The Significance of Education for Rectangularization of the Survival Curve in the United States

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Abstract

Studies of mortality compression at older ages often assume that compression is linked to socioeconomic development either over time or between nations. We extend this logic and argue that relative differentials in the degree of rectangularization will exist between socioeconomically advantaged and disadvantaged sub-populations within a single period and national context. The purpose of this paper is to empirically assess the degree to which the survival curves in the United States are more or less rectangular across major educational groups. Our analyses are based on data from the Health and Retirement Study and the National Health Interview Survey Longitudinal Mortality File, and we draw on the methodological approach recently introduced by Cheung, et al. (2005) to document rectangularization. Our results show higher modal ages of death and a greater degree of compression around the modal age of death among groups with higher levels of education. As hypothesized, the results suggest that rectangularization is more evident among groups with higher levels of education.

Fries (1980, 1983) argued that as the 20th century unfolded in developed nations, the average length of time spent in poor health prior to death became increasingly compressed into a smaller and later portion of life and that as a consequence the shape of the human survival curve became increasingly rectangular. Fries (1980, 1983) referred to the transformation in the shape of the human survival curve as “rectangularization.” Rectangularization occurs when the average age at death in a population increases alongside a decrease in the variation around the average age at death. Fries (1980, 1983) interpreted the “compression of morbidity” and “rectangularization” as an indication that populations in many developed nations were rapidly approaching a biologically determined upper-limit to the human lifespan, which he thought to be around 85 years of age.

Almost three decades after Fries (1980, 1983) first outlined his ideas linking the compression of morbidity and rectangularization to the existence of a biologically fixed limit to the average human lifespan, a substantial debate persists concerning both the existence of rectangularization and, especially, whether increased rectangularization signals the existence of a biological limit to the human lifespan. A key assumption made by Fries (1980, 1983) and in virtually all subsequent analyses of rectangularization is that differences in the degree of rectangularization observed in a population over time and/or between nations are closely linked with changes/differences in the level of socioeconomic development. We extend this logic and argue that differentials in rectangularization should exist across socioeconomically advantaged and socioeconomically disadvantaged populations within a single period and national context. Little is known about within-nation socioeconomic differentials in rectangularization. Here, we document the degree of rectangularization in major educational groups in the United States. We hypothesize that rectangularization should be most evident among highly educated persons. Moreover, highly educated women are expected to exhibit the greatest degree of rectangularization owing to the coincidence of sex and socioeconomic resources.

Previous Literature

In one of the earliest systematic tests of the rectangularization hypothesis, Myers and Manton (1984a) reported mixed evidence for rectangularization. They began by visually inspecting graphs of the U.S. survival curve for ages 0 to 120 for three years: 1900, 1960, and 1980. These survival curves suggested that increased rectangularization did occur over the period. Myers and Manton then examined sex and cause-specific differences in the distribution of the age at death by obtaining the mean age of death and calculating the standard deviation around the mean age at death with U.S. vital statistics data for the years 1962, 1967, 1971, 1975, and 1979. When examining all-cause mortality for all ages, they found evidence of increasing rectangularization over the period. However, when they examined all-cause and cause-specific mortality among the 60+ population, they found no evidence of rectangularization.

In response to the findings of Myers and Manton (1984a), Fries (1984) argued that the U.S. survival curve did become increasingly rectangular between 1900 and 1980 and that Myers and Manton (1984a) were unable to detect this trend in the 60+ population because their measures were problematic. Fries (1984:357-358) demonstrated that by truncating the survival curve to only examine deaths above age 60, Myers and Manton (1984a) artificially inflated the standard deviations that they produced, biasing their results to show a tendency toward de-rectangularization. However, Fries (1984) suggested that they could rectify this problem by examining the standard deviations around various percentiles of the distribution of deaths above a given age. Following Fries' (1984) critique, Myers and Manton (1984b) incorporated Fries' (1984) suggestions and reanalyzed the data from their earlier study for the 60+ population in

1962 and 1979. The results concerning rectangularization were mixed. In all instances, the mean age at death increased. However, changes in the amount of dispersion around the mean age of death differed by the percentile examined and sex. The standard deviation around the mean age of death between 1962 and 1979 decreased at the 75.0th, 33.3rd, and 25.0th percentiles, but remained the same at the 66.6th and 50.0th percentiles among men. However, the standard deviations around the mean ages of death corresponding to the 75.0th, 66.6th, 50.0th, 33.3rd, and 25.0th percentiles decreased for women between 1962 and 1979. Nonetheless, Myers and Manton (1984b) concluded that the analysis provided little evidence for rectangularization because the observed changes in the standard deviations generally were small.

Using a method similar to the one suggested by Fries (1984) and employed by Myers and Manton (1984b), Rothenberg, Lentzner, and Parker (1991) examined U.S. mortality data from 1962 to 1984. Surprisingly, their results demonstrated that the mean age at death rose over the period and that the variation around each percentile became larger. Thus, they concluded that there was an “expansion of mortality” among older adults in the U.S. between 1968 and 1984. Noting problems with the methods used to test for rectangularization in previous studies, Eakin and Witten (1995) developed a new mathematical approach to measure rectangularization (the prolate rectangularity index) and applied it to sex-specific U.S. life table data for the population ages 13+ in ten-year intervals between 1900-1980. The authors found evidence of increasing rectangularization over the period, but noted that the trend appeared to taper off in later periods.

Nusselder and Mackenbach (1996) argued that mixed evidence from earlier studies stemmed largely from loosely defined measures and the lack of uniform measures. They made a distinction between “absolute” and “relative” rectangularization. Absolute rectangularization involves the “concentration of deaths into a smaller age range” alongside an increase in the average life expectancy, while relative rectangularization involves the “concentration of deaths into a smaller portion of the life expectancy” alongside an increase in average life expectancy (Nusselder and Mackenbach 1996:774). Although the substantive conclusion concerning the presence or absence of rectangularization is not likely to change when examining absolute or relative rectangularization, the authors noted that researchers should explicitly state whether they are measuring rectangularization in an absolute or relative sense (779). Examining Dutch life table data from 1950 to 1992, their results were mixed, but generally supported the idea that the survival curve became increasingly rectangular over the period. However, the existence and degree of rectangularization depended upon the age at which the distribution was truncated (e.g., 0, 10, 30, 60, 85), sex, the particular period(s) considered, and whether they examined absolute or relative rectangularization. As Robine (2001) noted, this study nicely demonstrated that truncating the age range can, in many instances, influence the results of an analysis because the detection of rectangularization depends on the age at which the lower bound of the age distribution is set. In a similar analysis of rectangularization in the Netherlands by cause of death between 1970 and 1992 among the 60+ population, Nusselder and Mackenbach (1997) found evidence for rectangularization in the 1980s, but not in the 1970s. Additionally, decomposition analyses found that both increases in survival into older ages and changes in the cause of death structure contributed to rectangularization in the 1980s.

Paccaud, Pinto, Marazzi, and Mili (1998) conducted a “numerator analysis” similar to Myers and Manton (1984b), computed modal and median ages of death, and examined dispersion around the median age of death at various percentiles of the age distribution of deaths for the 50+ population in Switzerland between 1969 and 1994. They observed a monotonic increase in the median age of death over the period and found some evidence to suggest that mortality was becoming increasingly compressed over the period. However, they noted that the “findings gained in this study do not provide straightforward arguments in favour or against [rectangularization]” (Paccaud, et al. 1998:414). Wilmoth and Horiuchi (1999) examined Swedish (1751-1995), Japanese (1951-1995), and U.S. (1900-1995) life table data for evidence of rectangularization. They assessed the level of variability around life expectancy at birth using the interquartile range and found that variability around the age of death within nations slowed considerably in recent years, which they interpreted as evidence against “continuing rectangularization” (475).

Most recently, Cheung, Robine, Tu, and Caselli (2005) couched the issue of the rectangularization of a population’s survival curve in terms of the epidemiological transition. They proposed three key components to describe rectangularization -- “horizontalization,” “verticalization,” and “longevity extension.”

> “… ‘[H]orizontalization’ [which] corresponds to how long a cohort can live and how many cohort members survive before aging-related deaths significantly decrease the proportion of survivors[,] … ‘verticalization’ [which] corresponds to how concentrated aging-related deaths are around the modal age at death… [and] the ‘longevity extension’ [which] corresponds to how far the right hand tail of the survival curve, representing the highest normal life durations, can exceed the modal age at death” (246).

Drawing upon the work of Kannisto (2001) and Eakin and Witten (1995), the authors developed a method to summarize these three dimensions of the survival curve. They then apply the measures they develop to Hong Kong life table data from 1976 to 2001. Their results showed that the survival curve in Hong Kong became increasingly horizontal and vertical and that mortality became increasingly compressed around the modal age of death over the period. Taken together, the results suggest that rectangularization occurred in Hong Kong between 1976 and 2001.

Although some research finds either no (Manton and Stallard 1996; Rothenberg, Lentzner, and Parker 1991) or mixed (Myers and Manton 1984a, 1984b; Nusselder and Mackenbach 1996, 1997; Paccaud, Pinto, Marazzi, and Mili 1998) evidence of rectangularization, other research generally suggests that the survival curve actually has become increasingly rectangular over time (Fries 1980, 1984; Eakin and Witten 1995; Wilmoth and Horiuchi 1999; Cheung, Robine, Tu, and Caselli 2005). However, in many instances, interpreting the results generated across studies is difficult. First, there is little consistency in the methods employed to measure rectangularization across studies, making it difficult to directly compare the results (Wilmoth and Horiuchi 1999; Robine 2001; Cheung, et al. 2005). Second, as others note (e.g., Fries 1984; Robine 2001; Cheung, et al. 2005), most of the studies reporting no or mixed evidence of rectangularization contain inherent methodological limitations associated with imposing a lower-limit on the age range examined and measuring the dispersion around the age at death with either the standard deviation around the mean age of death (e.g., Manton and Myers 1984a), the standard deviation around percentiles corresponding to various ages in the distribution of deaths (e.g, Myers and Manton 1984b; Rothenberg , et al. 1991; Manton and Stallard 1996; Paccaud, et al. 1998), or other measures (e.g., Keyfitz' *H*; Nusselder and Mackenbach 1996, 1997) that are tied computationally to the mean age of death. Depending upon where the lower-bound of the age distribution is set, these methods tend to produce inflated standard deviations (Fries 1984; Robine 2001). Finally, many of the analyses utilize data from different nations. Although important in furthering our understanding of demographic processes linked to rectangularization, the interpretation of cross-national comparisons is complicated by differences in the socio-historical contexts between nations.

Conceptual Framework and Hypothesis

On a more conceptual level, interpreting evidence of rectangularization as an indication that a biologically based upper limit to human longevity exists is in itself problematic. The presence of rectangularization alone cannot conclusively establish the existence of biological limits to human longevity (Myers and Manton 1984b; Wilmoth 1997, 1998, 2000, Wilmoth and Horiuchi 1999). If biological limits to the human lifespan exist, rectangularization will occur, but rectangularization may also occur in the absence of biological limits. Causally attributing rectangularization to the existence of biological limits that govern the human lifespan is impossible without detailed information concerning both the socio-environmental and biological pathways leading up to death (Myers and Manton 1984b:574). There is little current evidence to suggest that we are approaching a biologically determined limit to life expectancy (Wilmoth 1998, 2000, Wilmoth and Horiuchi 1999). Although gains in life expectancy have slowed in recent decades, the populations of many developed nations have nonetheless continued to experience a decline in mortality rates (Wilmoth 1998:396). Moreover, research examining the complex causal associations between the biological and socio-environmental determinants of longevity suggests that socio-environmental factors play an important role (Vaupel, Carey, Christensen, Johnson, Yashin, Holm, Iachine, Kannisto, Khazaeli, Liedo, Longo, Zeng, Manton, Curtsinger 1998; De Benedicts, Tan, Christensen, Ukraintseva, Bonafè, Franceschi, Vaupel, and Yashin 2001). Taken together, these facts fundamentally challenge Fries’ (1980, 1983) assertion that average life expectancy at birth is biologically limited to 85 years of age.

While the existence of an upper limit to life expectancy is contested, many would agree that the reasons underlying the dramatic increases in life expectancy that occurred in the developed world over the course of the 20th century are largely attributable to socio-environmental factors.

In fact, the core assumption – whether made explicitly or implicitly – underlying the existence of rectangularization is that socio-environmental and medical advances tied to socioeconomic development are responsible for the increasingly rectangular shape of the human survival curve. This is why researchers typically examine survival curves over time. In these analyses, time essentially becomes a proxy used to gauge socioeconomic improvements.

As the epidemiologic transition took hold, improvements in the standard of living, public health, sanitation, and medical interventions ushered in a new era of historically unprecedented reductions in mortality at all ages (McKeown and Record 1962; Omran 1971). These reductions led to substantial increases in life expectancy in many parts of the world and, over time, fundamentally transformed the shape of the survival curve (Wilmoth and Horiuchi 1999). The more socioeconomic advancement within a nation, the greater the likelihood that the population as a whole will be healthier, live longer, and exhibit less variability around the average age of death (e.g., rectangularization will occur).

One of the most important routes to socioeconomic advancement and reductions in mortality within the developed world was the diffusion of mass education. A large body of research consistently documents an inverse association between education and a variety of health outcomes (Preston and Taubman 1994; Mirowsky and Ross 2003). Through education individuals increase their stock of human capital and gain access to a host of socioeconomic, social psychological, and sociobehavioral resources that allow them to optimize their health and, ultimately, stave off death (Ross and Wu 1996; Mirowsky and Ross 2003). The fact that SES-based disparities exist in the ability of people to optimize their health is an important, but often overlooked, point in previous analyses that focus on life expectancy and rectangularization. At the population level, the spread of education may also alter the dynamics of the social system

(Hayward, Crimmins, and Zhang 2006; Hidajat, Hayward, and Saito 2007). The diffusion of mass education throughout a population often occurs alongside improvements in the infrastructure of the healthcare system (Preston 1975; Hidajat, et al. 2007). As a result, the individual and institutional factors associated with the spread of education converge to increase the "'social capacity' for population health" (Easterlin 1997, as cited in Hayward, et al. 2006:230).

In this paper, we take a novel approach to inform the debate surrounding the existence of rectangularization. Increased socioeconomic development generally is assumed to be a prerequisite for rectangularization in analyses that compare survival curves across time and/or between nations. We build upon the logic inherent in this assumption concerning rectangularization and posit that the survival curves for members of socioeconomically advantaged sub-populations within a single national and historical context will display greater levels of rectangularization than the survival curves of the less socioeconomically advantaged members of society. This occurs because socioeconomic advantage brings with it a host of important material and non-material resources that allow people to optimize their health and, ultimately, extend their lives to reach the uppermost age limits given the conditions experienced under a prevailing mortality regime. We test our assertion by constructing sex and education specific life tables for the United States using data from the Health and Retirement Study (HRS) and the National Health Interview Survey Longitudinal Mortality File (NHSI-LMF). We measure the degree of rectangularization between educational groups for males and females in the United States aged 50 and above. We accomplish this by examining two (e.g., "verticalization" and "longevity extension") of the three dimensions originally outlined by Cheung, et al. (2005). We, however, do not reproduce Cheung et al.'s (2005) measure of "horizontalization". "Horizontalization" measures the degree to which the survival curve is more or less horizontal between the beginning age and the point at which aging-related deaths substantially begin to reduce number of survivors within a population. As our exploratory analyses confirmed, Cheung, et al.'s (2005) measure of "horizontalization" is not meaningful in our analyses. This is because there simply are not enough data points (e.g., single years of age) to accurately detect a change in the angle of the curve between exact age 50 and the point at which aging-related deaths begin to exert their full influence upon survivorship[1]. In accordance with the underlying assumptions of previous research in this area and the literature documenting a marked gradient in mortality by educational attainment, we hypothesize that the degree of rectangularization will be greater among sub-populations with higher levels of educational attainment.

Data, Measures, and Methods

Data. We draw on two national studies to examine educational differences in rectangularization. The first study is the Health and Retirement Study (HRS) for the 1992-2004 period in which mortality is linked to the National Death Index. The second study is the public-use National Health Interview Survey Linked Mortality Files (NHIS-LMF) for the 1989-1996 survey years linked to the NDI for 1989-2002. The HRS is a longitudinal, household-level survey that is representative of the U.S. civilian, non-institutionalized population ages 51 and above and their spouses. The NHIS is a cross sectional, household-level survey conducted annually by the U.S. National Center for Health Statistics (NCHS) that is representative of the U.S. civilian, non-institutionalized adult population ages 18 and over. The NDI is a collection of the death records from each state's vital statistics registry maintained by NCHS. Survey data

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[1] However, analyses with an earlier starting age would allow us to calculate Cheung, et al.'s (2005) measure of "horizontalization."

from the HRS[2] and NHIS[3] are probabilistically linked to records in the NDI by researchers at NCHS. The data were weighted using the appropriate sampling weights to correct for non-response and to ensure all estimates are representative of the civilian, non-institutionalized U.S. population[4]. However, we do not make adjustments for the complexity of the sampling designs because we do not conduct tests for statistical significance.

Measures. We utilize four variables from the HRS, NHIS and NDI in our analyses: vital status, age, sex, and completed years of formal schooling (e.g., education). All information pertaining to age, sex, and education come from the HRS or NHIS. In the HRS, the vital status of the respondent may come from either the HRS or the NDI. In order to capture all of the deaths in the HRS, we include deaths identified based on information found solely in the HRS, solely in the NDI, and in both the HRS and NDI. Unlike the HRS, the NHIS is not longitudinal. Thus, all the information pertaining to vital status in the NHIS-LMF comes from the probabilistic linkage to the NDI. With the obvious exception of the dummy variable for vital status (1=dead, 0=alive), all of the information in both surveys is self-reported or reported by a designated proxy respondent. Age refers to age in years. We utilized information concerning the month and year of interview and the self-reported month and year of birth to calculate each respondent's exact age as of January 1st in each year of observation. In the life tables, the age range is from exact age 50 to an open interval of 100+ years. Sex was coded as a dummy variable (1=female, 0=male).

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[2] For additional information on the HRS, refer to Servais (2008). This document and others are available on the HRS website (http://hrsonline.isr.umich.edu/).

[3] For an overview of the public-use NHIS-LMF, refer to Lochner, Hummer, Bartee, Wheatcroft, and Cox (2008). For an overview of the methodology used by NCHS to match the NHIS and the NDI, refer to NCHS (2005). Additional information on the NHIS-LMF is available from NCHS at http://www.cdc.gov/nchs/R&D/nchs_datalinkage/nhis_data_linkage_mortality_public-use.htm

[4] We conducted a series of exploratory analyses to inspect the HRS and NHIS-LMF data for age misreports. The results of these analyses (available on request) indicated that age misreports do not pose a problem.

Education in the HRS and NHIS is measured in years of completed formal education. We trichotomized educational attainment into the following categories: 0-11 years, 12 years, and 13+ years. Following the strategy outlined by Backlund, Sorlie, and Johnson (1999), we examined the functional form of the relationship between education (in years) and the risk of death by sex. The results indicated that a 3-category specification of education provided the best fit. However, our categorization of education is by no means definitive. We stress the necessity for further tests of the functional form of the association between education and mortality with larger datasets containing information from additional birth cohorts. At any rate, given that some of the cells in the HRS are sparsely populated (see Table 1), we chose not to further disaggregate the data into additional education categories (e.g., 0-11 years, 12 years, 13-15 years, 16+ years). Although we could disaggregate further in the NHIS-LMF, we chose not to in order to make our results as comparable as possible across datasets.

Finally, in both the HRS and the NHIS-LMF, our analyses are restricted to U.S.-born respondents with complete information on all of the variables of interest. Immigrants are excluded due to concerns over data quality and in an effort to reduce the heterogeneity of the population analyzed. In the NHIS-LMF, we restrict our analyses to the survey years 1989-1996. This is done because the NHIS did not collect information on nativity prior to 1989 and in 1997 the NHIS began top coding age at 85+ years. From 1986-1995, the NHIS top coded age at 99+ and in 1996 age was top coded at 90+ years. In addition, this was done for purposes of data quality. We conducted a series of exploratory analyses to gauge how closely the stylized mortality rates generated from the HRS and NHIS-LMF paralleled actual occurrence-exposure rates from the U.S. Vital Statistics. These analyses suggested that the HRS and NHIS-LMF survival curves for males were virtually identical and that both curves generally paralleled the survival curves from the U.S. Vital Statistics. For females, the survival curve from the HRS paralleled the survival curves from the U.S. Vital Statistics more closely than the survival curve generated from the NHIS-LMF, especially after ages 85 to 89. For these reasons, we further limit our sample to persons ages 89 and under at the time of interview. The final analytic sample sizes are N=30,390 for the HRS and N=172,139 for the NHIS-LMF, respectively.

Methods. All of the analyses were conducted using SAS. In order to apply the methodology used by Cheung, et al. (2005), we had to first generate a set of sex-education specific life tables from the HRS and NHIS-LMF. To estimate a set of equations that allowed us to calculate age-sex-education specific central death rates for the HRS and NHIS-LMF cohorts, we constructed person-year files and fitted a Gompertz model of mortality[5]. All of the analyses were sex-education specific. The general equations for males (1) and females (2) within each educational category were as follows:

$$\ln \mathrm{m}_{m}(\mathrm{x}) = \beta_{m0} + \beta_{m1}\mathrm{AGE}_{\mathrm{x}} \qquad (1)$$

$$\ln \mathrm{m}_{f}(\mathrm{x}) = \beta_{f0} + \beta_{f1}\mathrm{AGE}_{\mathrm{x}} \qquad (2)$$

where,

$$m(x) = \lim_{\Delta x \to 0} \frac{P(x + x + n)}{n}$$

The parameter estimates generated from the Gompertz models were used to solve the regression equations. Once exponentiated, the results from the models mimic conventional – but exponentially smoothed -- occurrence-exposure rates (e.g., the m_{x} values in a life table), which we then used to produce the life table functions (Teachman and Hayward 1993). The age range

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[5] Alternative functional forms were tested. However, we used the Gompertz model because, as expected, it provided the best fit.

in the life tables range from exact age 50 to an open interval of 100+. We do not calculate any of the measures after exact age 99[6]. On generating the life tables, we then followed the approach outlined by Cheung, et al. (2005) to reproduce their measures using data from the HRS and NHIS-LMF.

Cheung, et al. (2005) follow Kannisto's (2001) recommendation to avoid using life expectancy (i.e., e_x from the life table) as the measure of longevity. Instead, they use the modal age of death (M), which corresponds to the modal value in the d_x decrement function. According to Kannisto, the mode is preferable for two reasons. First, the mode (M) is in many instances a more intuitive measure than life expectancy. Second, unlike life expectancy, M is less susceptible to bias caused by truncating the age range examined. This is an important advantage of using M in our analyses because our survival curves begin at exact age 50. After computing M, we obtain a measure of "longevity extension" by computing the standard deviation above the mode, SD(M+) and obtain the ages of death within plus or minus three standard deviations of the mode (e.g., M-3*SD*(M+) and M+3*SD*(M+))[7]. M-3*SD*(M+) indicates the shortest life durations

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[6] This is a notable difference in our analyses and those by Cheung, et al. (2005) who produce calculations for deaths up to age 120. In our calculations, we truncate the deaths at exact age 99 for two reasons. First, there is a low density of deaths in beyond age 99, especially in the HRS. This introduces undue instability in the mortality estimates generated beyond age 99. Second, the algorithm used to produce the measures will not run if the open interval is included in the calculations because setting the open interval at 100+ does not allow the number deaths to gradually taper-off as they normally would in life tables generated from vital statistics registries. As a result, the d_x values beyond age 99 sharply increase in the open interval.

[7] Both Kannisto (2001) and Cheung, et al. (2005) obtain the ages at death within +/- 4 standard deviations of the modal age of death. Initially, we attempted to do this as well. However, we were unable to do so because for men in both the HRS and NHIS-LMF 4 standard deviations below the modal age of death extrapolated beyond the observed range of data, which caused SAS to return an error message and stop processing the data. The use of 3 standard deviations around the modal age at death gets around this problem and because dispersion around the mode is assumed to be normally distributed, 3 standard deviations still capture approximately 99.73% of the deaths around the mode, whereas 4 standard deviations capture approximately 99.99% of the deaths around the mode.

corresponding to aging-related deaths. M+3*SD*(M+) indicates longest life durations corresponding to aging-related deaths. The steepness of the survival curve in the region of the model age of death, i.e., verticalization, is captured by theta (θ). As aging-related deaths become more concentrated around M, θ declines in magnitude. Smaller values of θ therefore connote survival curves that are increasingly vertical.[8]

As suggested by Eakin and Witten (1995) and computed by Cheung, et al. (2005), the probability of survival and age are normalized in order to allow for easier comparisons across groups. In the case of age, normalization was accomplished simply by dividing each exact age x by the exact modal age at death obtained from the d_x column of life table, which normalized age around the modal age of death. Normalization was carried out for the probability of survival by dividing each of the l_x values by l_0 (e.g., 100,000), which rescaled the probability of survival to range from 0 to1.

Results

Descriptive Statistics. Table 1 displays the distribution of the deaths from the HRS and NHIS-LMF and Figures 1 through 4 graphically depict the distribution of the d_x and l_x values from the life tables generated using the HRS and NHIS-LMF. As shown in Table 1, there are relatively few deaths in the HRS among the oldest ages (90+), especially among men and the well educated. However, there are considerably more deaths at the oldest ages in the NHIS-LMF. In general, a visual inspection of the sex-education specific d_x and l_x values from the life tables generated from the HRS (Figures 1 and 2) and the NHIS-LMF (Figures 3 and 4) suggest that deaths become more compressed around the modal age of death at higher levels of education,

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[8] We encourage those interested in the computational details of the measures used in this paper to refer to Cheung, et al. (2005). Additionally, we direct interested readers to examine Eakin and Witten (1995) and, especially, Kannisto (2001) for background information concerning the computations developed by Cheung and colleagues.

particularly among females. Moreover, there is some evidence that the right hand tails of the survival curves are more vertical among the well-educated. Again, this is especially the case for females.

Rectangularization Analyses. The results of the *preliminary* analyses are displayed in Tables 3 (HRS) and 4 (NHIS-LMF). The results are similar between datasets. Taken as a whole, the analyses support our hypotheses that the degree of rectangularization is greater among groups with higher levels of educational attainment.

Tables 2 and 3 displays higher modal ages of death and smaller standard deviations above and around the modal age of death (*SD*(M+)) in both the HRS and NHIS-LMF among males and females with higher levels of education. *SD*(M+) is a measure of the variability above the modal age of death (e.g., longevity extension), while M-3SD(M+) and M+3SD(M+) measures the amount of dispersion (e.g., plus or minus three standard deviations) observed among aging-related deaths. The results also reveal that deaths are clustered more densely around the modal age of death among the groups with more education. Although this pattern is found for both males and females, there is less dispersion around the modal age of death among females. In both the HRS and NHIS-LMF, educationally-based differences at the lower bounds of the aging-related deaths (e.g., M-3*SD*(M+)) are profound. Groups with higher levels of education not only have higher modal ages of death and less dispersion around the modal ages of death than groups with lower levels of education, but the lower bounds of the variability around the modal age at death are also dramatically higher than those among the less educated. However, the results for the upper-bounds of aging-related deaths (e.g., M+3*SD*(M+)) do not conform to hypothesized patterns. In fact, among males, the values for M+3*SD*(M+) fluctuate considerably between educational groups and, contrary to our expectations, the values for M+3*SD*(M+) among females actually decrease at higher levels of education . We believe that the observed patterns for M+3*SD*(M+) are a direct result of truncating the age range at exact age 99. Understandably, Cheung, et al. (2005) placed a greater emphasis on the values for M+3*SD*(M+) than the values for the values for M-3*SD*(M+). However, we place a greater emphasis on the values for M+3*SD*(M+) because it is these values that most starkly demonstrate how much education matters for life expectancy. Although the results concerning longevity extension are mixed, the observed patterns are still generally consistent with our hypothesis that greater levels of mortality compression will occur among groups with higher levels of educational attainment.

Tables 2 and 3 display the values for verticalization (θ) generated from the HRS and NHIS-LMF. The values for theta measure the degree to which the right hand tail of the survival curve is more or less vertical between educational groups. As our hypotheses predict, the results from both the HRS and the NHIS-LMF show that the right hand tails of the survival curves are more vertical among groups with higher levels of education. The differences between educational groups are more pronounced among females in the HRS and males in the NHIS-LMF. Thus, the results are consistent with the existence of greater "verticalization" among groups with higher levels of educational attainment. Overall, the evidence displayed herein is consistent with notion that the survival curves among groups with higher levels of educational attainment are more rectangular than the survival curves among groups with lower levels of educational attainment.

Conclusion

In this paper, we examined education specific variations by sex in the rectangularization of the survival curve among the 50+ population in the United States. Rectangularization occurs when life expectancy increases alongside a decrease in the variation around the age at death. The majority of previous analyses examine rectangularization between populations and/or over time, under the assumption that differences in the degree of rectangularization between nations and over time indicate differing levels of socioeconomic and technological advancement. Consistent with this view, we hypothesized that the degree of rectangularization would be more pronounced among groups with higher educational attainment because, relative to persons with less education. This is because people with more education are better able to access a wide variety of resources that allow them to optimize their health and, ultimately, increase the length of their lives. We examined two dimensions of the survival curve ("verticalization" and "longevity extension") and applied the methods developed by Cheung, et al. (2005) to test our hypothesis. Overall, we find evidence supporting the notion that the survival curves among males and females with higher levels of education exhibit a greater amount of rectangularization than the survival curves of the less educated. To our knowledge, this is the first paper to explicitly examine educational variations in the rectangularization of the human survival curve.

The analyses presented are not without limitations. Truncating the age range at exact age 50 does not allow us to replicate all of the measures found in Cheung, et al. (2005). In particular, we cannot calculate their measure of "horizontalization" (β). In order to reliably calculate this particular measure, life tables that contain a mix of younger and older adults need to be assembled. Data from the NHIS-LMF and, potentially, the National Longitudinal Mortality Study (NLMS) could provide stable sex-education specific estimates for this purpose. In addition to allowing us to examine earlier stages of the adult life course, data from the NLMS would also allow us to examine trends in the relationship between sex, education, and rectangularization. Additionally, limiting the deaths at age 99 reduces the precision of our measure of longevity extension (e.g., M+3*SD*(M+)), causing these estimates to behave erratically in Tables 2 and 3. However, this limitation is mitigated considerably by the more precise calculations for the lower bound of aging-related deaths (e.g., M-3*SD*(M+). Due to our focus on educational differences in rectangularization, we argue that the lower bound of the dispersion around aging-related deaths are more important because they are a better measure of educationally-based disparities in the ability to optimize one's health and, ultimately, delay death.

Lastly, as previously stated, our trichotomized measure of education is not definitive. Although we examined the functional form of the relationship between education (in years) and the risk of death for males and females and found that a 3-category specification of education provided the best fit, we should continue to explore alternative specifications with larger datasets (like the NHIS-LMF) containing data for both younger and older adults. A larger dataset with younger cohorts would give us the ability to examine much more nuanced distinctions between education groups. We plan to continue refining our analyses in the coming months.

As populations in developed nations grey, it is imperative that researchers better understand the mortality dynamics of older adult populations. Policymakers overseeing large-scale, publicly financed healthcare and pension programs need detailed and accurate information on the mortality dynamics of older adults. Across the developed world, administrators of large-scale, publicly-financed programs rely upon this information as they plan for current and, especially, future expenditures incurred by their respective programs. Examining sex-education specific variations in rectangularization within a single national context as we have done hopefully will assist policymakers in ensuring the solvency of a wide range of important social and economic programs.

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Tables and Figures

Table 1. The Number of Deaths by Sex and Education, Health and Retirement Study (1992-2004) and National Health Interview Survey Linked Mortality File (1989-1996, 1989-2002)

Males	Total	Ages 90+
<u>HRS</u>		
Males		
0-11 Years	1,413	189
12 Years	854	50
13+ Years	849	67
Females		
0-11 Years	1,624	340
12 Years	999	118
13+ Years	749	148
<u>NHIS-LMF</u>		
Males		
0-11 Years	10,817	839
12 Years	7,538	310
13+ Years	6,165	341
Females		
0-11 Years	11,187	1,750
12 Years	8,904	816
13+ Years	5,090	703

Note: The analyses are limited to native-born U.S. respondents. In the NHIS-LMF, the analyses are further limited to respondents between the ages of 50 and 89 at the time of interview. Refer to the methods section for additional details.

Table 2. Variation in the Modal Age at Death (M) & the Degree of Verticalization (θ) of the Survival Curve by Years of Education Among U.S. Males and Females Ages 50+ in the HRS

	Education		
	0-11 Years	12 Years	13+ Years
Males			
Survival curves			
Modal age at death (M)	80.65	83.21	85.99
SD(M+)	8.10	7.48	6.26
M-3SD(M+)	56.36	60.76	67.20
M+3SD(M+)	104.94	105.66	104.78
Age at max acceleration	70.00	73.00	77.00
Age at max deceleration	93.00	95.00	97.00
Verticalization (θ)	23.74	22.39	20.53
Females			
Survival curves			
Modal age at death (M)	85.20	88.46	89.77
SD(M+)	7.07	5.59	4.87
M-3SD(M+)	63.99	71.68	75.16
M+3SD(M+)	106.40	105.23	104.39
Age at max acceleration	75.00	80.00	82.00
Age at max deceleration	97.00	99.00	99.00
Verticalization (θ)	22.33	19.41	17.58

Table 3. Variation in the Modal Age at Death (M) & the Degree of Verticalization (θ) of the Survival Curve by Years of Education Among U.S. Males and Females Ages 50+ in the NHIS-LMF

	Education		
	0-11 Years	12 Years	13+ Years
Males			
Survival curves			
Modal age at death (M)	79.06	82.97	85.16
SD(M+)	9.16	7.26	6.79
M-3SD(M+)	51.58	61.18	64.81
M+3SD(M+)	106.53	104.75	105.52
Age at max acceleration	67.00	73.00	76.00
Age at max deceleration	93.00	95.00	96.00
Verticalization (θ)	25.81	22.49	20.71
Females			
Survival curves			
Modal age at death (M)	85.48	88.19	89.58
SD(M+)	7.09	5.93	5.16
M-3SD(M+)	64.22	70.41	74.11
M+3SD(M+)	106.73	105.97	105.05
Age at max acceleration	74.00	79.00	81.00
Age at max deceleration	98.00	99.00	99.00
Verticalization (θ)	23.62	20.64	19.00

Figure 1. Survival Curves for U.S. Males Ages 50+ by Educational Attainment, HRS (1992-2004) and NHIS-LMF (NHIS: 1989-1996, Ages 50-89; NDI: 1989-2002)

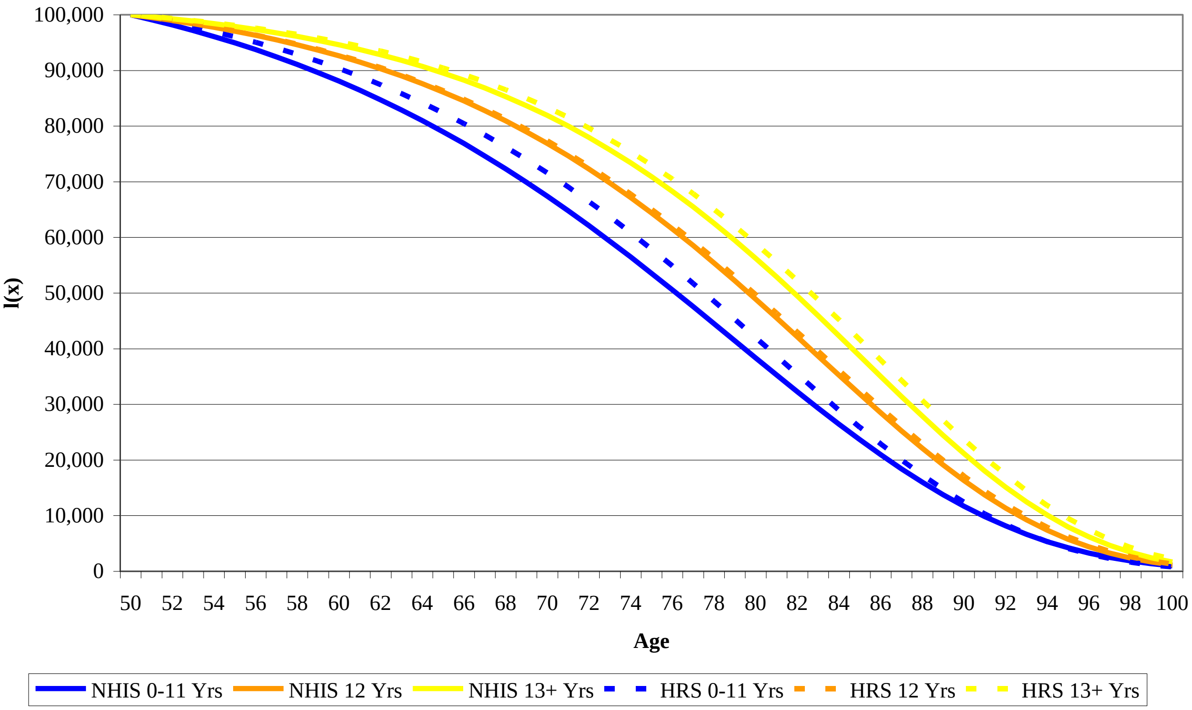

Figure 2. Survival Curves for U.S. Females Ages 50+ by Educational Attainment, HRS (1992-2004) and NHIS-LMF (NHIS: 1989-1996, Ages 50-89; NDI: 1989-2002)

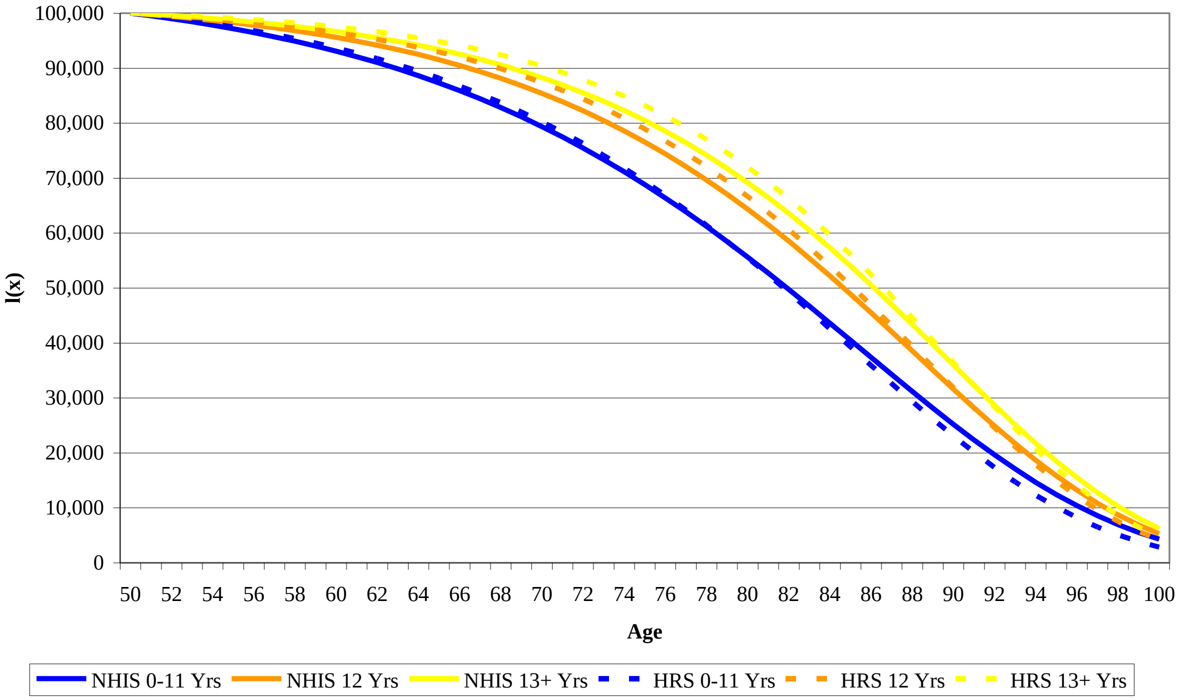

Figure 3. Number of Deaths in the Interval (dx) for U.S. Males Ages 50+ by Educational Attainment, HRS (1992-2004) and NHIS-LMF (NHIS: 1989-1996, Ages 50-89; NDI: 1989-2002)

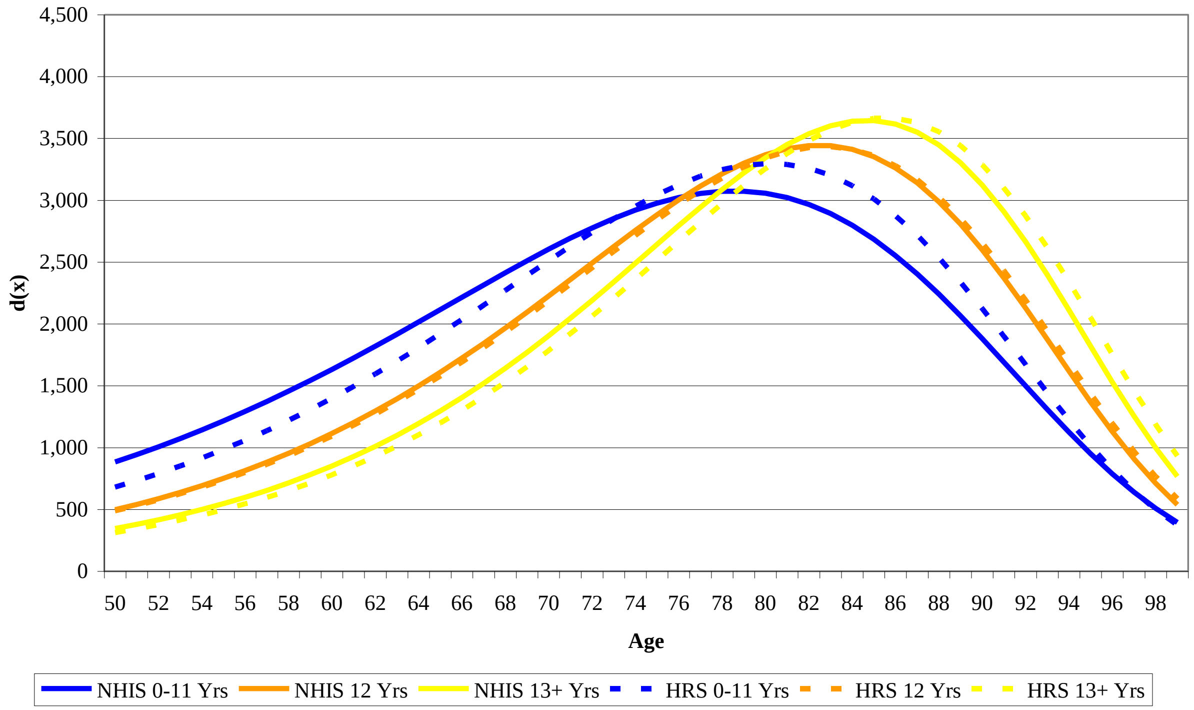

Figure 4. Number of Deaths in the Interval (d_x) for U.S. Males Ages 50+ by Educational Attainment, HRS (1992-2004) and NHIS-LMF (NHIS: 1989-1996, Ages 50-89; NDI: 1989-2002)