded as reported by the examinee.

Place of birth was categorized in four urbanization levels based on agrarian and total population size. This distinguishes rural communities (rural communities with 20% or more farming population), urbanized rural communities (rural communities with less than 20% farming population), towns (townships and cities with less than 100,000 inhabitants), and cities with populations of 100,000 or more.

Follow-up

As described elsewhere (Ekamper, van Poppel et al. 2013) we traced all examinees through population register records and national death records to ascertain vital status. Follow-up was until January 1, 2011, by which time the oldest men born in January 1944 had reached the age of 66 years.

Statistical analysis

We formulated a structural model to account for the interdependence of cognitive ability and education and their joint influence on mortality (Bijwaard, van Kippersluis et al. 2013), extending the structural equation model of Conti and Heckman (Conti and Heckman 2010; Conti, Heckman et al. 2010) to a Gompertz proportional hazard model. The model allows for interdependencies between educational choice, cognitive abilities and mortality. The underlying model assumption is that individuals base their educational choice on perceived health gains. The model consists of three parts: (i) the educational choice, (ii) potential mortality hazards and (iii) a measurement system for the latent abilities. Figure 1 shows the structure of the model.

The educational choice is endogenous. It is assumed that selection into schooling is fully accounted for by the observed individual characteristics and their latent cognitive ability. Define the indicator of education, *D*, taking the value *k* if the individual has attained education level *k* (1,..,4): $D = k$ if $\zeta_{k-1} < D^* \leq \zeta_k$ with $D^* = \gamma X + \alpha_D \theta + \upsilon_D$, the underlying latent utility of choosing a particular education level, which is continuous and depends linearly on the observed characteristics *X* and latent cognitive ability θ and where $\zeta_0 = -\infty$ and $\zeta_4 = \infty$. We assume that υ_D is normally distributed and assume an ordered probit model for the educational choice. Therefore the probability that an individual has attained education level k $\Pr(D = k)$ is given by $\Phi(\zeta_k - \gamma X - \alpha_D \theta) - \Phi(\zeta_{k-1} - \gamma X - \alpha_D \theta)$, with $\Phi(.)$ as the standard normal cumulative density.

The second part of the structural model comprises the potential mortality hazards. These hazards are potential because each individual's mortality is only observed for the actual education selection and not for potential alternatives in education level. For each education level we assume a Gompertz mortality rate. This provides accurate hazards for middle aged individuals (Gavrilov and Gavrilova 1991), with the potential hazard for education level k $\lambda^{(k)}(t) = \exp(a_k t + \beta_k X + \alpha_k \theta)$ depending on observed characteristics X and latent cognitive ability θ. The effect of latent ability on the mortality hazard is captured by α_1, α_2, α_3, and α_4.

The model is closed by three measurement equations linking the intelligence scores with the cognitive ability. Because for each IQ test, $q = 1,2,3$, the continuous score is only observed in six ordered IQ classes, an ordered probit is assumed with $M_q^* = \delta_q X + \alpha_{Mq}\theta + \upsilon_{Mq}$ where υ_{Mq} is normally distributed and $M_q = m$ if $\vartheta_{mq-1} < M_q^* \leq \vartheta_{mq}$. The probability to observe an individual in one of the IQ-classes is given by $\Pr(M_q = m) = \Phi(\vartheta_{mq} - \delta_q X - \alpha_{Mq}\theta) - \Phi(\vartheta_{mq-1} - \delta_q X - \alpha_{Mq}\theta)$.

An important feature of mortality outcomes is that some individuals are still alive at the end of observation period and are right censored. Another feature of our data is that all men were 18 years old at the start of the observation period at the time of military examination. We therefore condition on survival through age 18. With the distribution assumptions on the educational choice, the latent mortality hazards and the measurement system the likelihood function is defined. Details of the estimation procedure are presented in the Appendix.

The main estimand of interest is the difference in life-expectancy across education levels. To obtain the educational gains on mortality we need to compare the life expectancies given by the estimated mortality risk for each individual at each education level. As we only observe each individual in his chosen education level and not the counterfactual potential mortality, had this individual selected a different education level, we focus on the average educational gains.

To obtain the average gain in life expectancy we first calculate the average survival gain. From the survival functions, life expectancy and the gain in life expectancy can easily be obtained as being to the surface under the survival function. The gain in survival $\mathrm{G}_{\mathrm{ATEU}}^{\mathrm{k}}(\mathrm{t})$ at age t when the educational level improves from level k to $k+1$ with ($k=0,1,2;$ referring to primary school, lower vocational, and lower secondary education is:

$$G_{ATEU}^{k}(t) = \iint E\left[S^{(k+1)}(t) - S^{(k)}(t) | X = x, \theta = c, D = k\right] dF_{X,\theta|D=k}(x, c),$$

where X are in the included covariates and θ is the value of the latent cognitive ability. We integrate over the joint distribution of the covariates and the latent cognitive ability given education level k (the lowest of the two education levels) $F_{X,\theta|D=k}$ $F_{X,\theta}(x, c)$ to obtain the *average treatment effect on the untreated (ATEU).* This treatment effect measures the educational gain for those who attained a lower education level compared to those attaining the next higher level. From a policy perspective, this education effect on life expectancy ATEU is a most important measure.

The integrals cannot be solved analytically as the dimension of the covariates X is too large. The comparison of the survival functions also involves the counterfactual of surviving with another education level. Therefore simulations are needed to estimate the conditional survival differences. This is explained in more detail in the Appendix.

The relative impact of education and cognitive ability on mortality can be estimated by comparing the observed difference in life expectancy implied by the Kaplan-Meier survival curves, the implied educational gain from simple (uncorrelated) Gompertz survival models stratified by education level and the treatment effect obtained from the structural model. A limitation is that observations are limited to men aged 66 years which implies an upper bound for the Kaplan-Meier curves. We therefore compare the implied expected life expectancy from age 18-66 years by education level.

The surface on the Kaplan-Meier curves provides the crude difference in life expectancy from ages 18-66 years. The educational gain from our structural model provides the treatment effect. We define the difference between the crude difference and the treatment effect as the *selection effect*. This is the effect of individuals selecting themselves into different education levels on the basis of both observed individual characteristics and the unobserved cognitive ability. The educational gains based on the simple Gompertz models stratified by education level use the information contained in the included variables but not cognitive ability. From the difference between the educational gains of the structural model and the simple model we obtain the selection effect associated with the difference in cognitive ability (*selection effect cognitive ability*) and from the difference between the crude difference implied by the Kaplan-Meier curves and the simple model we obtain the selection effect associated with differences in observed characteristics (*selection effect observed*; by education level) .

The Gompertz survival models for each of the four education levels include birth order, urbanization status of municipality of birth, and father's occupation as covariates related to survival and the impact of the latent cognitive ability. The model only has a proportional hazard conditional on the latent ability. This is similar to including a (log-normal) frailty into the proportional hazard model.(Klein and Moeschberger 1997) All model estimations were carried out using STATA statistical software version 12. All the simulations to calculate the educational gains were obtained using R version 2.15.

Results

We identified 45,037 men for tracing at age 18, and ascertained vital status for 41,096 (91.2%) as per January 1, 2011. Among this group, 36,088 (80.1%) were alive and 5,008 (11.1%) had died. For 1,316 (2.9%), only a partial follow-up was possible due to emigrations or other reasons, and for 2,625 (5.8%) no follow-up was possible because of missing data. For this study, we excluded partly institutionalized conscripts who had attended special schools for the illiterate, handicapped, deaf-mute, or mentally retarded, and conscripts who had not completed schooling through 12 years. After exclusion of these 2,614 conscripts, 39,798 men remain for analysis.

Selected demographic and socioeconomic characteristics at the time of medical examinations are given in Table 1. Education level is strongly related to father's occupation; men with the highest education tend to have fathers in the most professional or managerial occupations. First born conscripts also tend to have higher education. In Table 2, intelligence test scores obtained by three instruments are presented by level of education. Again, men with the highest education tend to do best on all psychometric tests.

Kaplan-Meier survival curves for the four education categories primary lower vocational, higher vocational, and higher education are shown in Figure 2. Survival increases with the education level and the differences increase with age. (χ^2=128.79 by log-rank test with 3 degrees of freedom). In subgroup analyses, survival differences comparing adjacent education levels are also statistically significant, except for survival in the lower vocational and lower secondary education groups that shows no difference (χ^2=1.91; d.f.=1). Cox regression estimates of mortality risk show that men with lower vocational, higher vocational, and higher education have lower mortality compared to men with primary education only, with hazard ratios of 0.76 (95% CI 0.71 to 0.82), 0.73 (95% CI: 0.67 to 0.79), and 0.58 (95% CI: 0.52 to 0.64) respectively. In subgroup analyses, men with lower vocational schooling show lower mortality than men with primary education only (HR 0.76; 95% CI: 0.71 to 0.82) and men with higher education lower mortality than men with lower secondary education (HR 0.79; 95% CI: 0.73 to 0.87). Other adjacent education categories show no mortality differences.

Table 3 presents the estimated hazard ratios (HR), mortality, odds ratios (OR), education choice and measurement equations, of our structural model where the latent cognitive ability is assumed to follow a standard normal distribution. The results for stratified models by education level ignoring the interdependence are shown in Table A1 in the Appendix. The first row of Table 3 shows that our latent factor of cognitive ability is strongly related to intelligence and education choice: the higher the cognitive ability, the higher the intelligence score and the higher the attained education level. A one standard deviation higher cognitive ability increases the odds of higher education 3.09 times and the odds of higher intelligence 4.02 (Raven), 6.88 (Arithmetic) and 6.62 (Language) times. Higher cognitive ability estimates show a lower mortality (HR: 0.76 to 0.90) for all education classes which is especially pronounced (and statistically significant) for the second (HR: 0.76; 95% CI: 0.70, 0.83) and third (HR: 0.85; 95% CI: 0.77, 0.94) education level. The baseline mortality, reflected in the scale and shape of the Gompertz mortality hazard, differs substantially among the four educational groups (log-scale -9.685 to -10.211 and shape 0.083 to 0.090). As shown in Table 1, men with fathers in professional or managerial positions are more likely to obtain higher education (OR: 1.54; 95% CI: 1.48, 1.60) and there is an education gradient by father's level of occupation. Father's occupation has a similar relation to the measures of intelligence (OR: Raven 1.16; Arithmetic 1.58; Language 1.58). The impact of father's occupation on the mortality hazard within education level is variable.

Implicit in Table 3 is that the life expectancy in each education group not only depends on education level but also varies depending on the value of the included control factors. We therefore calculate the average life expectancy implied by the estimated models averaging over the distribution of these factors. We use the factor distribution, stratified by education level, to estimate the average life-expectancy for the average person in that education level a) for individuals who actually attained that level and b) for individuals in the next higher education level.

Table 4 presents the average life expectancy in years at age 18 by education level. The upper part of the Table provides the life expectancies derived from a simple stratified Gompertz models. These life expectancies at age 18 among men with the lowest to the highest education category range from 59.5 to 66.4 years (Table 5, upper part diagonal). There is a monotone, non-linear, relation between education level and life expectancy. Individuals in the highest education-class live, on average, almost six years longer than individuals in the lowest education class. The implied education gains on the life expectancy (ATEU) for men aged 18 are from primary education to lower vocational education are 2.2 years (61.7 minus 59.5 years) with a 95% CI from 0.6 to 3.8 years, from lower vocational to lower secondary are 1.4 years (95% CI: 0.1 to 2.7) and from lower secondary education to higher education 2.9 years (95% CI: 1.0; 4.8).

The lower part of Table 4 provides the life expectancies implied by the structural model, either across all education levels, ignoring the heterogeneity in the observed individual characteristics, or stratified by education level. With the structural model the expected differences in life expectancy by education level are smaller than with simple stratified Gompertz models. The structural model accounts for the cognitive ability that both influences educational choice and mortality and this leads to a higher life expectancy estimate for the lowest education level and a lower life expectancy for the highest education level. Nevertheless, education level still plays a dominant (and significant) role in mortality; substantial differences in life expectancy are implied by changes in the coefficients of the mortality hazard. Based on our model, men with the lowest level of education might have lived 2 years longer (62.6 vs 60.6 years; 95% CI: 1.0 to 2.9) had they attained the level of lower vocational education. The implied gain in life expectancy for men with lower vocational education had they attained lower secondary education is 0.3 years (95% CI: -0.4 to 1.0). And men with lower secondary education might have gained 1.9 years of life (95% CI: 0.9 to 2.9) had they attained higher education. That differences in non-education factors appear to less important can be seen from comparing the life expectancies within columns. As an example, there is little change in the life expectancy of individuals with lower vocational education when the factor distribution of those with lower secondary education is applied.

In Table 5, we decompose the estimated gains in life expectancy between 18-66 years from the Kaplan-Meier curves into treatment and selection effects. The estimated treatment gains (column 1) are expressed in additional months lived associated with a shift to the next higher education level. We report gains in months because the gains in life expectancy (average months lived) are limited to the observation window 18 to 66 years. The estimated gains are 5.7 (95% CI: 4.2 to 7.2) additional months moving from the primary to the lower vocational education level, -1.2 months moving from lower vocational to lower secondary, and 1.4 months (95% CI: 0.2 to 2.7) moving from lower secondary to higher education. For the intermediate education group with lower vocational education the treatment effect of education is negative. The selection effect, i.e. the positive impact on months lived for individuals selecting themselves into the next higher education level, is positive for all education levels. It amounts to one to two additional months of life (Table 5, column 2).

Next we decompose the total selection effect into two components: one attributable to selection on other observable characteristics and the other to selection on cognitive ability. (Table 5, columns 3 and 4). The latter effect is predominant moving up one level of education and amounts to 1.0 (primary to lower vocational), 1.7 (lower vocational to lower secondary) or 1.3 (lower vocational to higher) additional months lived.

Although the proportion of individuals lost to follow-up is relatively small, we carried out sensitivity analyses comparing the extreme scenarios under which all individuals lost to follow-up were either assumed to be dead or alive. This did not change the obtained treatment and selection effects. Assuming that missing individuals are in fact alive does increase the calculated life expectancies, but this had no impact on the reported survival differences associated with education levels.

Discussion

Our findings confirm a strong selection into education based on socio-economic background and cognitive ability. This is in agreement with findings from the United States where the correlation between IQ scores and years of education is about 0.55, and years of education are also positively correlated with the occupation/education of a child's parents.(Neisser, Boodoo et al. 1996). We therefore used a structural model to estimate the independent and combined effects of education and cognitive ability on life-expectancy and found that the highest education levels are still associated with the highest life expectancy. Our analyses suggest that improvements in education are likely to have significant beneficial effects on life expectancy. These findings are more optimistic than previous reports suggesting that the direct effects of education on mortality may be limited or even absent. (Lleras-Muney 2005; Kippersluis van, O'Donnell et al. 2011; Meghir, Palme et al. 2012; Clark and Royer 2013)

Our contribution to the literature is twofold. First, we use an innovative structural model to estimate gains in life expectancy accounting for cognitive ability and education choice. Second, we apply the model to a large nationally representative study population to obtain accurate and unbiased effect estimates.

Our study is based on military examination records from male births in the Netherlands in the years 1944-1947 for the study of the relation between prenatal famine exposure and mortality through age 63.(Ekamper, van Poppel et al. 2013) For that reason, men born in the Western Netherlands in 1944-1945 were over-represented. In this population, there was no relation however between famine conditions around birth and either mental performance (Stein, Susser et al. 1972) or education at age 18.(Ekamper, van Poppel et al. 2013) The study population appears suitable therefore to obtain unbiased estimates of the relation between cognitive ability, education, and mortality.

Overall mortality from age 18 to the end of the observation period for the study population was 12.7%, in close agreement with estimates based on national cohort life tables.(Ekamper, van Poppel et al. 2013) For 5.8% of men it was not possible to ascertain vital status at any point in time for the lack of linkages across databases of information collected at age 18 with current data. These men could have died or could still be living in the Netherlands. As the traced and untraced men did not differ with respect to available demographic and examination characteristics at age 18 we think that this study population provides unbiased effect estimates of the likely benefits of increased education on mortality.

The Raven test is widely used to test military conscripts across the world for its ease of administration and interpretation. At the age of 18, the examinees can be also assumed to have reached the peak of their problem solving skills on the tests of mental performance.(Flynn 1987) There has been a significant increase over time in the mean Raven scores of Dutch military recruits. In 1952, only 0.38 % of Dutch recruits had IQs over 140 but this proportion had increased to 9% in 1982.(de Leeuw and Meester 1984) The reasons for this score increase over time are unclear (Flynn 1987) IQ score changes over time are not likely to impact on our study findings however because all IQ measurements were completed in a narrow time window of less than 3 years and the age at examination for the study population did not change. Although the study group was closely matched on both year of birth and year of examination of intelligence scores we nevertheless evaluated the effects of additional adjustments for year of birth and year of examination to exclude any time-related trends and found no changes from our reported estimates.

A drawback of our data is that only information on men and not on women is available. Bijwaard et al.(Bijwaard, van Kippersluis et al. 2013) , using survey data from a slightly older cohort, found that educational gains for women appear to be higher than for men, in spite of the higher survival difference of women with lower vs higher education. These findings are based on much smaller numbers than the current study however and therefore need to be interpreted with caution.

The study findings apply to men born 1944-1947 who were examined in the early 1960s and our specific mortality findings may therefore not apply to contemporary populations in the Netherlands. There has been a major change in the education system in the Netherlands in 1968 and some of the specific education strata in this study no longer exist.(Vrooman and Dronkers 1986) In addition, the percentage of people with more than six years of post-primary school education is currently much higher compared to the past.(Tieben and Wolbers 2010) Although we expect our general conclusion to hold that education itself effects survival, further long term studies will be needed to quantify these effects for contemporary school types.

In the shorter term, our models could be used to estimate the effects of education on health outcomes in contemporary populations. In many countries, including the Netherlands, annual individual level educational test scores are collected nationwide from kindergarten onwards. Of special importance from a policy perspective would be the analysis of health outcomes by ethnicity in view of the underrepresentation of many ethnic populations in the higher levels of national education systems. These analyses will further clarify the role of education on health and mortality in specific population groups.

In conclusion, we assessed in this study the potential gains in life expectancy from increased education, corrected for selection into education and differences in intelligence and found significant positive gains. Our findings comparing results from alternative models confirm the strong selection into education based on socio-economic background and on cognitive ability but nevertheless show significant beneficial gains from increased education.

For future research, we hope that similar analyses will be carried out in other countries with comparable data. Comparisons of study findings may then allow further specifications of the impact of education on survival inequalities over time. The continued analysis of this aging study population in the Netherlands will provide more refined estimates of education effects on survival to the large group of men who live beyond the age of 66 years.

Table 1. Population characteristics at age 18 years by level of education

	Primary education	Lower vocational	Lower secondary	Higher education	All levels
	n=5,712	n=14,572	n=13,124	n=6,390	39,798
Birth order					
1	*28%*	*32%*	*39%*	*42%*	*36%*
2	27%	30%	31%	30%	30%
3	19%	18%	16%	15%	17%
4	11%	9%	7%	7%	8%
5+	15%	10%	7%	5%	9%
Religion					
Roman Catholic	40%	33%	30%	32%	33%
Dutch Reformed	26%	31%	31%	30%	30%
Other	4%	8%	9%	10%	8%
No Religion	30%	28%	29%	28%	29%
Place of birth					
Rural	18%	24%	18%	21%	21%
Urbanized Rural	3%	4%	4%	4%	4%
Town	10%	9%	9%	12%	10%
City	68%	63%	69%	63%	66%
Father's occupation					
Professional	9%	10%	17%	39%	17%
Clerical	20%	30%	43%	43%	35%
Farmer	3%	6%	2%	2%	3%
Semi-skilled	38%	33%	23%	9%	27%
Laborer	23%	15%	9%	3%	12%
Unknown	8%	6%	5%	4%	6%

Table 2. Intelligence scores at age 18 years by level of education

	Primary education	**Lower vocational**	**Lower secondary**	**Higher education**	**All levels**
	n=5,712	n=14,572	n=13,124	n=6,390	39,798
Raven score					
1 highest	3%	16%	28%	49%	24%
2	18%	34%	39%	36%	34%
3	23%	25%	19%	9%	20%
4	22%	14%	8%	3%	11%
5	22%	7%	3%	1%	7%
6 lowest	8%	2%	1%	0%	2%
Arithmetic test score					
1 highest	0%	7%	17%	52%	17%
2	2%	24%	39%	37%	28%
3	10%	27%	28%	7%	21%
4	25%	22%	11%	1%	15%
5	43%	16%	3%	0%	13%
6 lowest	17%	2%	0%	0%	3%
Language test score					
1 highest	0%	4%	23%	52%	17%
2	4%	20%	48%	39%	30%
3	18%	33%	20%	5%	22%
4	29%	27%	5%	1%	16%
5	35%	12%	1%	0%	10%
6 lowest	10%	1%	0%	0%	2%
Test scores not available	3%	2%	2%	3%	2%

Table 3: Estimated parameters of structural model

	Educational choice (OR)	**Intelligence measure (OR)**			**Mortality hazard (HR)**			
	D	Raven	Arithmetic	Language	Λ_1 Primary education	Λ_2 Lower vocational	Λ_3 Lower secondary	Λ_4 Higher education
Cognitive ability	**3.09**	**4.02**	**6.99**	**6.62**	0.90	**0.76**	**0.85**	0.86
	(3.02; 3.16)	(3.92; 4.13)	(5.83; 8.38)	(5.44; 8.05)	(0.80; 1.01)	(0.70; 0.83)	(0.77; 0.94)	(0.71; 1.04)
Birth order	**0.89**	**0.93**	**0.81**	**0.78**	0.99	0.98	1.01	0.99
	(0.88; 0.90)	(0.92; 0.94)	(0.79; 0.83)	(0.76; 0.80)	(0.96; 1.03)	(0.96; 1.01)	(0.97; 1.04)	(0.93; 1.05)
Religion (ref = No religion)								
Roman Catholic	0.99	1.03	**1.24**	1.05	1.04	0.92	0.97	1.14
	(0.96; 1.03)	(0.99; 1.07)	(1.14; 1.34)	(0.97; 1.15)	(0.89; 1.21)	(0.82; 1.04)	(0.86; 1.10)	(0.93; 1.40)
Dutch Reformed	**1.06**	0.99	**1.35**	**1.25**	0.96	0.98	0.96	1.00
	(1.02; 1.10)	(0.96; 1.03)	(1.24; 1.47)	(1.15; 1.36)	(0.81; 1.14)	(0.87; 1.10)	(0.85; 1.08)	(0.81; 1.22)
Other Religion	**1.31**	**1.13**	**2.15**	**2.34**	0.73	0.94	**0.81**	0.79
	(1.24; 1.39)	(1.07; 1.20)	(1.88; 2.45)	(2.04; 2.68)	(0.50; 1.05)	(0.79; 1.12)	(0.67; 0.98)	(0.58; 1.08)
Urbanization (ref=City)								
Rural	1.01	**0.86**	0.98	**0.91**	0.90	0.94	0.91	0.89
	(0.97; 1.05)	(0.83; 0.90)	(0.90; 1.07)	(0.84; 0.99)	(0.75; 1.07)	(0.84; 1.06)	(0.79; 1.04)	(0.73; 1.09)
Urbanized Rural	0.96	**0.85**	0.92	0.87	1.01	1.07	1.01	1.17
	(0.90; 1.04)	(0.79; 0.92)	(0.78; 1.10)	(0.73; 1.04)	(0.72; 1.43)	(0.85; 1.34)	(0.78; 1.30)	(0.80; 1.72)
Town	**1.05**	**1.05**	**1.36**	**1.15**	0.85	1.05	1.05	**0.72**
	(1.00; 1.10)	(1.00; 1.11)	(1.21; 1.52)	(1.03; 1.29)	(0.68; 1.06)	(0.90; 1.23)	(0.89; 1.24)	(0.55; 0.94)
Father's occupation (Ref=Clerical)								
Professional	**1.54**	**1.16**	**1.58**	**1.58**	**0.74**	1.00	0.97	1.11
	(1.48; 1.60)	(1.11; 1.21)	(1.43; 1.75)	(1.43; 1.75)	(0.56; 0.97)	(0.85; 1.17)	(0.84; 1.12)	(0.93; 1.32)
Farmer	**0.53**	**0.55**	**0.30**	**0.22**	0.94	1.04	1.17	1.68
	(0.49; 0.57)	(0.50; 0.60)	(0.25; 0.37)	(0.18; 0.27)	(0.62; 1.44)	(0.84; 1.30)	(0.84; 1.65)	(0.99; 2.85)
Semi-skilled	**0.45**	**0.64**	**0.24**	**0.22**	1.00	0.99	**1.14**	1.26
	(0.43; 0.46)	(0.61; 0.66)	(0.22; 0.26)	(0.20; 0.24)	(0.84; 1.19)	(0.88; 1.10)	(1.01; 1.29)	(0.96; 1.66)
Laborer	**0.37**	**0.54**	**0.15**	**0.15**	1.13	1.01	1.16	1.39
	(0.36; 0.39)	(0.51; 0.57)	(0.13; 0.17)	(0.13; 0.17)	(0.94; 1.37)	(0.87; 1.16)	(0.98; 1.38)	(0.93; 2.07)
Unknown	**0.55**	**0.74**	**0.30**	**0.35**	1.01	**1.41**	1.06	**1.60**
	(0.51; 0.58)	(0.69; 0.79)	(0.26; 0.35)	(0.30; 0.40)	(0.77; 1.32)	(1.18; 1.68)	(0.84; 1.33)	(1.12; 2.28)
scale (log)	-	-	-	-	-9.685	-10.211	-9.996	-10.079
	-	-	-	-	(-10.08; -9.29)	(-10.48; -9.94)	(-10.28; -9.72)	(-10.53; -9.63)
shape	-	-	-	-	0.085	0.090	0.086	0.083
	-	-	-	-	(0.079; 0.092)	(0.086; 0.095)	(0.081; 0.091)	(0.076;0.091)

Table 4: Life expectancy in years (95% CI) at age 18 by education level estimated from simple Gompertz and Structural Models

	Education level			
	Primary education	**Lower vocational**	**Lower secondary**	**Higher education**
Simple Gompertz				
Factor distribution				
Primary education	59.5 (59.5; 60.9)	61.7 (60.8; 62.6)		
Lower vocational		61.6 (60.8; 62.5)	63.0 (62.0; 64.0)	
Lower secondary			63.2 (62.2; 64.2)	66.1 (64.4; 67.7)
Higher education				66.4 (64.7; 68.0)
Structural model				
Factor distribution				
Primary education	60.6 (59.8; 61.3)	62.6 (62.1; 63.1)		
Lower vocational		62.6 (62.1; 63.1)	62.9 (62.4; 66.0)	
Lower secondary			63.2 (62.7; 63.6)	65.1 (64.2; 66.0)
Higher education				65.6 (64.7; 66.5)

Table 5: Decomposition of the estimated gains in life expectancy in months (95% CI) from age 18 to 66 years into treatment and selection effects, on observables and selection on cognitive ability

	Treatment effect	Selection effect		
		Total	Observed	Cognition
From primary to lower vocational	**5.7**	1.0	-0.1	1.0
	(4.2; 7.2)	(-0.6; 2.5)	(-0.6; 0.5)	(-0.5; 2.5)
From lower vocational to lower secondary	**-1.2**	**1.4**	-0.3	**1.7**
	(-2.1; -0.2)	(0.4; 2.4)	(-0.7; 0.1)	(0.8; 2.7)
From lower secondary to higher	**1.4**	**2.1**	**0.7**	**1.3**
	(0.2; 2.7)	(0.7; 3.4)	(0.3 ; 1.2)	(0.0; 2.6)

Change in expected life expectancy in months over the period 18-66 years.
Treatment effect: estimated gain from (latent class) model
Selection effect: remaining difference from implied life expectancy based on Kaplan-Meier curves

Figure 1: Schematic depiction of the structural equation model

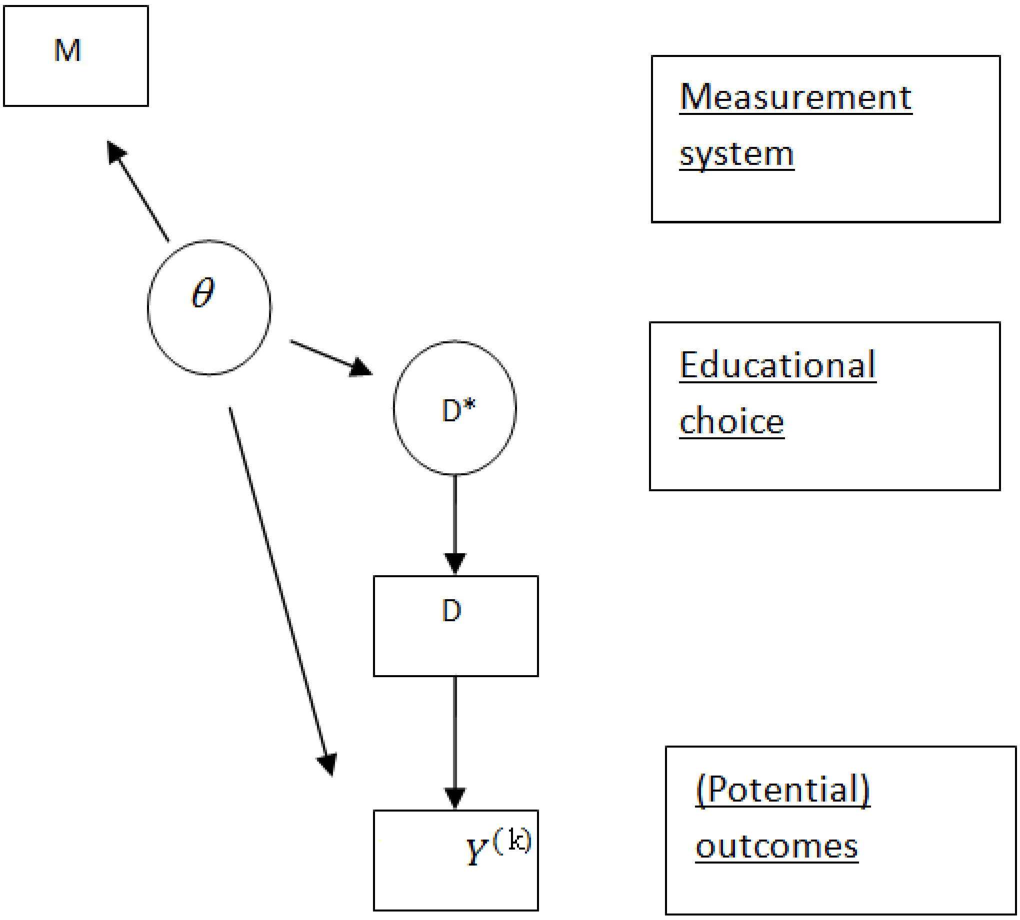
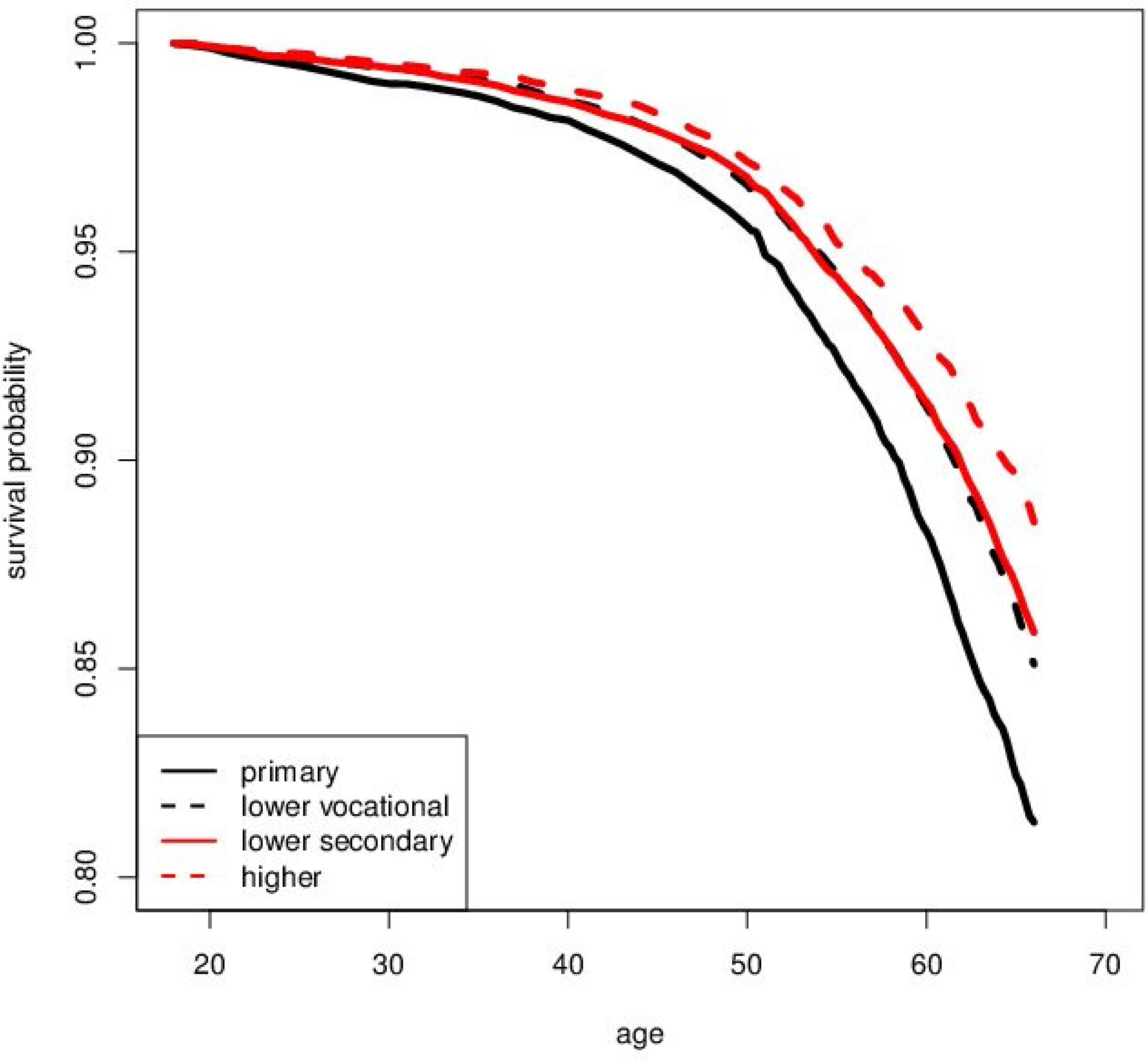


Figure 2: Kaplan-Meier estimates of survival by education level



References

Batty, G. D. and I. J. Deary (2004). "Early life intelligence and adult health." BMJ **329**(7466): 585-6.

Batty, G. D., I. J. Deary, et al. (2007). "Premorbid (early life) IQ and later mortality risk: systematic review." Ann Epidemiol **17**(4): 278-88.

Bijwaard, G. E., H. van Kippersluis, et al. (2013). "Education and Health: The Role of Cognitive Ability." Tinbergen Institute Discussion Paper (13-044).

Bruggink, J. W. (2009). "Ontwikkelingen in de (gezonde) levensverwachting naar opleidingsniveau, Bevolkingstrends 2009 (4), 71-74." Bevolkingstrends 2009 (4) 71-74, from http://www.cbs.nl/nl-NL/menu/themas/bevolking/publicaties/bevolkingstrends/archief/2009/2009-k4-b15-p71-art.htm. Accessed January 22,2014.

Calvin, C. M., I. J. Deary, et al. (2011). "Intelligence in youth and all-cause-mortality: systematic review with meta-analysis." Int J Epidemiol **40**(3): 626-44.

Clark, D. and D. Royer (2013). "The effect of education on adult mortality and health: Evidence from Britain." American Economic Review **103**(6): 2087-2120.

Conti, G. and J. J. Heckman (2010). "Understanding the Early Origins of the Education-Health Gradient: A Framework That Can Also Be Applied to Analyze Gene-Environment Interactions." Perspect Psychol Sci **5**(5): 585-605.

Conti, G., J. J. Heckman, et al. (2010). "The education-health gradient." American Economic Review Papers and Proceedings **100**(2): 234-38.

de Leeuw, J. and A. C. Meester (1984). "Over het intelligentie onderzoek bij de militaire keuringen vanaf 1925 tot heden (Intelligence - as tested as selectections for the military service from 1925 to the present)." Mens en Maatschappij **59**: 5-26.

Deary, I. (2008). "Why do intelligent people live longer?" Nature **456**(7219): 175-6.

Deary, I. J. and W. Johnson (2010). "Intelligence and education: causal perceptions drive analytic processes and therefore conclusions." Int J Epidemiol **39**(5): 1362-9.

Doornbos, G. and D. Kromhout (1990). "Educational level and mortality in a 32-year follow-up study of 18-year-old men in The Netherlands." Int J Epidemiol **19**(2): 374-9.

Ekamper, P., F. van Poppel, et al. (2013). "Independent and additive association of prenatal famine exposure and intermediary life conditions with adult mortality between age 18-63 years." Soc Sci Med.

Elbers, C., and G. Ridder. (1982). "True and spurious duration dependence: The identifiability of proportional hazards models." Review of Economic Studies **49**: 403-410.

Flynn, J. R. (1987). "Massive IQ gains in 14 nations: What IQ tests really measure." Psychological Bulletin **101**(2): 171-191.

Gavrilov, L. A. and N. S. Gavrilova (1991). The biology of life span: a quantitative approach. New York, Harwood Academic Publisher.

Hayward, M. D. and B. K. Gorman (2004). "The long arm of childhood: The influence of early-life conditions on men's mortality." Demography **41**(1): 87-107.

Huisman, M., A. E. Kunst, et al. (2005). "Educational inequalities in cause-specific mortality in middle-aged and older men and women in eight western European populations." Lancet **365**(9458): 493-500.

Huisman, M., A. E. Kunst, et al. (2005). "Intelligence and socioeconomic inequalities in health." Lancet **366**(9488): 807-8.

van Kippersluis, H., O. O'Donnell, et al. (2011). "Long run returns to education: does schooling lead to an extended old age?" J Hum Resources **46**(4): 695-721.

Klein, J. P. and M. L. Moeschberger (1997). Survival analysis. Techniques for censored and truncated data. New York, Springer Science.

Kuh, D., M. Richards, et al. (2004). "Childhood cognitive ability and deaths up until middle age: a post-war birth cohort study." Int J Epidemiol **33**(2): 408-13.

Lleras-Muney, A. (2005). "The relationship between education and adult mortality in the United States " Rev Economic Studies **72**: 189-221.

Meghir, C., M. Palme, et al. (2012). "Education, health and mortality: evidence from a social experiment." NBER working paper No. 17932.

Neisser, U., G. Boodoo, et al. (1996). "Intelligence: Knowns and unknowns." American Psychologist.**51**(2): 77-101.

Press, W. H., B. P. Flannery, S. A. Teukolsky, and W.T. Vetterling. (1993). Numerical Recipes in C: The Art of Scientific Computing. Second Edition. Cambridge: Cambridge UP.

Preston, S. H., M. E. Hill, et al. (1998). "Childhood conditions that predict survival to advanced ages among African-Americans." Social Science and Medicine **47**(9): 1231-1246.
Schröder, H., and Ganzeboom, H. B. G. (2014). "Measuring and Modelling Level of Education in European Societies." European Sociological Review, 30(1), 119-136.
Stein, Z., M. Susser, et al. (1972). "Nutrition and mental performance." Science **178**(62): 708-13.
Strand, B. H. and A. E. Kunst (2007). "Childhood socioeconomic position and cause-specific mortality in early adulthood." American Journal of Epidemiology **165**(1): 85-93.
Tieben, N. and M. H. J. Wolbers (2010). " Transitions to post-secondary and tertiary education in the Netherlands: a trend analysis of unconditional and conditional socio-economic background effects." Higher Education **60**: 85-100.
Vrooman, J. C., and Dronkers, J. (1986). "Changing Educational Attainment Processes: Some Evidence from the Netherlands." Sociology of Education, *59*(2), 69-78.

Appendix

Here we discuss some additional methodological issues involved in the structural model.

Combining the distribution assumptions on the educational choice, the latent mortality hazards and the measurement system allows us to write down the likelihood function. Unfortunately, estimation based on the maximum of the likelihood function involves the calculation of an integral that does not have an analytical solution, due to the latent cognitive ability. This one dimensional integral can be approximated very well using a Gaussian quadrature, which is a numerical integration method based on Hermite polynomials (Press et al 1993). Bijwaard et al.(Bijwaard, van Kippersluis et al. 2013) provide a full description of the estimation of a similar model. The only difference is that we have a system of ordered probit measurements, while they have continuous measurements.

The integral in calculating the gain in survival $G^{k}_{ATEU}(t)$cannot be solved analytically, we therefore resort to a simulation procedure to obtain the survival gains and the life expectancies. For each education level we simulate the survival of 10,000 individuals. To each individual we assign observed characteristics based on the empirical distribution in the sample. The simulation procedure consists of five steps:

1. Draw a vector of parameter estimates assuming that the estimator is normally distributed around the point estimates with a variance-covariance matrix equal to the estimated one.
2. Compute the conditional hazard rates based on these parameter values and individual characteristics using the two Gompertz mortality hazard rates (*D=k* and *D=k+1*) conditional on the value of the latent cognitive ability.
3. Determine the unconditional survival function for every individual and for the whole age-range from 18 to 110 and by integrating out the latent cognitive ability through Gaussian quadrature methods.
4. Calculate the average (over the 10,000 individuals) survival at each age (with steps of a month)
5. Calculate the life expectancy from the surface under the survival function.

We repeat these steps 100 times to obtain 100 independent observations of the life expectancy for each education level. Bijwaard et al.(Bijwaard, van Kippersluis et al. 2013) provide the details of this procedure.

Without additional restrictions on the distribution of the latent factors the model is not identified. The restrictions required for identification differ however from the restrictions on the latent factors in a standard structural equations model. In our case, an intrinsically non-linear duration outcome is modeled instead of a linear outcome. Identification of our model is closely related to the identification in a mixed proportional hazard (MPH) model, where the unobserved heterogeneity is assumed to have a log-normal distribution. An MPH model is identified when the unobserved heterogeneity term has a finite mean and is independent of the other observed factors (Elbers and Ridder 1982). We assume a normal distribution for the latent cognitive skills. For identification we set the variance of θ to one (Bijwaard, van Kippersluis et al. 2013). Thus the latent cognitive skills are assumed to follow a standard normal distribution.

Table A 1: Estimated parameters of separate Gompertz, education and intelligence models

	Educational choice (OR)	**Intelligence measurement (OR)**			**Mortality hazard (HR)**			
	D	Raven	Arithmetic	Language	Λ_1 Primary education	Λ_2 Lower vocational	Λ_3 Lower secondary	Λ_4 Higher education
Birth order	**0.89**	**0.95**	**0.93**	**0.92**	0.99	0.98	1.00	0.99
	(0.91; 0.92)	(0.95; 0.96)	(0.93; 0.94)	(0.92; 0.93)	(0.96; 1.02)	(0.95; 1.00)	(0.97; 1.04)	(0.93; 1.05)
Religion (ref = No religion)								
Roman Catholic	0.99	1.02	**1.06**	1.02	1.03	0.92	0.97	1.15
	(0.96; 1.02)	(0.99; 1.05)	(1.04; 1.09)	(0.99; 1.04)	(0.89; 1.20)	(0.82; 1.04)	(0.85; 1.10)	(0.94; 1.41)
Dutch Reformed	**1.05**	1.00	**1.10**	**1.07**	0.96	0.98	0.96	1.00
	(1.02; 1.08)	(0.97; 1.02)	(1.07; 1.13)	(1.04; 1.10)	(0.81; 1.15)	(0.87; 1.10)	(0.85; 1.08)	(0.82; 1.23)
Other Religion	**1.23**	**1.09**	**1.26**	**1.30**	0.73	0.95	**0.83**	0.81
	(1.18; 1.29)	(1.05; 1.14)	(1.21; 1.32)	(1.25; 1.36)	(0.50; 1.06)	(0.80; 1.14)	(0.68; 1.00)	(0.59; 1.10)
Place of Birth (ref=City)								
Rural	1.01	**0.90**	0.99	**0.97**	0.90	0.94	0.91	0.90
	(0.98; 1.04)	(0.87; 0.92)	(0.96; 1.02)	(0.94; 0.99)	(0.75; 1.08)	(0.84; 1.06)	(0.79; 1.04)	(0.74; 1.09)
Urbanized Rural	0.99	**0.91**	1.00	0.96	1.02	1.07	0.99	1.17
	(0.93; 1.04)	(0.86; 0.96)	(0.94; 1.05)	(0.91; 1.01)	(0.72; 1.45)	(0.85; 1.34)	(0.77; 1.29)	(0.80; 1.72)
Town	1.04	**1.04**	**1.10**	**1.04**	0.86	1.05	1.05	**0.72**
	(1.00; 1.08)	(1.00; 1.07)	(1.06; 1.14)	(1.01; 1.08)	(0.69; 1.07)	(0.90; 1.22)	(0.89; 1.24)	(0.55; 0.95)
Father's occupation (Ref=Clerical)								
Professional	**1.41**	**1.11**	**1.15**	**1.15**	**0.75**	1.03	0.99	1.13
	(1.37; 1.46)	(1.07; 1.14)	(1.12; 1.19)	(1.12; 1.19)	(0.57; 0.99)	(0.88; 1.21)	(0.86; 1.13)	(0.95; 1.35)
Farmer	**0.61**	**0.65**	**0.69**	**0.62**	0.93	1.02	1.11	1.59
	(0.58; 0.65)	(0.62; 0.69)	(0.65; 0.73)	(0.59; 0.66)	(0.61; 1.43)	(0.82; 1.26)	(0.79; 1.55)	(0.95; 2.68)
Semi-skilled	**0.53**	**0.73**	**0.64**	**0.61**	0.97	0.93	1.09	1.21
	(0.52; 0.55)	(0.71; 0.75)	(0.62; 0.65)	(0.60; 0.63)	(0.82; 1.16)	(0.83; 1.04)	(0.97; 1.23)	(0.92; 1.59)
Laborer	**0.46**	**0.64**	**0.54**	**0.54**	1.10	0.94	1.10	1.30
	(0.45; 0.48)	(0.62; 0.66)	(0.53; 0.56)	(0.52; 0.56)	(0.91; 1.33)	(0.82; 1.08)	(0.93; 1.30)	(0.88; 1.92)
Unknown	**0.63**	**0.81**	**0.69**	**0.71**	0.99	**1.36**	1.02	**1.54**
	(0.60; 0.66)	(0.77; 0.85)	(0.66; 0.72)	(0.68; 0.74)	(0.76; 1.30)	(1.14; 1.62)	(0.81; 1.27)	(1.08; 2.20)
scale (log)	-	-	-	-	-9.572	-10.089	-9.978	-10.149
	-	-	-	-	(-9.95; -9.20)	(-10.36; -9.82)	(-10.26; -9.70)	(-10.59; -9.70)
shape	-	-	-	-	0.085	0.090	0.086	0.083
		-	-	-	(0.079; 0.092)	(0.086; 0.095)	(0.081; 0.091)	(0.076;0.091)