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Trends and Group Differences in the Association between Educational Attainment and U.S. Adult Mortality: Implications for Understanding Education's Causal Influence*

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Abstract

Has the shape of the association between educational attainment and U.S. adult mortality changed in recent decades? If so, is it changing consistently across demographic groups? What can changes in the shape of the association tell us about the possible mechanisms in play for improving health and lowering mortality risk over the adult life course? This paper develops the argument that societal technological change may have had profound effects on the importance of educational attainment – particularly advanced education – in the U.S. adult population for garnering health advantages and that these changes should be reflected in changes in the functional form of the association between educational attainment and mortality. We review the historical evidence on the changing functional form of the association, drawing on studies based in the United States, to assess whether these changes are consistent with our argument about the role of technological change. We also provide an updated analysis of these functional form patterns and trends, contrasting data from the early 21st Century with data from the late 20th Century. This updated evidence suggests that the shape of the association between educational attainment and U.S. adult mortality appears to be reflecting lower and lower adult mortality for very highly educated Americans compared to their low-educated counterparts in the 21st Century. We draw on this review and updated evidence to reflect on the question whether education's association with adult mortality has become increasingly causal in recent decades, why, and the potential research, policy, and global implications of these changes.

Has the shape of the association between educational attainment and U.S. adult mortality changed in recent decades? If so, how is it changing? Is it changing consistently across demographic groups? The answers to these questions are critical in understanding the kinds of mechanisms by which educational attainment operates or whether changes in the shape of

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the association are being driven by unobserved factors such as intelligence or child health. In addition, answers to these questions may point to whether the association is becoming more causal for particular subgroups of the population and help identify what societal level conditions may be contributing to these changes.

This paper offers a conceptual framework for understanding how macro societal changes may be influencing changes in the functional form of the association between educational attainment and adult mortality. We focus specifically on the possible implications of rapid technological change for changes in the shape of the association between individuals' educational attainment and adult mortality risk. We then turn to a review of the evidence on the changing functional form of the association between educational attainment and adult mortality, drawing on studies based in the United States, to assess whether the empirical evidence thus far is consistent with our argument regarding the role of technological change in influencing the functional form. Particular attention is given to how widespread the changes are across race and gender subgroups of the population. We further provide an updated analysis of these functional form patterns and trends, contrasting data from the late 20th Century with data from the early 21st Century. We draw on this review and our updated evidence to reflect on the question whether education's association with adult mortality has become increasingly causal in recent decades, among whom, why, and the potential research, policy, and global implications of these changes.

The Conceptual Links between Educational Attainment and Adult Mortality

It is not news that high educational attainment is strongly associated with lower U.S. adult mortality (Feldman et al. 1989; Hummer and Lariscy 2011; Kitagawa and Hauser 1973; Preston and Taubman 1994). Very often, the interpretation of this association is rooted in the idea that education fosters the creation of individuals' "health capital" throughout the adult life course (Cutler and Lleras-Muney 2010; Hummer and Hernandez 2013). This interpretation is portrayed heuristically in Figure 1. On average, individuals' higher levels of education improve access to better jobs and associated extrinsic and intrinsic rewards and psychosocial resources – factors that have long been shown to be associated with lower mortality and better health (House 2002; Marmot and Wilkinson 2001; Marmot et al. 1997; Moore and Hayward 1990; Ross and Wu 1996). Educational attainment also provides individuals with the means to acquire valuable information about, and support for, healthy life styles and health care that also reduce mortality (Lantz et al. 1998; Rogers, Hummer and Everett 2013; Ross and Wu 1996; Schoeni et al. 2010). Education influences persons' access to valuable networks and social relationships and the mobilization of those relationships (Hout 2012; Lin 1999), which have been shown to benefit health (Berkman et al. 2000; House, Landis and Umberson 1988). And, education also fosters the development of general cognitive skills in individuals, and a greater sense of control and human agency that are critical in garnering health advantages (Baker et al. 2011). In terms of general cognitive skills, education teaches people how to learn, communicate more effectively, be proactive in figuring things out, be analytical in problem solving and so on – factors that are critical in producing health and managing health problems. With greater human agency and feelings of control that accrue from education comes the ability to make health-related choices that maximize health advantages (Mirowsky and Ross 2003). Framed in these terms, persons with advanced education are presumed to have a bounty of resources that can be used to garner health advantages compared to less educated persons (Hout 2012; Link and Phelan 1995; Mirowsky and Ross 2003). This is the basis for the idea that a significant part of the association between educational attainment and adult mortality is causal.

Life course research on achievement processes points to the possibility that the education-mortality association also reflects other early life conditions such as the childhood socioeconomic and health environment, shown in Figure 1. Childhood socioeconomic advantages are associated with a lower risk of adult mortality and health problems (Hayward and Gorman 2004; Luo and Waite 2005; Montez and Hayward 2011). Similarly, childhood health problems also have been linked to higher mortality risks and health problems in adulthood (Blackwell, Hayward and Crimmins 2001; Haas 2007). Some researchers have also suggested that IQ may be an “elusive fundamental cause” of health that may account for the associations between socioeconomic factors such as education and adult health (Gottfredson and Deary 2004). With respect to effects of childhood socioeconomic disadvantages, much of these effects have been shown to operate through adult conditions such as educational attainment and income (Hayward and Gorman 2004). Moreover, Hayward’s and Gorman’s (2004) results suggested that the effects of adult socioeconomic factors on mortality are highly robust to controls for early life conditions, and that the association between educational attainment and adult mortality is potentially *underestimated* when childhood conditions are not controlled. Link and colleagues (2008) similarly observed in analyses of the Wisconsin Longitudinal Study and the Health and Retirement Study data sets that the associations between educational attainment, income, and adult mortality changed very little when intelligence was controlled and that there was no direct effect of intelligence. In addition, a very recent study by Montez and Hayward (2014) documented, using the Health and Retirement Study, that educational attainment’s association with later life health and mortality was not simply a reflection of childhood health conditions or socioeconomic status – a pattern consistent with prior research. Thus, when controlling for early life conditions such as childhood socioeconomic disadvantages, childhood health problems and IQ, educational attainment’s association with adult mortality appears to be highly robust in the older American population in the latter part of the 20th Century.

At the population level, the educational attainment of a society reflects not only the aggregate stock of human capital but also the “…institutional, physical capital, and educational requirements for the technology of disease control…” (Easterlin 1997:81) – the social capacity for population health. The rising educational attainment in a population signals improvements in a broad spectrum of technological knowledge that can help human survival and enhance health, which coincide with other health-related infrastructural changes in communities. The idea of “social capacity for health,” an institutional rather than individualistic perspective, is similar to the concept of technophysio evolution (Fogel 2004; Fogel and Costa 1997). This latter concept was introduced to explain the existence of a synergistic association between technological and physiological improvements over the past 300 years. The core idea is that humans, through the development of scientific knowledge and technology, have gained unprecedented control over their environment. This control has made possible the extraordinary improvements in body size, longevity, and the "… robustness and capacity of vital organ systems" (Fogel 2004:21). It is important to note, however, that the idea of technophysio evolution does not imply constantly improving population health. Instead, it points to the increasing importance of *human control* over the environment as a key determinant of population health.

An important consideration is the pace of technological change and how it influences changes in the association between *individuals'* educational attainment and mortality risk. In this sense, education refers to qualities that adhere to the person. As noted by Easterlin (1996), however, educational attainment *in the population* is an important indicator not only of the stock of human capital but also of the "stock" of technological knowledge and associated institutional resources that individuals' have access to and may act on to garner health advantages. This suggests that as educational attainment in the population increases, the abundance and variety of resources that can be used by individuals should grow substantially.

In the case of the United States, only 6.2 percent of the adult population aged 25 years and older had a bachelor's degree or higher in 1950, while only 34.3 percent had a high school diploma or higher (Bauman and Graf 2003). By 2000, 24.4 percent of the adult population had a bachelor's degree or higher, while over 80 percent had a high school diploma or more. By 2009, 27.9 percent of the adult population had a bachelor's degree or higher and 85.3 percent had a high school degree or higher (Ryan and Siebens 2012). Over the course of the last half of the 20th Century, there was a groundswell of advanced education in the American population and this has continued into the first decade of the 21st Century. These changes point to a dramatic increase in the social capacity for population health in the United States.

Who is most likely to take advantage of the dramatic growth in the social capacity for population health that is reflective of the rapidly changing technological context of the United States? Conceptually, it should be highly educated persons. For example, highly educated persons should be the first to learn about new technologies – perhaps through their social networks of other highly educated persons. Highly educated persons also should be the most capable of incorporating information about new health-related technologies and resources and acting on this information. Moreover, highly educated persons are also the most likely to have the socioeconomic resources – good jobs with premium health insurance coverage, high incomes, and personal/family wealth – to take advantage of potentially expensive innovations that improve health and lengthen life. In an era, then, of increasing social capacity for health, including fast-paced technological changes, one would expect high educational attainment at the individual level to be a key correlate of lower mortality risk. In other words, given the growth of advanced education in the United States over the latter half of the 20th Century and into the 21st Century, the benefits of increased educational attainment at the population level should be most readily observable among very highly educated individuals.

That said, there could also be differences across population subgroups in the pace by which people with high levels of education are able to translate their education into improved health and longer life. Men, more so than women, have been and continue to be in advantaged structural positions in U.S. society that may facilitate the transformation of their increasing educational resources into health and longevity outcomes (Ross, Masters and Hummer 2012). Similarly, white Americans as compared with African Americans have long held more advantageous structural positions in American society that may facilitate the more rapid transformation of high educational resources into health and longevity benefits (Fischer and Hout 2006). Thus, while increasing levels of educational attainment should benefit the health and longevity of individuals in all population groups in the context of a highly complex technologically- and information-based society, there may also be differential rewards to high educational attainment across population groups based on the unique structural positions of groups to best capitalize on increasing education in an era of rapid technological change.

The Changing Relationship between Educational Attainment and U.S. Adult Mortality

As noted earlier, we examine changes in the functional form of the association between individual-level educational attainment and the risk of U.S. adult mortality to gain leverage on the ways in which the association has changed and the underlying forces that may be responsible for these changes. Three main theoretical mechanisms are presumed to be operating to define the functional form, the combination of which may change across time and differ across population subgroup. The first is *selection:* changes in the education-mortality association may be influenced by the characteristics of people who comprise different levels of educational attainment. For example, the diminishing prevalence of persons with less than a high school education points to a more negatively selected group at this level while the growing prevalence of persons with a bachelor's degree and higher points to a less positively selected group at these levels. The second mechanism is termed *human capital*, which is related to the epidemiological idea of exposure. For example, each additional year of education may lower mortality risk by increasing cognitive function, sense of control, access to information, valuable social ties, and problem solving skills. The third mechanism is credentialism, where educational degrees are presumed to open up opportunities that lead to more income, better jobs, and other societal rewards. We emphasize that these mechanisms could be in play simultaneously, and as we suggest below, that is probably the case in recent decades.

Kitagawa and Hauser (Kitagawa and Hauser 1973) offered the first in-depth look at how educational attainment was related to adult mortality in their landmark study of mortality in the American population in 1960. Their study was based on a matched record dataset, which combined information from death records and the 1960 decennial census for persons ages 25 years and older. Table 1 shows the sex- and age-specific standardized mortality ratios for white men and women by educational attainment produced by Kitagawa and Hauser (1973, Table 2.1). The results shown in the table are useful in establishing an empirical baseline to assess changes in the functional form of the association between education attainment and U.S. adult mortality in the latter part of the 20th Century.

A couple of patterns are important to note. First, there is virtually no educational gradient in mortality for men ages 65 years and older; mortality is relatively constant across all educational levels. Second, among men ages 25–64 years, mortality rates are relatively constant up through 4 years of high school, where there is a modest drop in mortality. The largest drop in mortality is observed fairly far into the educational distribution – at 4 years of college or more. The educational gradient for men 25–64 years is thus relatively constant or weak until 4 years of college. For older women, mortality does not vary substantially until the college education level (of which there are very few observations in these data). Women 25–64 years of age experience some fluctuations in mortality at lower levels of education, which are difficult to interpret. There are very few women of these ages with 0–4 years of education, pointing to likely effects of negative selection for these women's mortality risk. Mortality appears to drop modestly among those who had some high school education, with modest drops again for women who had 4 years or more college. It is important to note that these drops are relatively small in magnitude. The functional form especially men ages 25–64 years appeared to largely conform to the idea of credentialism. That is, mortality typically dropped at the point in the educational distribution indicative of high school. For women 65+ years, although mortality drops substantially at college graduation, it is also important to note that this is a highly and positively selected group of women at this time period. In the 1960 white male working-aged population, then, access to job rewards made possible by educational credentials appears to be the principal mechanism underlying the relatively modest association between educational attainment and adult mortality. This mechanism was less evident for the other sex and age groups.

Kitagawa and Hauser (1973) did not separately specify educational differences in mortality for African Americans. But for non-whites (not shown in Table 1, but available in Kitagawa and Hauser (1973, p. 14), a group largely composed of African Americans in the 1960 U.S. population, educational differences in adult mortality were very modest; that is, there appeared to have been only very slight advantages for highly educated non-whites at that time.

A number of studies documented changes in the educational gradient in mortality in the latter portion of the 20th Century (Feldman et al. 1989; Pappas et al. 1993; Preston and Elo 1995). For example, Feldman and colleagues documented a widening gradient among white men 55–64 and 65–74 years of age between 1960 and 1971–84 that was heavily driven by declines in mortality among those with 12 years of education and higher. The changes in educational gradients for women were much less pronounced. Preston and Elo reported results comparing the mortality rates of white men ages 25–64 in 1960 with same-aged men in 1975–1985; their findings were consistent with Feldman et al. However, they also reported that educational differences in mortality for women ages 25–64 may have actually narrowed between 1960 and the mid-1980s. Recently, Masters and colleagues (2012) showed that the widening gradient was largely a cohort phenomenon driven primarily by dramatic drops in mortality among persons with more than 12 years of education in more recent American birth cohorts. Although these studies did not specifically attend to the functional form of the association, their analyses provide an important historical backdrop to two later studies examining the functional form of the association between educational attainment and adult mortality (Backlund, Sorlie and Johnson 1999; Montez, Hummer and Hayward). It is these two studies that we build directly on in this paper.

Backlund and colleagues (1999) analyzed the functional form of the relationship between educational attainment and mortality for persons ages 25–64 from the National Longitudinal Mortality Study, where mortality was assessed for the 1979–89 period. Their results showed that the association between educational attainment and the risk of death was not monotonic for either men or women, but instead was a step function with discontinuities at 12 and 16 years of education. The risk of death was essentially constant prior and subsequent to the steps, pointing to the importance of adult labor market-related rewards associated with educational degrees in explaining the association. In addition, their findings indicated that linear specifications of the association between education and mortality were driven by the underlying discontinuities. There was no significant evidence of an exposure/human capital model for the working-aged adult population during this period. Although there were clear declines in mortality between 1960 (the Kitagawa and Hauser study) and the 1980s, the more pronounced discontinuities in the 1980s, especially among men, point to the growing importance of labor market-related mechanisms in accounting for changes in the education-mortality association over the 25 year period between 1960 and 1985. Unfortunately, Backlund et al. did not separately specify their functional form models for whites and blacks.

Montez and colleagues extended the work by Backland and colleagues and also used the National Longitudinal Mortality Study to examine the functional form of the association – using updated data for the 1979–1998 period. Similar to Backlund et al., Montez and colleagues statistically evaluated an extensive array of functional forms to identify which forms best captured the association; unlike Backlund et al., Montez et al. separately specified their models by race in addition to gender. In contrast to the findings from Backlund et al., Montez et al. showed that the preferred functional form for the adult population as a whole was a shallow linear decline in mortality as education increased from 0 to 11 years, a step reduction in mortality at 12 years of education and then another linear decline in the risk of death that was steeper compared to the slope between 0–11 years of education. Shown heuristically in Figure 2, this overall pattern was evident for both white men and women, and was a good fit – although not the best fit – for blacks. The best fit for blacks was that documented by Backlund et al. for the working-aged population as a whole in 1979–89: step reductions in mortality at 12 and 16 years of education with constant slopes between the steps. A recent study by Everett and colleagues reported similar results to those of Montez et al. (Everett, Rehkopf and Rogers 2013).

It is difficult to fully compare the results from Backlund et al. and Montez et al. because of differences in model specification and the age ranges under study. Backlund et al. controlled for a variety of factors that are statistically associated with educational attainment (e.g., race, income and occupational status) while Montez et al. estimated the gross association between education and mortality risk within age/sex/race groups. It is important to note, however, that Backlund et al. identified “step changes with varying slopes” as a close alternative best functional form for men. And, similar to Montez et al., the “step changes with varying slopes” form was statistically preferable compared to a continuous functional form. The

Backlund et al. study also only considered U.S. adults aged 25–64, while Montez et al. considered adults as young as 25 and as old as 100.

Although there are only a few data points and the statistical modeling approaches differ across studies, it is clear that the functional form of the association between educational attainment and adult mortality changed in significant ways over the latter half of the 20th Century United States. For the population in 1960, a credentialist explanation appears to best characterize the association between education and mortality for whites, while there was very little association between education and adult mortality for non-whites at the time. A credentialist explanation also held in the 1980s, but there is some evidence that a combined "credentialist-human capital" model began to emerge during this period. By the 1990s, the combined "credentialist-human capital" approach appeared to have gained ground. Especially notable in the 1990s was the emergence of a strongly-graded linear relationship between educational attainment and the risk of death after 12 years of education (Montez et al. 2012), as depicted in Figure 2. Moreover, there were no apparent floor effects with advanced education. This pattern is highly consistent with the idea that each additional year of education (after high school) provides a bounty of resources that allow persons to garner health and, eventually, longevity advantages. In addition to access to good jobs, the pattern points to the importance of greater access to information and support for healthy lifestyles and health care, valuable networks and social relationships and the ability to mobilize those relationships, and greater general cognitive skills, sense of control and human agency. In the context of rapid technological change, it is plausible that these types of mechanisms are especially valuable resources in reducing the risk of adult mortality for highly educated American adults in the current socio-technological context.

In the analysis that follows, we update the functional form patterns documented by Montez and colleagues. We specifically contrast the functional forms for two periods – 1986–99 and 2000–2006 – using the National Health Interview Survey Linked Mortality Files. The first period is roughly comparable to that analyzed by Montez and colleagues and provides a sense of the reliability of their earlier results using a different data set; the latter period provides a glimpse into whether the patterns Montez et al. (2012) documented have continued or perhaps even become stronger in the early 21st Century. Caution is warranted when interpreting the changes we report below. The period of time for change is relatively short. We thus rely on graphical methods to display the changes we observe in the data. The results are thus suggestive and do not test a specific hypothesis about changes in functional form. Nonetheless, as will be evident, the patterns of functional form we document are highly consistent with Montez et al. (2012) and, if anything, the linear decline in the risk of death with educational attainment after 12 years has become statistically stronger in just a very short period of time.

Data and Methods

Data

Our update of how education is associated with the risk of U.S. adult mortality draws on nationally representative data from the National Health Interview Survey Linked Mortality Files (NHIS-LMF) from 1986 to 2006 (National Center for Health Statistics 2005, 2010).

Note that these data differ from those used by Montez and colleagues. The reason is that the NLMS does not at this point have more current information on mortality than was used by the Montez et al. study. In addition, although the NHIS-LMF contains fewer deaths than the NLMS, the NHIS-LMF information for the 1986–1999 period provides a test of the reliability of the functional form results from the earlier Montez et al. study based on data from the late 20th Century.

The NHIS is a cross-sectional survey, administered annually, with mortality follow-up for survey participants based on probable linkages with the National Death Index (NDI). We combined the 1986–2004 NHIS years with NDI death linkages through the end of 2006 and converted the file to a person-year format. We further restricted the sample to non-Hispanic whites and blacks aged 45 to 84 at any time during the follow-up period, so that persons entering the survey at younger ages could still contribute person-years once they reach the minimum age limit. Person years 85 and older were excluded in order to avoid age misreporting and because the NHIS began coding age using an open interval (85+) in 1997. Appendix A summarizes the number of respondents, deaths, and person-years by sex, race, and educational attainment.

Age at death was calculated based on the birth date, by year and month, and the year of death (the NHIS-LMF public use files do not report exact date of death). Birth year was missing in 0.17 percent of cases, and was imputed by subtracting the respondent's current age from the survey year (age was required for survey eligibility and was never missing). Missing cases for birth month (0.24%) were imputed through drawing from a uniform distribution. Finally, age was calculated as a time-varying covariate by rounding to the nearest integer as of January 1 of each year.

The primary predictor variable of interest is educational attainment, reported in the NHIS in completed years until 1996 and using a combination of completed years and educational categories thereafter. We adopted the measurement approach by Montez et al. to maintain consistency throughout the study period. Specifically, educational categories were translated into years of education: the categories "12th grade, no degree," "high school graduate," and "GED or equivalent" were coded as 12 years; "some college, no degree" and associate's degree were coded as 14; bachelor's degree coded as 16; and master's, professional, and doctoral degrees coded as 18. To evaluate the optimal functional form of the relationship between educational attainment and adult mortality, we also created dummy variables for various combinations of educational levels and categories (X_{lths} = [0–11]; X_{hs} = [12]; $X_{lths+hs}$ = [0–12]; X_{hs+sc} = [12, 14]; X_{sc} = [14]; X_{co} = [16, 18]; X_{sc+co} = [14, 16, 18]). Educational attainment was missing in less than one percent of the data, in which case the observations were omitted.

In the present study, we forego an analysis of possible pathways linking educational attainment with the risk of death. The rationale for our focus on the reduced functional forms is that the measures of possible pathways only capture a subset of pathways and are measured only at one point in time in our data; thus, we have no way of measuring the length of exposure and timing of exposure of important pathways. The one-point-in-time measurement of potential pathway covariates also means that they may be highly endogenous to health changes, thus introducing problems of reverse causality. Finally, it is important to note that given the data structure with respect to the baseline and follow-up period to identify mortality, covariate status at baseline is not very proximal to exposure and death for many individuals. This design feature would introduce significant ambiguity in the interpretation of education-mortality functional forms.

Analysis

Following the modeling approach by Montez and colleagues (2012), we estimated 13 logistic regression models to predict the log odds of adult mortality for different measures of educational attainment, controlling for age in single years within the range of 45–84. These 13 models were estimated for all four race-sex groups separately for the late 20th Century period (1986–1999) and the early 21st Century period (2000–2006). Although the NHIS oversamples blacks by design, all models are un-weighted given that they are already stratified by race. The models were specified as follows, with the group containing 12 years of education generally omitted and treated as the reference category (for additional details see Montez, et al. 2012):

Model 1, Semi-nonparametric:

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_0+b_2X_1+\cdots+b_{15}X_{18} \quad (1)$$

Model 2, Continuous:

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed} \quad (2)$$

Models 3–6, Step changes with zero slopes:

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{lths+hs}+b_2X_{sc+co} \quad (3)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{lths}+b_2X_{hs}+b_3X_{sc+co} \quad (4)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{lths}+b_2X_{hs+sc}+b_3X_{co} \quad (5)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{lths}+b_2X_{hs}+b_3X_{sc}+b_4X_{co} \quad (6)$$

Models 7–10, Step changes with constant (nonzero) slopes:

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths+hs}+b_3X_{sc+co} \quad (7)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths}+b_3X_{hs}+b_4X_{sc+co} \quad (8)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths}+b_3X_{hs+sc}+b_4X_{co} \quad (9)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths}+b_3X_{hs}+b_4X_{sc}+b_5X_{co} \quad (10)$$

Models 11–13, Step changes with varying slopes:

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths+hs}+b_3X_{sc+co}+b_4(X_{ed}\times X_{lths+hs})+b_5(X_{ed}\times X_{sc+co}) \quad (11)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths}+b_3X_{hs+sc}+b_4X_{co}+b_5(X_{ed}\times X_{lths})+b_6(X_{ed}\times X_{hs+sc})+b_7(X_{ed}\times X_{co}) \quad (12)$$

$$log\left(\frac{p}{1-p}\right)=a+b_0Age+b_1X_{ed}+b_2X_{lths}+b_3(X_{ed}\times X_{lths}) \quad (13)$$

The Bayesian information criterion (BIC) was used to evaluate model fit and rank competing functional forms, with the optimal form having the smallest BIC value. The BIC takes the form:

$$BIC=k\ln(N)-2[\ln(\hat{L}_0)-\ln(\hat{L}_1)] \quad (14)$$

where *k* is the number of model parameters (i.e., the number of betas excluding the intercept), *N* is the sample size, and $\hat{L}_0$ and $\hat{L}_1$ are the maximized likelihood functions for the null and comparison model, respectively. Comparing BIC values across competing models does not constitute a formal statistical test, but it is appropriate for discriminating between non-nested models with a varying number of parameters (Raftery 1995).

New Empirical Results

Table 2 displays the rank order of functional forms for the relationship between educational attainment and adult mortality specific to the four race-sex groups for the 20th Century (1986–1999) and 21st Century (2000–2006) periods under study. The models' BICs for the competing functional forms are reported in Appendix B. Perfectly consistent with the results of Montez et al. (2012) that were based on data from the National Longitudinal Mortality Study for a similar time period, a model of step changes with varying slopes (Model 13) ranks as the best-fitting for both non-Hispanic white men and women in the 1986–1999 time period. More specifically, as depicted by the dotted lines in the upper two panels of Figure 3, this functional form documents the relationship between educational attainment and adult mortality as a shallow downward slope from very low levels of education up through 11 years, a sizable step-change down in mortality risk at 12 years (coinciding with a high school degree), and then a steeper downward slope beyond 12 years all the way through the highest levels of attainment. Importantly, there is no flattening of the slopes at high levels of education; non-Hispanic white men and women with very high levels of education have the lowest adult mortality risk. This step-change with varying slopes pattern for white men and women in 1986–1999 reflects both a credentialism explanation of the education-mortality association (the step-change at 12 years of attainment) and a human capital explanation, particularly with the steep downward slope of mortality risk with increasing education beyond 12 years.

Also consistent with Montez et al. (2012), Table 2 shows that the preferred functional forms for both black women and black men during the 1986–1999 period differ from whites and fully reflect a credentialism-based association between educational attainment and adult mortality. The 1986–1999 preferred forms for black women and black men differ only slightly, as both reflect step changes downward in mortality risk as individuals reach 12 years of education (both women and men) and again at 14 years (women) or 16 years (men). For both black women and men, there were no downward slopes in mortality risk between steps in the 1986–99 period.

The preferred functional forms for the more recent period of 2000–2006 are shown on the right side of Table 2 and are graphed as solid lines in Figure 3. Confidence intervals are shown in the figure for each period's functional form; no confidence internals are shown around the reference group(s) because the coefficient is zero by definition. As shown in Table 2, the contemporary period is characterized by some shifts, but much stability, in preferred functional form for the four demographic groups under study compared with 1986–1999. While white women exhibit the same preferred functional form in 2000–2006 as compared to 1986–1999, white men's preferred form in the more recent period suggests consistent linear decreases in mortality risk between educational credential categories along with step changes down at 12 years (i.e., high school graduation) and 16 years (college graduation) of attainment. For both white women and men, the preferred functional forms in the recent period continue to reflect a combination of both human capital- and credentialism-based associations between educational attainment and mortality risk.

The shift in form for black men in 2000–2006 is more substantial. Rather than being fully credential-based as in 1986–1999, the preferred form (and the 2nd most preferred form) in the contemporary period reflects consistently decreasing mortality risk across the range of educational attainment for black men (See Model 2 in Table 2 and Figure 3 for the graphical display). Such a pattern is much more closely aligned with that of white men than was previously the case and may indicate a shift toward education-based human capital benefits for black men. Black women's preferred functional form in 2000–2006 continues to reflect a credential-based pattern, as was the case in 1986–1999. There are sharp declines in mortality risk for black women at 12 and 16 years of schooling, but flat slopes in-between those points.

The functional form results for all four demographic groups depicted in Figure 3 also suggest that the contemporary period of 2000–2006 is characterized by mortality risks that are relatively higher for individuals with less than 12 years of education in comparison to 1986–1999, while the most highly educated women and men tend to display lower relative mortality risks in 2000–2006 in comparison to 1986–1999. The higher relative risks in the more recent period could be reflecting increasingly negative selection into low educational attainment – that is, those groups are becoming smaller and may increasingly be composed of populations that are at high risk for mortality aside from their low educational attainment. On the other hand, the increasing relative risk of mortality for low educated persons in all four demographic groups could also be reflecting greater penalties associated with low education in the current US context of fast paced technological change. At the higher levels of educational attainment, the modestly lower levels of relative risk in 2000–2006 compared with 1986–1999 for each of the groups is most likely not due to changes in selectivity, since more (rather than fewer) individuals are achieving high levels of education, as discussed above. The lower relative mortality among the most highly educated persons in U.S. society within each of the groups is most likely a reflection of the greater health-related benefits that are accruing to persons with high levels of education.

Discussion

Our review of the empirical literature as well as our analysis of updated functional forms suggest that a combined credentialist-human capital model emerged fairly rapidly at the end of the 20th Century as the best functional form capturing the association between educational attainment and mortality in the U.S. adult population. The one group that is an exception to this pattern is black women, for whom a credentialist model continues to characterize mortality risk across levels of educational attainment. The emergence of the combined credentialist-human capital model alerts us to a couple of issues. First, with the exception of black women, multiple mechanisms arising from educational attainment now seem to be influencing adult mortality in the United States. The step reduction at mortality with 12 years of educational attainment points strongly to high school graduation opening up labor market opportunities that markedly reduce mortality risk. The steep downward slope of mortality risk after 12 years of education for white men and women and black men, however, points to the importance of other types of mechanisms that give rise to the dose-response relationship at the high end of the educational attainment distribution. Thus, different mechanisms appear to be operating in different parts of the educational distribution. This was not the case in 1960 based on patterns observed in the Kitagawa-Hauser study.

Drawing on recent literature, we posited a number of possible mechanisms that might account for the post-high school strong linear association -- psychosocial resources, valuable information and support for healthy lifestyles and quality medical care, social networks and relationships, greater cognitive skills, and a greater sense of control and human agency. All of these mechanisms are strongly associated with educational attainment, and this is

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especially the case for persons at the upper end of the distribution. In addition, given the association between education and the broad range of mechanisms, it seems plausible that the strong linear relationship reflects the increased *combination* of multiple mechanisms that produce the very low rates of mortality among those with advanced education. An important study by Cutler and Lleras-Muney (2010) illustrates this point in terms of health behaviors. A strong positive association was observed between each additional year of post-secondary educational attainment with being a non-smoker, having a BMI = 30, doing vigorous activity, exhibiting low rates of excessive drinking, having had colorectal screening, having had a mammogram, regularly wearing a seat belt, and having working smoke detectors in the home. With each additional year of educational attainment, well-educated persons increasingly displayed a wide range of positive health behaviors, indicating that very highly educated people are equipped with a bundle of resources that have implications for adult health and longevity (Link and Phelan 1995).

In thinking about the historical changes in the functional form, it is crucial to understand that the changes in the association likely reflect changes in the larger social environment that brought into play new mechanisms that play out at different points in the educational distribution. Turning the clock back to 1960, one might even wonder whether education was a crucial factor in enhancing life chances for some groups in the American population. An educational gradient was not observed for men aged 65 years and older, and the gradient was very shallow among men 25–64 years and largely driven by the step reduction in mortality with 4 or more years of college education. Moreover, there was no educational gradient in mortality among nonwhites at that time. If we asked the question in 1960 – does educational attainment have a causal effect on the risk of death among U.S. males and nonwhites? – the answer might very well be probably not.

What, then, happened in American society that made it possible for the emergence of the credentialist-human capital functional form? Although we posited that fast-paced technological changes and the maturation of an information-based society provided the platform on which these mechanisms developed, it remains unclear exactly how this actually occurred. Yet, several important trends support this idea. For example, the 1964 Surgeon General's Report on Smoking and Health was associated with the decline in smoking among highly educated persons and the concentration of smokers at the low end of the educational distribution (Denney et al. 2010; Meara, Richards and Cutler 2008; Pampel 2003). The availability of medical technology and health information not only rapidly increased over the latter part of the 20th Century, but so did the means to access that information and technology, particularly among well educated persons who were themselves technologically savvy and who had access to information sources such as the internet (Brodie et al. 2000). The economic returns to a bachelor's degree also generally increased over the second half of the 20th Century for whites and especially for women (DiPrete and Buchmann 2006). Black women's economic returns to a bachelor's degree also have increased since 1980, but the trend for black men is less clear. Since 1990, both white men and women who have a bachelor's degree have also been more likely to get married and stay married than persons with only a high school diploma (DiPrete and Buchmann 2006), also facilitating improved health among the highly educated. Marital homogamy has also substantially increased since

1960, due especially to the rigidity at both ends of the educational distribution (Schwartz and Mare 2005), pointing to a growing separation of educational groups across families and the concentration of economic and psychosocial resources at the upper end of the educational distribution. All of these long-term trends point to the increased concentration of resources that could be used to garner health advantages among the most highly educated groups in the U.S. adult population, especially white Americans.

A few recent studies have directly addressed the question of causality in the education-mortality relationship, and have come to different conclusions (e.g., Behrman et al. 2011; Lleras-Muney 2005). Although it is not possible to evaluate these studies here because of their different designs, measures, and even countries examined, we nonetheless think that it is conceptually plausible that studies like these may come to different conclusions at least in part because of differences in historical and social contexts which make it possible for educational attainment—perhaps in different parts of the educational distribution and for different social groups—to have a causal effect. As is evident in our review, educational attainment's association with mortality in the United States has changed dramatically over the course of the latter half of the 20th Century – although clearly not for all demographic groups. At best, the empirical evidence points to the plausibility that educational attainment's effect has grown over the time period, for only some parts of the educational attainment distribution, and for some demographic groups. In the case of the United States, the current associations are thus likely to be highly dependent on exogenous conditions that allow those with advanced education to garner a variety of types of resources and that also allow for the deployment of those resources to garner health advantages. In this framework, there is no inherent causal association between educational attainment and adult mortality; instead, the causal association is dependent upon the time, place, and social environment under study.

Looking ahead, at least three important research issues – all of which are related to social policy – will be critical in this area of study. First, although much of our discussion has focused on the strongly graded association between post-high school educational attainment and adult mortality, our new functional form results for the 21st Century demonstrate increasingly high relative mortality for low-educated individuals compared to their moderately- and highly-educated counterparts. Unclear is which U.S. adults are continuing to attain fewer than 12 years of schooling and what are their prospects for a long and healthy life. Given that close to one-eighth of the young adult U.S. population continues to fall into this low-educated category (Hummer and Hernandez 2013), the continued analysis of who comprises this group and how they fare in terms of health and mortality will continue to be important looking to the future. Given the updated results shown here as well as related studies (Masters et al. 2012) their long-term health and mortality prospects appear relatively less favorable than they were in previous cohorts; social/educational policy interventions may be of tremendous need in the coming decades to reduce the numbers and risks of this increasingly vulnerable and most likely negatively selected group. Indeed, in the highly complex technological- and information-based 21st Century, not having a basic high school degree appears to increasingly be a ticket toward a short and unhealthy life.

Second, and in contrast, which population groups and individuals are attaining the highest levels of education in U.S. society and how long and how healthy will their lives of be? This is an incredibly provocative question given that human history has never before witnessed sizable numbers of people with such high levels of education aging into (very) old adulthood. Although the specific mechanisms by which very highly educated individuals are translating their educational resources into (substantial) health and longevity advantages remain future topics for research, the functional form results of Montez et al. (2012) and our current analysis strongly suggest that very high education in an increasingly complex and technological society is strongly associated with living a (very) long life. This strong pattern is even more interesting when the growing numbers of very highly educated individuals are considered; no longer are these individuals the "select few." Moreover, given the increasing heterogeneous educational experiences in the population, it will also be important to better understand the specific educational characteristics and resources that such very highly educated individuals are bringing into older adulthood. For example: A) what kinds of schools did such individuals attend? B) What courses did they take? C) What degrees did they earn? D) Does the timing of their education matter (e.g., going to college years after completing high school)? E) What social networks did such individuals develop while in school? F) How do the types of colleges, majors, degrees, and timing differentiate the work careers of those with advanced education? The answers to such questions could help in understanding the ways that very high educational attainment has become so strongly correlated with low mortality in U.S. society and aid in policy efforts toward enhancing the value of education for health and longevity outcomes.

Last but not least, it is crucial to understand how the shape of the association between educational attainment and adult mortality is changing for major groups within a society over time. Our subgroup analysis above, for example, documented that African American women continue to be characterized by a preferred functional form between educational attainment and adult mortality that is fully credential-based. Thus, at least in terms of the longevity benefits of educational attainment in the early 21st Century, African American women appear to be completely dependent upon degreed credentials and benefit much less (if at all) from the accumulation of educationally-based human capital. Such a pattern points to a more rigidly defined (i.e., degree-based) social and economic stratification system for African American women compared to other groups – an unfortunate and continued reflection of race/gender-based structural inequality in U.S. society. Continued research is needed to monitor the education-mortality association for both minority and majority groups in U.S. society in the hopes that all groups may one day benefit from high educational attainment in the same manner. Of course, social policies that help equalize educational attainment across groups – both in terms of quantity and quality – and help African Americans obtain equal benefits from their high educational attainment continue to be needed. Furthermore, future work in this area must also consider the minority populations (e.g., Hispanics, Asian Americans, and Native Americans) we could not consider here simply for reasons of sparse data.

Although our discussion has emphasized what has transpired in the United States, the issues we have discussed are clearly global in nature. As societies experience rapid technological change, rapid increases in educational attainment, and growth in information-dependent lifestyles, will they too experience similar changes in the association between educational attainment and adult mortality? A growing number of high-income countries, for example, already exceed the United States' rates of college graduation and also have lower rates of high school dropout (OECD 2011). These differences point to the possibility that different causal mechanisms associated with educational attainment are already in play in other high-income countries. At the same time, high-income countries differ in their institutional arrangements and public polices in ways that may either accentuate or dampen the importance of *individuals'* educational attainment in garnering health resources in the highly complex 21st Century environment. As researchers attempt to gain traction on the question of the causal nature of the association between educational attainment and adult mortality, it is crucial to be mindful that no one study, no matter the sophistication of its methodological approach, is likely to end the debate. Instead, we suggest the debate should increasingly be concerned with the conditions under which the relationship between educational attainment and adult mortality changes in magnitude and shape, with causal implications drawn from study results in a contextually specific manner.

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Highlights

- Documents how the shape of the association between education and adult mortality in the United States changed over a 50-year period
- Identifies critical racial and gender differences in how the association has changed over the 50-year period
- Reviews the macro societal forces that have contributed to the changing nature of the relationship
- Discusses the implications of the changing nature of the association between educational attainment and mortality for investigating causal effects and mechanisms.

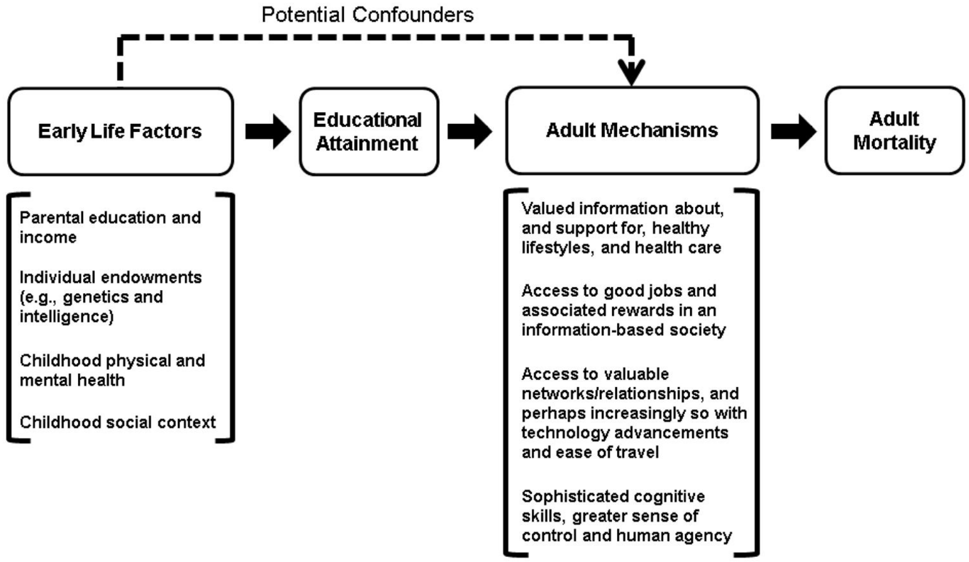

Figure 1.
Conceptual model depicting the relationship between educational attainment and adult mortality

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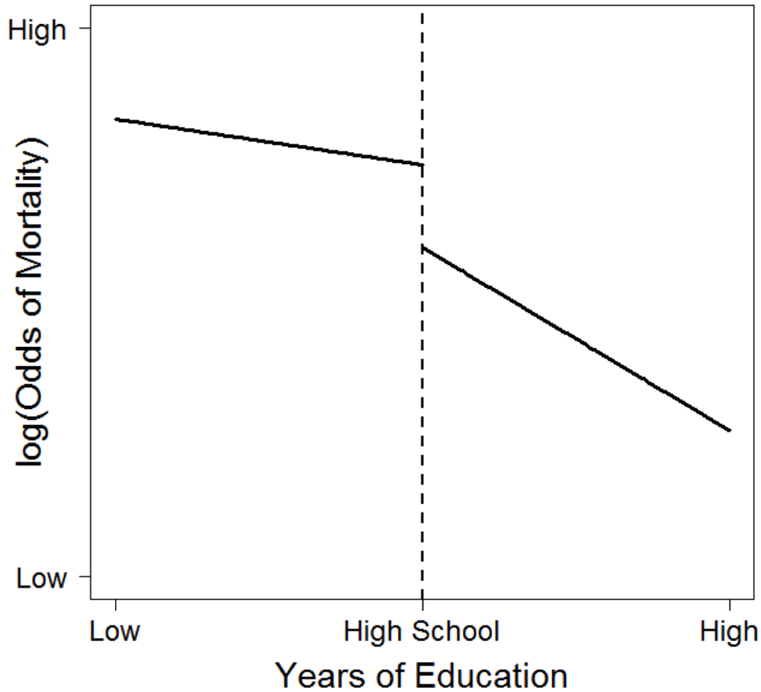

Figure 2.
Relationship between educational attainment and mortality for U.S. adults

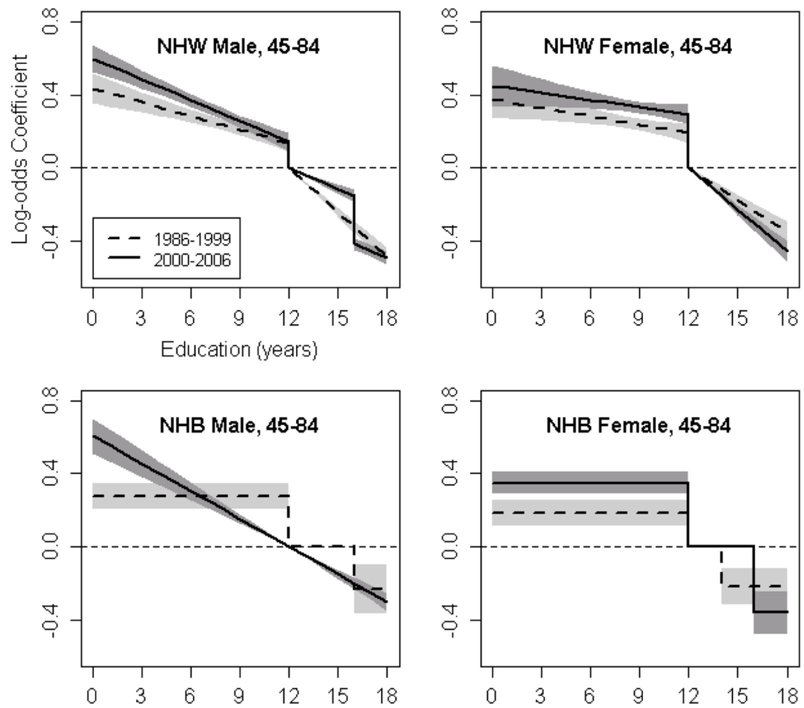

Figure 3.

Log-odds coefficients of the risk of adult mortality by educational attainment, U.S. 1986–2006 (optimal functional form with 95% confidence bands)

* NHW = non-Hispanic white; NHB = non-Hispanic black.

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Table 1

Sex and age-specific standardized mortality ratios for white men and women by educational attainment, U.S. 1960

	Men		Women	
Years of school completed	**25–64 years**	**65+ years**	**25–64 years**	**65+ years**
All persons	1.00	1.00	1.00	1.00
0–4	1.15	1.02	1.60	1.17
5–7	1.14	1.00	1.18	1.04
8	1.07	1.00	1.08	1.03
High school				
1–3 years	1.03		0.91	
4 years	0.91	0.99	0.87	0.94
College				
1–3 years	0.85		0.82	
4 years or more	0.70	0.98	0.78	0.70

Source: Reported in Kitagawa and Hauser 1973, Table 2.1.

Table 2

Ranking of functional forms of the association between educational attainment and U.S. adult mortality, ages 45–84

	1986–1999				2000–2006			
Model	**NHW Male**	**NHW Female**	**NHB Male**	**NHB Female**	**NHW Male**	**NHW Female**	**NHB Male**	**NHB Female**
1. Semi-Nonparametric	11	12	13	13	11	12	13	13
2. Continuous (ed)	10	10	4	3	9	10	1	10
Step Changes with Zero Slopes								
3. lths+hs, sc+co	13	13	12	7	13	13	12	12
4. lths, hs, sc+co	12	9	2	1	12	9	11	5
5. lths, hs+sc, co	8	7	1	2	8	7	5	1
6. lths, hs, sc, co	7	3	7	5	7	2	9	3
Step Changes with Constant, Nonzero Slopes								
7. ed, lths+hs, sc+co	3	4	8	10	4	4	7	6
8. ed, lths, hs, sc+co	9	6	6	6	10	8	6	8
9. ed, lths, hs+sc, co	2	2	5	8	1	3	3	2
10. ed, lths, hs, sc, co	4	5	9	11	5	5	8	7
Step Changes with Varying Slopes								
11. ed, lths+hs, sc+co, ed x (lths+hs), ed x (sc+co)	6	11	10	9	6	11	4	11
12. ed, lths, hs+co, ed x lths, ed x (hs+sc), ed x co	5	8	11	12	3	6	10	9
13. ed, lths, ed x lths	1	1	3	4	2	1	2	4
Pseudo-R^2 of top ranking model	0.102	0.090	0.070	0.062	0.106	0.106	0.079	0.074

* All models are unadjusted for sampling weights and design; Top ranking models are shaded.

** NHW = non-Hispanic white; NHB = non-Hispanic black.

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Appendix A

Sample size and number of deaths by race, sex, and educational attainment

	Non-Hispanic Whites				Non-Hispanic Blacks			
Education	**Deaths**	**N**	**%N**	**PY**	**Deaths**	**N**	**%N**	**PY**
Males								
0–11	16,617	46,563	15.5	522,934	4,997	13,622	31.0	147,690
12	17,508	104,701	34.9	1,051,808	2,471	16,035	36.4	146,444
13–15	7,749	63,603	21.2	602,159	1,019	8,656	19.7	73,151
16+	8,037	85,302	28.4	868,146	588	5,688	12.9	51,603
Females								
0–11	13,771	46,334	14.4	598,219	4,915	17,707	28.7	210,051
12	17,591	133,062	41.3	1,489,013	2,748	23,341	37.8	229,393
13–15	6,226	73,897	22.9	718,670	1,002	12,933	20.9	109,562
16+	3,882	68,884	21.4	667,748	561	7,821	12.7	72,772

Appendix B

Model BIC for competing functional forms of the association between educational attainment and U.S. adult mortality, ages 45–84

	NHW Male		NHW Female		NHB Male		NHB Female	
Model	**1986–99**	**2000–06**	**1986–99**	**2000–06**	**1986–99**	**2000–06**	**1986–99**	**2000–06**
1	220,009.1	238,476.6	194,635.3	216,698.1	38,570.7	42,224.3	41,037.4	48,547.1
2	219,922.8	238,413.3	194,517.1	216,654.0	38,435.6	42,086.2	40,899.7	48,435.2
3	220,255.1	238,933.0	194,722.6	217,050.2	38,464.4	42,151.2	40,906.5	48,499.4
4	220,032.1	238,660.2	194,513.9	216,637.0	38,431.7	42,117.1	40,893.9	48,410.6
5	219,911.3	238,389.8	194,502.3	216,567.1	38,429.4	42,097.6	40,897.8	48,388.2
6	219,898.9	238,377.3	194,494.4	216,546.4	38,439.6	42,107.2	40,903.6	48,399.5
7	219,875.6	238,343.6	194,499.0	216,553.5	38,448.6	42,105.4	40,914.9	48,411.4
8	219,921.7	238,431.9	194,499.4	216,591.8	38,439.0	42,103.8	40,904.2	48,417.1
9	219,866.6	238,330.6	194,492.9	216,552.4	38,437.5	42,093.3	40,907.5	48,399.4
10	219,875.6	238,343.6	194,499.0	216,553.5	38,448.6	42,105.4	40,914.9	48,411.4
11	219,894.0	238,365.3	194,537.3	216,673.1	38,451.2	42,096.6	40,911.3	48,447.3
12	219,883.7	238,343.2	194,511.2	216,564.6	38,457.8	42,113.8	40,926.0	48,423.4
13	219,864.2	238,342.2	194,483.1	216,542.5	38,434.9	42,093.2	40,901.5	48,402.5

[*] All models are unadjusted for sampling weights and design