Demography (2012) 49:315–336
DOI 10.1007/s13524-011-0082-8

Educational Attainment and Adult Mortality in the United States: A Systematic Analysis of Functional Form

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Published online: 13 January 2012

Abstract A vast literature has documented the inverse association between educational attainment and U.S. adult mortality risk but given little attention to identifying the optimal functional form of the association. A theoretical explanation of the association hinges on our ability to describe it empirically. Using the 1979–1998 National Longitudinal Mortality Study for non-Hispanic white and black adults aged 25–100 years during the mortality follow-up period (N = 1,008,215), we evaluated 13 functional forms across race-gender-age subgroups to determine which form(s) best captured the association. Results revealed that the preferred functional form includes a linear decline in mortality risk from 0 to 11 years of education, followed by a step-change reduction in mortality risk upon attainment of a high school diploma, at which point mortality risk resumes a linear decline but with a steeper slope than that prior to a high school diploma. The findings provide important clues for theoretical development of explanatory mechanisms: an explanation for the selected functional form may require integrating a credentialist perspective to explain the step-change reduction in mortality risk upon attainment of a high school diploma, with a human capital perspective to explain the linear declines before and after a high school diploma.

Keywords Mortality · Education · Functional form

Introduction

Adult mortality rates in the United States plummeted throughout the twentieth century, leading to record highs in life expectancy in the first decade of the twenty-first

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century. At the same time, educational differences in mortality persisted over the latter half of the twentieth century (Elo and Preston 1996; Glied and Lleras-Muney 2008; Kitagawa and Hauser 1973; Lauderdale 2001; Lin et al. 2003; Molla et al. 2004; Rogers et al. 2000), a relationship that seems to be at least partly causal (Glied and Lleras-Muney 2008; Lleras-Muney 2005; Smith 2004). The relationship between educational attainment and adult mortality now garners attention by researchers across a range of scientific disciplines, and socioeconomic-related mortality differences—including those by educational attainment—stand at the heart of the public health agenda of the United States. The reduction of educational differences in mortality was a key goal for *Healthy People 2010* and will likely remain so for *Healthy People 2020* when its goals, objectives, and action plans are released (U.S. Department of Health and Human Services 2000). Several recent studies have heightened scientific and policy interest in the question, documenting a widening, rather than narrowing, of the educational gap over the last two decades (Jemal et al. 2008; Meara et al. 2008; Montez et al. 2011).

Although this association has generated significant scientific attention over the last 20 years (for a review, see Hummer and Lariscy 2011), surprisingly few studies have investigated precisely how educational attainment is associated with mortality. Is each additional year of education associated with a diminished risk of death, or does education's influence plateau after a certain level of achievement? Do individuals reduce the risk of death by achieving certain credentials, such as a high school diploma or a college degree? Similarly, is the association between education and mortality shared across major demographic groups? Do males and females share the same benefits of education, or are the benefits less evident for women, as some researchers have suggested? Does education confer the same health benefits for blacks and whites? Does education's association with mortality hold across the entire adult age range? Clearly it is important to take this demographic heterogeneity into account when documenting the functional form of the education-mortality relationship among the American population.

The overall goal of this study, then, is to conduct a thorough examination of the association between educational attainment and adult mortality in the United States. We focus on two questions: (1) Among a predetermined set of functional forms that is justified by previous research, what form best describes the association between educational attainment and overall U.S. adult mortality? (2) Which one or more of these functional forms best describes the relationship between educational attainment and adult mortality for different age, gender, and race subgroups of the population? Answering these fundamental questions thoroughly will move the scientific and policy communities toward a richer understanding of one of the core relationships in social science today—that is, how group differences in the length of life within a population are structured by a principal component of socioeconomic status.

Previous Research

To date, only a few studies have conducted in-depth assessments of how education is associated with the risk of death. The work of Backlund et al. (1999), using an earlier version of U.S. data (from the 1980s) that we also make use of in this study, is the most thorough treatment of this topic to date. Backlund and colleagues tested which of four different functional forms (one continuous and three discontinuous) best captured the relationship between educational attainment and mortality among working-aged adults (25- to 64-year-olds). Their results clearly showed that a discontinuous form (with education categorized as less than a high school diploma, a high school diploma but no college degree, or a college degree or more) best depicted the relationship. For men, in particular, the reduced mortality risk associated with a college degree was especially pronounced. Their estimates were based on competing functional form models that controlled for the age, race, employment status, marital status, and household size of respondents. Such a strategy might be questioned based on the possible downstream influences of educational attainment on employment status in particular, as well as on marital status. Nonetheless, it is the most complete and informative paper on this topic.

Other papers document that both continuous measures of educational attainment and categorical schemes yield valuable insights into the education-mortality relationship that are not readily apparent when only one specification is used (Elo et al. 2006; Elo and Preston 1996; Zajacova and Hummer 2009). For example, Elo and Preston (1996) used a continuous specification of educational attainment to demonstrate that, on average, the log-odds of mortality risk for U.S. adults dropped roughly 5% for each additional year of education among individuals 25–64 years of age, and 2%–3% for each additional year of education for persons aged 65 and older.

Nonetheless, none of these papers specifically examined competing functional forms of the education-mortality relationship. Further, none assessed whether the functional form of the relationship differed across key demographic subgroups, an important issue given what appears to be differing magnitudes in the association across categories of age, gender, and race in the United States (Backlund et al. 1999; Crimmins 2005; Elo and Preston 1996; Kimbro et al. 2008; Lin et al. 2003; Zajacova and Hummer 2009). Indeed, structural and behavioral factors may suppress or accentuate the benefits of education for certain demographic groups, thereby altering the functional form of their education-mortality association. For instance, if low education is particularly detrimental for men because of their high propensity to engage in risky behaviors, such as smoking, and their limited social ties (e.g., Montez et al. 2009; Nathanson and Lopez 1987), the functional form may be nonlinear among men but not women. The form may also vary between whites and blacks. For example, structural disadvantage may produce a nonlinear association among lesser-educated blacks, while cumulative advantage may accentuate the benefits of higher education among whites.

Conceptual Framework

Educational attainment is one of the principal components of socioeconomic status, along with occupation, income, and wealth. Nonetheless, there are clear reasons for using educational attainment as the key indicator of socioeconomic status when studying adult health and mortality differences (Hummer et al. 1998; Preston and Taubman 1994). First, educational attainment is most often completed early in adult life and usually remains constant throughout the life course. In contrast, occupation, income, and wealth accumulation vary considerably throughout the life course and, at least in part, respond to health fluctuations (Smith 2004). Second, measures of educational attainment may be more relevant than other measures of socioeconomic status for individuals who have either retired from the workforce, are currently unemployed, or are out of the labor force. Third, survey respondents—who make up the individuals used in our analysis below—are more likely to report educational attainment (and with reasonable accuracy) than other socioeconomic indicators, particularly income and wealth. Finally, educational attainment typically precedes occupation, income, and the accumulation of wealth in both the life course sense and causal sense (Mirowsky and Ross 2003).

Most data sets that document U.S. adult mortality contain a single indicator of years of completed school. This indicator is typically specified in one of three distinct ways, and in most research, the specifications are not evaluated against one another. First, educational attainment is sometimes specified in a continuous fashion with values ranging from 0 to 17 or so (Zajacova 2006). Second, educational attainment is sometimes specified in a set of categories (e.g., 0–8, 9–12, 13+ years) that is partially based on important attainment thresholds, but that also plays to the strengths and weaknesses of official U.S. mortality data that are based on counts of death certificates in the numerator and census estimates in the denominator (Christenson and Johnson 1995; Meara et al. 2008; Molla et al. 2004). Finally, education is also often specified in a set of categories that demarcate important cut-points (e.g., 0–11, 12, 13–15, 16+ years) in the educational distribution of degrees that are usually awarded after a certain number of years of attained education (Montez et al. 2009; Pappas et al. 1993; Phelan et al. 2004; Rogers et al. 2000).

The current study moves beyond all previous studies in this area in multiple ways. First, it includes the most comprehensive set of functional forms tested within a single study. We examine 13 forms derived from a review of the education-mortality literature (Hummer and Lariscy 2011) and the four forms tested within the most extensive study to date (Backlund et al. 1999). Second, we examine functional forms for gender, race, and age subgroups because the benefits of education for mortality risk may differ for men versus women (Elo and Preston 1996; Montez et al. 2009), for whites versus blacks (Crimmins and Saito 2001; Lin et al. 2003), and for younger versus older adults (Lauderdale 2001; Lynch 2003). It is important to consider this demographic heterogeneity when evaluating functional forms. As mentioned previously, the most extensive study to date aggregated across race and was restricted to working-age adults (Backlund et al. 1999). Third, we evaluate basic associations between education and mortality risk (which do not include employment or income measures) to ensure that our estimates reflect the actual association, as opposed to the residual association net of explanatory mechanisms. Fourth, we identify the optimal functional form(s) among those tested using the Bayesian information criterion, which penalizes overspecified models and is generally preferred when the sample size is large and the models are not nested (Raftery 1995). The 13 forms are summarized in

Table 1 Predetermined functional forms of the association between educational attainment and U.S. adult all-cause mortality risk

Semi-Nonparametric Model

1. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_0 + b_2X_{2.5} + b_3X_{5.5} + \ldots + b_{11}X_{19}$

Continuous Model

2. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed}$

Step Changes With Zero Slopes

3. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{lths+hs} + b_2X_{sc+co}$
4. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{lths} + b_2X_{hs} + b_3X_{sc+co}$
5. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{lths} + b_2X_{hs+sc} + b_3X_{co}$
6. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{lths} + b_2X_{hs} + b_3X_{sc} + b_4X_{co}$

Step Changes With Constant, Nonzero Slopes

7. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths+hs} + b_3X_{sc+co}$
8. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths} + b_3X_{hs} + b_4X_{sc+co}$
9. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths} + b_3X_{hs+sc} + b_4X_{co}$
10. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths} + b_3X_{hs} + b_4X_{sc} + b_5X_{co}$

Step Changes With Varying Slopes

11. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths+hs} + b_3X_{sc+co} + b_4(X_{ed})\times(X_{lths+hs}) + b_5(X_{ed})\times(X_{sc+co})$
12. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths} + b_3X_{hs+sc} + b_4X_{co} + b_5(X_{ed})\times(X_{lths}) + b_6(X_{ed})\times(X_{hs+sc}) + b_7(X_{ed})\times(X_{co})$
13. $\log[p/(1-p)] = \alpha + b_0\mathbf{Z} + b_1X_{ed} + b_2X_{lths} + b_3(X_{ed})\times(X_{lths})$

Notes: Except for the continuous model, all models exclude the variable that contains a high school diploma as the omitted reference. See the text for a description of the education variables (X_i). The vector **Z** includes age and, in models that aggregate across race, it also includes a dichotomous indicator where non-Hispanic black = 1 and non-Hispanic white = 0.

Table 1. Our next set of subsections briefly describes each of these potential functional forms.

Model 1: Semi-Nonparametric Model

The first of our 13 specifications is a semi-nonparametric model that allows each measured level of educational attainment in our data set (the 1979–1998 National Longitudinal Mortality Study, or NLMS) to vary with mortality risk in whatever way it might to best fit the data. This specification, then, is largely (but not completely) devoid of theoretical content and simply lets each measured level speak for itself. That is, each measured level is included as a dummy variable and may exhibit a higher or lower mortality risk in relation to the reference category (12 years of education). Note that this model is not strictly a nonparametric specification because some years of educational attainment are grouped within the 1979–1998 NLMS, particularly postsecondary years starting with the 1992 NLMS. Thus, we do not have the exact years (or smaller units such as half-years, months, or days) of attainment that would allow us to estimate a strict nonparametric model. To help address this limitation in our data, we also conduct a sensitivity analysis of this and the other 12 functional forms using the pre-1992 subset of NLMS survey years, which contains single years of educational attainment from 0 to 18 or more.

Model 2: Continuous Model

We refer to our second specification as a continuous model. Here, educational attainment is specified as a continuous (linear) variable, with the assumption that each additional year of educational attainment yields an associated decrease in the log-odds of mortality that is consistent throughout the education distribution (Zajacova 2006). This specification best reflects the idea that educational attainment is a form of human capital (Becker 1993; Ross and Mirowsky 1999); that is, each additional year allows individuals to better develop their cognitive functioning, increase their sense of control, improve their health behavior, acquire job-related skills, and develop the resources that are necessary to live healthier and longer lives. Such a specification implies no discontinuities in the association. Consequently, there are no particular gains associated with, for example, completing high school or college.

Models 3–6: Step Change(s) with Zero Slopes

The next set of four models in Table 1 includes step-change specifications. In these models, mortality reductions are associated with increases in education, but only when such increases propel individuals into an advanced educational category. That is, there are no mortality benefits of higher levels of education within specified educational categories. Several of these step-change models are credential-based (Collins 1979). For example, obtaining a high school diploma or a college degree may increase the ability of individuals to qualify for certain jobs, earn greater income, and achieve a higher social status, all of which have lifelong influences on health and age-specific risk of mortality. The findings of Backlund et al. (1999), discussed earlier, clearly fit a specification within this category. Recall that they found that the categories of less than a high school diploma (i.e., 0–11 years), a high school diploma but no college degree (i.e., 12–15 years), and a college degree or higher (i.e., 16+ years) best captured the relationship between educational attainment and mortality among U.S. working-aged adults during the 1980s. Related work on other U.S. health outcomes, however, has found little support for a credential-based specification of educational attainment (Ross and Mirowsky 1999).

The specific distinctions in the four models within this general category are relatively modest and simply reflect differences in both the number of educational categories that are specified and exactly how these categories are composed. Model 3 specifies two categories of educational attainment: everyone with a high school diploma or less is included in the first category, and everyone with anything more than a high school diploma is included in the second category. This is most closely related to measurement schemes that are used with official U.S. mortality data (Christenson and Johnson 1995; Molla et al. 2004). Model 4 includes three categories of educational attainment: less than a high school diploma, a high school diploma but nothing further, and anything more than a high school diploma. Model 5 also includes three categories of attainment and is identical to the best specification identified by Backlund et al. (1999): less than a high school diploma, a high school diploma along with persons who have some college but no college degree, and persons with a college degree or higher. Finally, Model 6 includes four different categories of educational attainment: less than a high school diploma, a high school diploma, some college but no college degree, and a college degree or higher.

Models 7–10: Step Change(s) with Constant, Nonzero Slopes

Our next set of four models contains hybrids of the step-change and continuous approaches. In these models, each year of education is associated with a reduction in the log-odds of mortality risk (as indicated in each of these models by a continuous variable of educational attainment) by the same amount, although an additional step-change decrease is experienced each time an important new level of attainment is acquired. Thus, step changes in these models work above and beyond each additional year of education to influence mortality risk. As a result, this set of four models repeats the previous four categorical models (Models 3–6), but does so with the additional continuous variable of educational attainment included (Models 7–10). Backlund et al. (1999) specifically tested the third specification within this group of four models (our Model 9) but found that it fit less well than their strictly categorical specification (our Model 5).

Models 11–13: Step Change(s) with Varying Slopes

Our next set of three models also contains hybrids of the step-change and continuous approaches. However, unlike Models 7–10, they allow the continuous reduction in mortality risk associated with each additional year of education to be steeper within certain step-change demarcations than others. Models 11–13 reflect the idea that mortality risk reduction may occur at different paces along the education continuum if, for example, the primary mediators through which education is associated with reduced mortality risk vary along the way. For instance, each year of education prior to a high school diploma may reduce mortality risk by X% through improved cognitive function, sense of control, and health behaviors; while each year of education beyond a high school diploma may reduce mortality risk by Y% through more fulfilling and lucrative employment. To allow for varying slopes between important attainment levels, these models include interaction terms between attainment levels and the continuous measure of education. Model 11 includes one slope from zero years through a high school diploma, a step change when some college has been attained, and a second slope thereafter. Model 12 includes two step changes and three slopes: it includes one slope from 0 to 11 years of education, a step change at a high school diploma, followed by a second slope until a college degree is attained, at which point there is another step change, followed by a third slope from that point onward. Backlund et al. (1999) tested this specification but found that it fit less well than their strictly categorical specification (our Model 5). Finally, Model 13 includes one slope from 0 to 11 years of education, and a step change at a high school diploma, after which a second slope is evident.

The 13 functional forms include educational groups that are relatively common among recent cohorts of non-Hispanic whites and blacks (the focus of this analysis). Thus, we do not estimate forms that contain a separate grouping for 0–8 years of education. Although having only a primary school education was not uncommon among elderly cohorts, it has become a very rare educational attainment level, particularly among non-Hispanic whites and blacks. In the United States in 2008, just 1.4% of non-Hispanic whites and 2.2% of blacks aged 25–64 years reported only a primary school education (U.S. Census Bureau 2008b).

Data and Methods

Data

We estimate the models testing the alternative functional forms by using the National Longitudinal Mortality Study (NLMS; Rogot et al. 1992), which was created by linking adult respondents from multiple waves of the Current Population Survey (CPS) to death records in the National Death Index (NDI). The CPS is a monthly survey of approximately 57,000 households that collects demographic and socioeconomic information from a nationally representative sample of the civilian noninstitutionalized population of the United States (U.S. Census Bureau 2008a). The NDI is a computerized database of all certified deaths in the United States since 1979. Here, we use the most recent version of the NLMS, which links adult respondents from a 1980 census subsample and 23 waves of the CPS starting March 1979 and ending March 1998 to death records in the NDI through December 31, 2001. It contains roughly 3 million records and over 250,000 deaths. Our analyses are based on the private-use version of the 1979–1998 NLMS because, unlike the public-use version, it contains detailed information on date of birth, timing of interview, and date of death, which are important pieces of information for specifying the exact age of respondents and creating our person-year data structure.

The NLMS is the best data set available for our study's objectives. The NLMS provides an exceptionally large sample size and ample number of deaths for estimating race-gender-age stratified models. In addition, the NLMS provides information on the full range of educational attainment, including, for example, single years of education below a high school diploma on one extreme, and a range of post-secondary categories (e.g., associate's, bachelor's, master's and doctorate degrees) on the other.

Sample

Although our NLMS sample includes respondents from all 23 waves of the CPS, we excluded the 1980 census subsample because education data are unavailable. We included non-Hispanic whites and non-Hispanic blacks between 25 and 97 years of age at interview. We excluded groups other than non-Hispanic whites and blacks because of the greater potential for education to be obtained abroad among groups with high levels of immigration, and because information on nativity is available for only a subset of CPS waves. We removed respondents 98 years of age at interview because the NLMS top-codes ages at 98 years. Roughly 3.5% of respondents did not provide their month and/or year of birth. For these respondents, we imputed month of birth by random assignment, and year of birth by subtracting their age from their year of interview. Among the resulting sample, we excluded 0.01% of adults who were missing information on educational attainment. These criteria resulted in a final analytic sample of 1,008,215 adults, with 164,289 (16.3%) of these individuals identified as subsequent decedents in the NDI.

Educational Attainment

Our education variable represents completed years of education. The NLMS provides a standardized measure of educational attainment across the 1979–1998 CPS years to account for changes in how the CPS recorded education before and after 1992. Prior to 1992, education was recorded in single years from 0 to 18+. Beginning in 1992, it was recorded in one-, two-, or four-year increments prior to 9th grade; one-year increments from 9th through 12th grade but no diploma; and as degrees obtained for the remaining educational levels (e.g., high school diploma or equivalent (GED), associate degree, bachelor's degree). Please refer to the discussion for an overview of potential implications of combining high school diploma holders with GED recipients. From the NLMS-standardized education measure, we created several additional measures of educational attainment. We created a continuous measure (X_{ed}) that includes 0, 2.5, 5.5, 7.5, 9, 10, 11, 12, 14, 16, and 19 years to estimate the continuous functional form, where 2.5, 5.5, and 7.5 reflect the midpoint of the standardized education groupings for 1–4 years, 5–6 years, and 7–8 years, respectively. Based on this continuous measure, we created 11 dichotomous variables (X_0, $X_{2.5}$, $X_{5.5}$, . . . , X_{19}) to estimate the semi-nonparametric functional form. We created several additional dichotomous variables to identify educational attainment subgroups for the remaining functional forms:

X_{lths}	= 1	for 0–11 years of education or 12 years but without a diploma or GED
X_{hs}	= 1	for a high school diploma or GED
$X_{lths+hs}$	= 1	for up to and including a high school diploma or GED
X_{hs+sc}	= 1	for a high school diploma, GED, or some college but no bachelor's degree
X_{sc}	= 1	for some college but no bachelor's degree
X_{co}	= 1	for a bachelor's degree or higher
X_{sc+co}	= 1	for some college but no bachelor's degree, or a bachelor's degree or higher

Methods

For each of 10 race-gender-age subgroups, we estimated the 13 logistic regression models shown in Table 1 to predict the annual odds of death from age and the specific functional form of education. We did not adjust for potential mediators, such as income, because our aim was to identify the best *gross* form of the education-mortality relationship, and not the best form *net* of mediating pathways. The models are based on a person-year data structure in which we aged every adult by one year beginning with their interview year until their year of death or until the end of the follow-up period if they survived. In doing so, a small percentage of person-year records were aged beyond 100 years. To mitigate the chance that these records represented adults whose CPS records were difficult to match to the NDI, as opposed to true centenarians, we removed the 0.01% of person-year records for ages 100 and older. With the exception of the continuous functional form, all models removed the education group that contained a high school diploma as the omitted reference. We did not adjust the models for the complex survey design of the CPS because previous research with the NLMS found that point estimates and standard errors are not materially affected (see Backlund et al. 1999) and because unweighted analyses are generally preferred when the weights are largely a function of the predictors (Winship and Radbill 1994). Finally, the 10 race-gender-age subgroups included two large groups (non-Hispanic white and black males 25–100 years, non-Hispanic white and black females 25–100 years) and eight subgroups defined by all combinations of two racial/ethnic groups (non-Hispanic white, non-Hispanic black), two genders (male, female), and two age groups (25–64, 65–100), where all age groups refer to person-year ages during the follow-up period.

We determined the best of the 13 functional forms for the relationship between education and mortality risk for each race-gender-age subgroup using the Bayesian information criterion (BIC). The BIC is preferable to a likelihood ratio χ^2 test when the sample size is large, as well as when the models to be compared are not nested (Raftery 1995). We identified the best functional form for each race-gender-age subgroup as the logistic regression model with the smallest BIC value. The BIC value is calculated as

$$\begin{aligned} \text{BIC} = & -1 \times [-2\text{LL}_0 - (-2\text{LL}_1)] \\ & + [(\text{number of non-intercept model parameters}) \times \ln(N)], \end{aligned} \quad (1)$$

where -2LL_0 reflects the deviance associated with the intercept-only model, -2LL_1 reflects the deviance associated with the specified model, and N reflects the sample size (Raftery 1995).

Access to the private-use version of the NLMS is highly restricted to protect the confidentiality of certain survey information. Thus, we did not have access to the individual-level NLMS data. Instead, we conducted our analyses in coordination with U.S. Census Bureau staff. This entailed jointly developing the SAS programs for the analysis, which the Census Bureau staff processed and subsequently provided to us in the form of SAS output files.

Results

One of the main advantages of using the 1979–1998 NLMS for our objectives is the unusually large sample size available for race-gender-age stratified analyses. This advantage is illustrated in Table 2, which shows the number of deaths and respondents from individual, not person-year, records. Even subgroups that tend to be underrepresented in national surveys have a relatively large sample size in the NLMS. For instance, our analytic sample contains roughly 1,000 non-Hispanic black women, aged 65–97 years with more than a high school diploma, who experienced 350 deaths during the follow-up period.

Figure 1 displays the log-odds coefficients estimated from the semi-nonparametric form (Model 1) for each measured level of education. The figure illustrates some expected patterns. For example, the inverse association between education and

Table 2 Sample sizes and number of deaths by race-gender-age[a] group and educational attainment

	Non-Hispanic Whites				Non-Hispanic Blacks			
	Age 25–64		Age 65–97		Age 25–64		Age 65–97	
Education	Deaths	*N*	Deaths	*N*	Deaths	*N*	Deaths	*N*
Males								
Less than high school	11,761	56,873	23,220	35,894	2,717	11,162	2,847	4,763
High school	12,824	128,255	10,315	21,090	1,252	12,331	385	836
Some college	4,852	71,878	3,950	8,882	503	6,309	138	340
College	4,966	96,400	4,606	10,858	264	4,076	117	280
Total	34,403	353,406	42,091	76,724	4,736	33,878	3,487	6,219
Females								
Less than high school	7,861	56,529	25,378	47,548	2,418	14,620	3,230	6,787
High school	10,481	165,130	13,702	36,185	1,220	17,777	535	1,594
Some college	2,985	77,891	5,013	13,550	363	8,896	176	530
College	2,075	75,285	3,735	9,651	226	5,551	174	464
Total	23,402	374,835	47,828	106,934	4,227	46,844	4,115	9,375

[a]Age reflects age at interview. Sample sizes and deaths reflect individual respondents, not person-years.

mortality risk appears steeper among persons aged 25–64 years than among those 65–100 years within each race-gender group. A large body of literature has documented this pattern and debated its causes, such as increasing returns to education among younger cohorts, decreasing returns to education with age due to disengagement from social stratification systems and/or a greater influence of biological aging processes, compositional changes within educational strata, or simply an artifact of mortality selection. The figure also suggests a few other, perhaps unexpected, patterns that are formally evaluated in the following section. For instance, there appear to be relatively modest linear declines in the log-odds coefficients from 0 to 11 years, followed by step-change reductions at the high school diploma level, followed by some subgroups (particularly those aged 25–64 years) displaying steeper linear declines from a high school diploma onward.

We now formally examine which of the 13 functional forms best describes the association between education and overall adult mortality. The first two columns of Fig. 2 contain rankings of the 13 functional forms—from best to worst, based on BIC values—for non-Hispanic white and black males 25–100 years in column 1, and for non-Hispanic white and black females 25–100 years in column 2. The results show that Model 13 has the smallest BIC value for both men and women, and thus best describes the association between education and mortality risk among the 13 functional forms. The figure also identifies models with the next two smallest BIC values in light shade. If these values are within two BIC units of the optimal form, they are considered to provide a similarly good fit to the data (Raftery 1995) and are identified in the figure by dark shades, like the optimal form. The pseudo-R^2 for both models is a reasonably high .15. Thus, these results corroborate our visual inspection of Fig. 1 by identifying the best of the 13 functional forms for U.S. adult women and

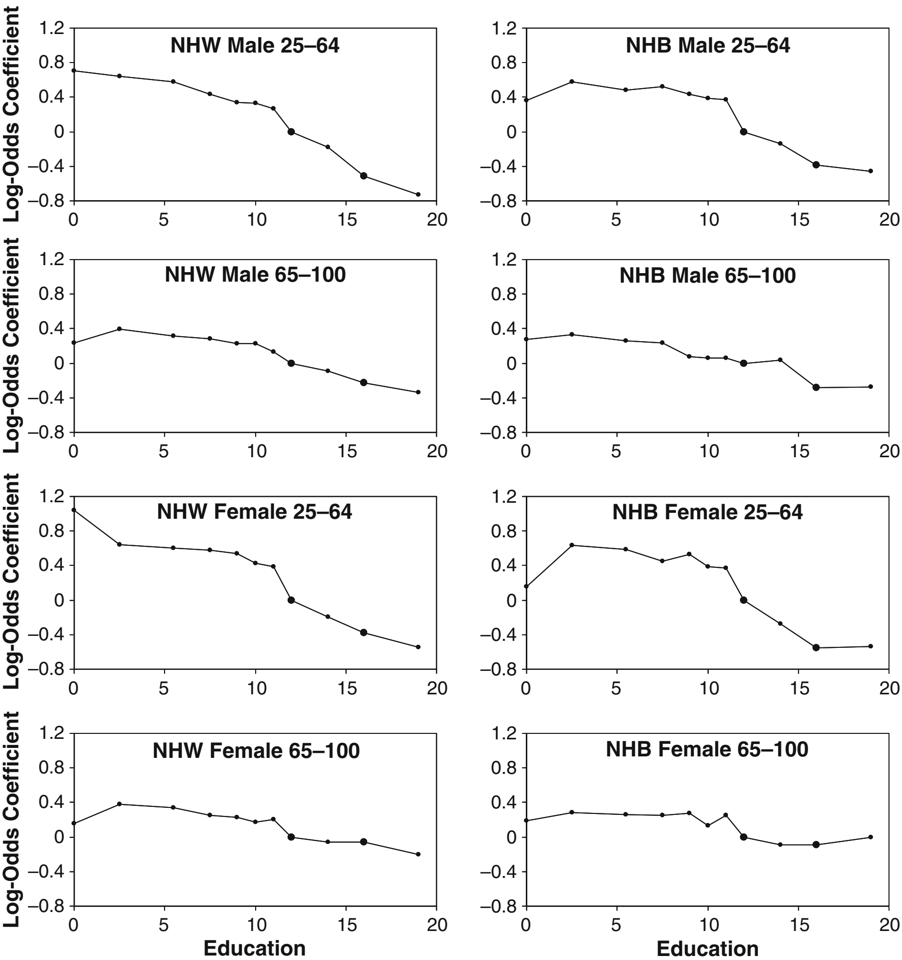

Fig. 1 Log-odds coefficients for semi-nonparametric levels of educational attainment (functional form 1) by race-gender-age. NHW refers to non-Hispanic white and NHB refers to non-Hispanic black. A high school diploma and a bachelor's degree are indicated with enlarged markers

men overall as a linear decline in mortality risk across 0–11 years of education, perhaps followed by a step change at a high school diploma, and a different linear decline from a high school diploma onward.

We now examine which one or more functional forms best describe the association between education and mortality risk for different race, gender, and age subgroups. We first discuss the results for whites shown in columns 3–6 of Fig. 2. The best functional form identified for all white females and older white males is, again, Model 13. For younger white males, Model 13 is the second-best model. For these men, Model 9 performs somewhat better and includes a constant linear decline in mortality risk throughout the education continuum, with additional step-change reductions at a high school diploma and a college degree. Indeed, Model 9 performs fairly well for all subgroups of whites. A more general inspection of the rankings for whites reveals other interesting patterns. First, the semi-nonparametric

Functional Form	NHW/B Male 25–100	NHW/B Female 25–100	NHW Male 25–64	NHW Male 65–100	NHW Female 25–64	NHW Female 65–100	NHB Male 25–64	NHB Male 65–100	NHB Female 25–64	NHB Female 65–100
1. Semi-Nonparametric	4	9	10	6	11	7	12	13	12	13
2. Continuous (ed)	12	12	8	10	9	10	9	1	10	7
Step Changes With Zero Slopes										
3. lths+hs, sc+co	13	13	13	13	13	13	13	12	13	11
4. lths, hs, sc+co	10	6	12	12	7	6	3	10	1	1
5. lths, hs+sc, co	7	8	11	8	8	9	1	8	5	2
6. lths, hs, sc, co	5	2	9	7	6	8	5	11	3	4
Step Changes With Constant, Nonzero Slopes										
7. ed, lths+hs, sc+co	11	10	7	9	10	11	10	2	9	8
8. ed, lths, hs, sc+co	8	5	5	5	2	2	6	6	2	3
9. ed, lths, hs+sc, co	6	7	1	2	3	3	4	3	6	6
10. ed, lths, hs, sc, co	3	4	3	3	4	4	7	7	7	9
Step Changes With Varying Slopes										
11. ed, lths+hs, sc+co, ed×lths+hs, ed×sc+co	9	11	6	11	12	12	11	4	11	10
12. ed, lths, hs+sc, co, ed×lths, ed×hs+sc, ed×co	2	3	4	4	5	5	8	9	8	12
13. ed, lths, ed×lths	1	1	2	1	1	1	2	5	4	5
Pseudo-R^2 for Optimal Functional Form	.15	.15	.06	.04	.06	.05	.05	.02	.05	.02

Fig. 2 Ranking of functional forms for the association between educational attainment and U.S. adult all-cause mortality risk within each race-gender-age group based on the Bayesian information criterion (BIC). Age reflects person-year age. NHW refers to non-Hispanic white, NHB refers to non-Hispanic black, and NHW/B refers to both groups combined. For each subgroup, the optimal functional form is the form with the smallest BIC value (shown by darkest shade). The next two smallest BIC values are indicated by a light shade. If those BIC values were within two points of the optimal form, they are indicated by the dark shade instead of the light shade because a difference in BIC of less than two points is not practically meaningful (Raftery 1995). Pseudo-R^2 = [$-2LL_0 - (-2LL_1)$] / ($-2LL_0$), where $-2LL_0$ and $-2LL_1$ are the deviances of the intercept and specified models, respectively

model and the continuous model perform poorly. The continuous model has a ranking between 8 and 10 of the 13 models, and for older whites, it actually performs worse than the semi-nonparametric model. Second, the set of models described by “step changes with zero slopes” also performs poorly. Third, all models that combine a high school diploma with less than high school provide the worst fit to the data compared with other models in each respective set. For example, Model 3 performs worse than Models 4–6, Model 7 performs worse than Models 8–10, and Model 11 performs worse than Models 12–13. These results reveal a fundamental difference in mortality risk before and after a high school diploma for whites. Taken together, the results for whites generally identify Model 13 as the preferred functional form.

The results for blacks are shown in columns 7–10 in Fig. 2. The pattern is not as consistent as it was for whites, although there tends to be a clustering of better-performing models within the “step changes with zero slope” set of models. For older blacks, choosing an optimal functional form may be a moot point given that there is little mortality risk reduction with increasing education, which is illustrated in Fig. 1 and by the small pseudo-R^2 values (0.02) for the best functional forms in Fig. 2. For younger black men, Model 5, which includes step changes at a high school diploma and at a college degree but zero slopes throughout, performs best. For these men, Model 13 (which was the best form overall for whites) performs second best. The results for young black women highlight a model that contains step changes at high school, and again at some college, with zero slopes throughout as the best form (Model 4); and the same step changes but with constant, nonzero slopes as the second-best model (Model 8). Model 13 is ranked as the fourth-best model. Similar to whites, the continuous model fits poorly (except for older black males), and the distinction between 0–11 years of education versus a high school diploma is large. Taken together, the results for young blacks identify models with step changes and zero slopes as the best-fitting models, with Model 13 emerging as a close alternative.

Given that Model 13 is the optimal form for whites and a good form for blacks, we provide log-odds coefficients for this model by race-gender-age in Table 3. For the two overall population groups in columns 1 and 2, the coefficients confirm that the step change in mortality risk at a high school diploma is statistically significant and substantively large (–0.519 for males, –0.210 for females) and that the linear decline in mortality risk is much shallower across 0–11 years of education (–0.011 for males, –0.004 for females) than it is from a high school diploma onward (–0.073 for males, –0.043 for females). Columns 3–6 show similar findings for the four age-sex subgroups of whites. An exception is that the step-change reduction at a high school diploma is not statistically significant for white women aged 25–64 years, which is surprising given the visually impressive step change in Fig. 1. As expected, the coefficients for blacks in columns 7–10 are not consistently significant because of the weaker inverse association between education and mortality risk among older blacks, and because Model 13 was not the top-ranked form for blacks. However, consistent with the findings for whites, the linear decline in mortality risk among blacks is shallower across 0–11 years of education than it is starting with a high school diploma onward, and the step-change reduction in mortality risk at a high school diploma is significant for women (–0.567) using this functional form.

Table 3 Log-odds coefficients for functional form 13, "step change at a high school diploma with varying slopes," by race-gender-age[a]

	NHW/B Males 25+	NHW/B Females 25+	NHW Males 25–64	NHW Males 65+	NHW Females 25–64	NHW Females 65+	NHB Males 25–64	NHB Males 65+	NHB Females 25–64	NHB Females 65+
Intercept	−8.350***	−9.543***	−8.266***	−7.934***	−9.536***	−9.606***	−7.4`57***	−6.106***	−7.739***	−7.603***
Age[a]	0.078***	0.082***	0.083***	0.070***	0.089***	0.081***	0.067***	0.045***	0.070***	0.053***
Non-Hispanic Black	0.143***	0.163***	—	—	—-	—-	—-	—-	—-	—-
Education (measured in years)	−0.073***	−0.043***	−0.110***	−0.051***	−0.085***	−0.025***	−0.074***	−0.042**	−0.103***	−0.009
Less Than High School	−0.519***	−0.210***	−0.542***	−0.175***	−0.115	0.093*	−0.284	−0.142	−0.567*	0.198
Education × Less Than High School	0.062***	0.039***	0.064***	0.029***	0.040***	0.006	0.055***	0.016	0.080***	0.003
Slope Before a High School Diploma	−0.011	−0.004	−0.046	−0.022	−0.045	−0.019	−0.019	−0.026	−0.023	−0.006
Slope Starting at High School Diploma	−0.073	−0.043	−0.110	−0.051	−0.085	−0.025	−0.074	−0.042	−0.103	−0.009
Deaths	84,561	79,068	18,422	57,932	11,468	59,299	3,109	5,098	2,629	5,672
Person-Years	6,519,840	7,669,169	4,504,231	1,474,417	4,804,487	2,077,311	425,657	115,535	600,261	187,110
Pseudo-R^2	.15	.15	.06	.04	.06	.05	.05	.02	.05	.02

Note: NHW refers to non-Hispanic white, NHB refers to non-Hispanic black, and NHW/B refers to both groups combined.

[a]Age reflects person-year age.

*$p < .05$; **$p < .01$; ***$p < .001$

The information in Table 3 can also be used to estimate the magnitude of the high school credential effect on mortality risk reduction. In other words, how many additional years of (pre-diploma) education does a high school diploma "instantly" confer in terms of mortality risk reduction? These additional years are over and above the reduction expected from an incremental (pre-diploma) year of education. We estimate this credential effect by subtracting the log-odds of death for a person with a high school diploma (assuming the linear reduction from 0 to 11 years continued to the diploma) from the log-odds of death for the same person (assuming a step-change reduction at the diploma) and dividing this difference by the slope of the decline from 0 to 11 years. For example, a high school diploma for young white males is "instantly" worth (in terms of reduced mortality risk) roughly five years of pre-diploma education $\{(-0.11\times 12) - [(-0.11\times 11) - 0.542 + (0.064 \times 11) - 0.046] / (-0.046)\}$, while it is worth more (eight years) for older white males. For white females, a diploma is worth roughly eight years for younger women and nine years for older women. Consistent with Figs. 1 and 2, the high school credential effect is much greater for blacks. In terms of mortality reduction, earning a high school diploma is worth as much as 20 pre-diploma years for younger black males, 2 years for older black males, 17 years for younger black females, and 39 years for older black females. In other words, the benefit of finishing high school for U.S. adult mortality risk is substantial, particularly for blacks. It is worth *much more* than an incremental year of pre-diploma education.

Lastly, we conducted a sensitivity analysis using the 1979–1991 portion of the NLMS, which codes education in single years from 0 to 18+. Recall that our main analysis used an NLMS-standardized measure of education across 1979–1998, which groups some years of education, particularly following a high school diploma. Thus, the standardized measure imposes some structure on the data. Analyzing the 1979–1991 portion allowed us to estimate a purer nonparametric form and to examine the effect of single years of education following a high school diploma. Our sensitivity analysis yielded findings (available on request) that were very similar to our main analysis, with one minor exception: for the two main groups of men and women, and for seven of the eight smaller subgroups, the sensitivity analysis identified the same optimal form as the original analysis. For the subgroup of younger white women, the optimal form in the original analysis was the second-best form in the sensitivity analysis behind Model 8, which includes step changes at a high school diploma and again at some college, with constant slopes throughout; however, evidence in favor of Model 8 over the original model was not strong. In addition, the sensitivity analysis similarly showed a much shallower linear decline in mortality risk before a high school diploma compared with after.

Discussion

Our systematic investigation of 13 predefined functional forms for the association between educational attainment and U.S. adult mortality risk reveals a general preference for a form that includes a modest linear decline in mortality risk between 0 and 11 years of education, followed by a step-change reduction in mortality risk upon attainment of a high school diploma, at which point mortality risk continues to decline linearly but with a much steeper slope than that prior to a high school diploma. This functional form best describes the association when aggregating non-Hispanic white and black males aged 25–100 years, and for their female counterparts. Our more detailed race-gender-age stratified analyses find that the same form is also generally preferred for whites. This form also provides a good fit for blacks, ranking in the top two to five best forms. However, the best functional form for blacks appears to fall within the set that includes step changes with zero slopes. Given that most analyses combine whites and blacks, or stratify with the intent to compare results, our findings suggest that the functional form described above (Model 13 in our analysis) is generally preferred. That said, analyses that specifically focus on non-Hispanic blacks may want to explore the set of models described by step changes with zero slopes to evaluate whether they generate more informative results.

Our findings are significant for the education-mortality literature and may have important social policy implications. First, for both whites and (to a lesser extent) blacks, each additional year of education is associated with lower mortality risk, regardless of whether the year results in a credential: there appears to be no ceiling effect on the longevity benefits of education (see also Rogers et al. 2010). Second, for whites and blacks, mortality risk reduction occurs at a faster pace with additional years of education following a high school diploma than before it. Future research should examine why this occurs—that is, the mechanisms and selection processes that account for this differential pacing. Third, for whites and especially for blacks, completing high school has a particularly pronounced effect on mortality risk—much more than just another year of pre-diploma education. In terms of mortality risk reduction, a high school diploma is equivalent to 5–9 years of pre-diploma education for whites and more than 17 years for blacks (except for older black men, who gain little). Such a step change makes sense in that a diploma is the basic requirement for obtaining a decent-paying, rewarding job and for enrolling in higher education in the United States (Day and Newburger 2002). Aggressively reducing the high school dropout rate—a problem which has been increasing among recent birth cohorts (Heckman and LaFontaine 2008)—is thus reinforced with our results. High school completion is important not only for our future labor force but also for the length of life of millions of Americans. Fourth, for whites and blacks, attending college lowers mortality risk even if it does not result in a bachelor's degree; and for younger men, graduating from college is also particularly beneficial for mortality risk. Lastly, what matters most for blacks are credentials: blacks receive relatively little mortality risk reduction from noncredential years of education compared with whites.

Our finding that credentials are what matter most for blacks is likely a manifestation of structural conditions, such as residential segregation, school quality, early family environments, and employment discrimination. For instance, smaller mortality risk reduction for each year of schooling may reflect the fact that black youth are more likely to attend inner-city, poorer-quality schools (Neal 2006); and disparities in school quality explain a substantial portion of the black-white achievement gap during schooling (Hanushek and Rivkin 2006) and the wage gap after schooling (Maxwell 1994). Further, black youth may be hindered from fully engaging in or benefiting from their schooling experience regardless of its quality, considering the backdrop of material and psychosocial adversities they are more likely to experience at home than are white youth (Neal 2006). The magnified returns to credentials among blacks may be partly a consequence of greater selectivity of black youths (compared with other blacks) than white youths (compared with other whites) among college entrants, which inflates estimates of the returns to college for blacks (Maxwell 1994). The returns might also indicate employers' overemphasis on credentials as evidence of ability among black applicants.

Thus, our results have certain policy implications for education and race. The smaller mortality risk reduction for nondegree years of schooling among blacks points to the need for widespread implementation of education policies such as smaller class size, school vouchers, and comprehensive curricula reforms that shrink the black-white achievement gap (see Chubb and Loveless 2002), in addition to health policies that promote early childhood well-being among the economically disadvantaged. In addition, the magnified gains from credentials point to the need for policies that facilitate access to college for more black youth, not just the academically select (Maxwell 1994), and policies that enforce equality in employment hiring and promotion.

For several reasons, our findings depart from Backlund et al. (1999). They found that when aggregating across racial/ethnic groups, the education-mortality association for both men and women was best specified with a "step changes with zero slopes" categorization (less than a high school diploma, a high school diploma but no college degree, or a college degree or more). A likely explanation for the discrepant findings is that we examined the *gross* association between education and mortality risk, whereas Backlund and colleagues examined the association *net* of household size, employment status, and marital status. Because these factors are correlated with education, controlling for them may have had the unintended consequence of explaining away a portion of the association, leaving a residual portion available for investigation. Nevertheless, our conclusions do not differ dramatically. Indeed, Backlund et al. (1999) stated that the "step changes with varying slopes" model was a statistically close alternative form for men. Furthermore, consistent with our findings, they found that the "step changes with varying slopes" model provided a significantly better fit than the continuous model for men and women.

Our findings are also broadly consistent with other research that has found that the association between education and physical functioning is essentially but not completely linear (Ross and Mirowsky 1999), and that there is a step-change improvement in physical functioning upon attainment of a high school diploma (Mirowsky and Ross 2003) but no step change upon attainment of a bachelor's degree (Mirowsky and Ross 2003; Ross and Mirowsky 1999). Yet, it is important to keep in mind that our analysis did not categorically reject a college credential effect. For younger men, models that included step changes at a high school diploma and a college degree performed somewhat better than the overall preferred form. For other subgroups, however, our preferred form(s) did not include a college credential effect.

Our study also provides important clues for further theoretical development and testing of explanatory mechanisms. For instance, the theoretical explanation for our preferred functional form may require integrating a credentialist perspective (Collins

1979) to explain the step-change reduction in mortality risk upon attainment of a high school diploma, along with a human-capital perspective (Becker 1993; Mirowsky and Ross 2003) to explain the linear declines before and after a high school diploma. The search for explanatory mechanisms will need to employ a data set that contains a wide range of potential mechanisms, such as income, occupation, wealth, health behaviors, social ties, and psychosocial resources at relevant and perhaps multiple points in the life course. The NLMS is the best data set available for our present objective of identifying the optimal functional form across race-gender-age subgroups because of its large sample size and its rich data on educational attainment. However, it is not well suited for future research that aims to uncover the causal mechanisms that link education to the risk of death. For instance, income and occupation are collected once at the time of survey in the NLMS, even though mortality follow-up extends for up to 23 years. Measures of cumulative exposure across long-term income and occupation trajectories are needed to capture the consequences of these mediators on adult mortality risk (Deaton 1999; Moore and Hayward 1990).

In addition, information on health behaviors is severely limited in the NLMS. Data on smoking behavior were collected in just 5 of the 23 waves used here. Data on other important health behaviors, such as alcohol consumption and physical exercise, as well as psychosocial resources, such as a sense of control and marital history, are unavailable. Future research should also evaluate cause-specific mortality. We selected all-cause mortality because it is one of the best indicators of overall population health, and thus seemed to be the logical choice for launching this work. However, the best functional form for all-cause mortality is not necessarily the best form for cause-specific mortality. We also encourage periodic examinations of the functional form. As education levels continue to rise and higher education becomes even more critical in the labor market, the functional form of the education-mortality association may change as a consequence.

One limitation of the NLMS is that it does not distinguish a high school diploma from a GED. Studies of men show that labor market outcomes among GED recipients resemble high school dropouts more than diploma holders (Cameron and Heckman 1993), although GED recipients experience greater wage growth over time than dropouts (Murnane et al. 1995). The mortality risk of GED recipients compared with diploma holders has also become increasingly greater among men (Rogers et al. 2010). Rogers and colleagues posited that the increasing significance among men may reflect the fact that the GED was established to facilitate college attendance among World War II veterans, but has over time become a terminal degree for individuals with academic trajectories interrupted by events such as health problems and incarceration. Potentially higher mortality rates among GED recipients compared with high school diploma holders should not alter our conclusions, however. As Cameron and Heckman (1993) pointed out, analyses that combine diploma holders and GED recipients underestimate the (labor market) benefits of the combined group compared with dropouts and, likewise, overestimate the benefits of a college degree compared with the combined group. Thus, our significant decline in mortality risk between dropouts and those in the combined high school diploma/GED group is a conservative estimate that may be even more pronounced if we could distinguish diploma holders from GED recipients.

In conclusion, this study serves as a reminder that research on the functional forms of sociodemographic relationships, while an often-ignored issue, is fundamental for understanding those relationships. We close by emphasizing that more attention needs to be given to such foundational work throughout the discipline. Take, for example, the relationship between household income and child health. Child welfare policies could benefit from knowing whether each additional unit of household income similarly improves child health or if there are step-change or threshold effects. Is there actually a meaningful, step-change improvement in child health after a household surpasses the established poverty line, as implied by policies that target poverty reduction? More generally, is there a step change anywhere in the income distribution that could provide an empirical basis for a particular poverty line for child health policies? Is there a point in the income distribution at which additional income has a negligible benefit on child health? As another example, public health interventions to combat teenage smoking could benefit from knowing whether each year of education similarly reduces the odds of smoking or whether there are step-change or threshold effects that suggest that certain school years are crucial for interventions.

Such functional form questions are not dry, technical issues, but have the potential to be very important for policymakers and instrumental in theory building. For instance, we illustrated that each year of education can reduce mortality risk without any apparent threshold effect; that the pacing of the reduction is steeper following a high school diploma; that efforts to combat the high school dropout rate may yield substantial returns for the health and longevity of Americans; that what matters most for blacks are credentials rather than incremental years of education; and that structural conditions that impede access to quality educations—whether primary, secondary, or tertiary—can modify the form of one of the most fundamental relationships in social science. Thus, we urge demographers to devote more time to functional form issues in order to provide a clearer description of the phenomena we wish to explain and to lay a stronger foundation for public and health policy.

Acknowledgments This research was supported by a grant from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (1 R01-HD053696, PI Robert A. Hummer) and by infrastructure (5 R24 HD042849) and training (5 T32 HD007081) grants awarded to the Population Research Center at the University of Texas at Austin by the Eunice Kennedy Shriver National Institute of Child Health and Human Development, and by the Robert Wood Johnson Foundation Health & Society Scholars program. We thank John L. Boies and Norman J. Johnson from the U.S. Census Bureau for their technical assistance. We are grateful to the editors and reviewers of *Demography* for their insightful and constructive comments on this article.

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