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Appendix
Estimating Life Tables That Reflect Socioeconomic Differences In Mortality

Jeffrey R. Brown, Jeffrey B. Liebman, and Joshua Pollet

Three of the papers in this volume (Brown, Feldstein-Liebman, and Liebman) make use of a new set of life tables that differentiate mortality experience by sex, race, and education level.[1] This appendix describes the methodology used to develop these life tables and presents the estimates themselves.

The underlying data for these life tables come from the National Longitudinal Mortality Survey (NLMS). The NLMS was created by matching individuals who were in the Current Population Survey (CPS) between 1979 and 1985 to death records from the National Death Index (NDI). This match occurred in 1989. The total sample population from the CPS data is 1,046,959, and by 1989 the NDI had death records for 69,385 of the individuals in the sample population. Since the earliest data are from 1979 and the match to mortality records occurred in 1989, each person in the sample was followed for a maximum of ten years (Rogot et al. 1992).

Because the CPS contains detailed demographic information for each sample member, this matched data set can be used to generate mortality estimates that take into account a wide variety of demographic characteristics. However, since the probability of death at a given age is small, especially at younger ages, we limited our categories to ones representing race,

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1. Because we have continued to refine these mortality tables over time, the three papers use slightly different versions of these mortality tables.

ethnicity, sex, and education level. We chose these characteristics because, unlike household income or marital status, these are largely predetermined and invariant to change at the time an individual enters the labor force.[2,3] In particular, we divided the data into six race-ethnicity-gender categories: non-Hispanic white males, non-Hispanic black males, and Hispanic males (table A.1), and non-Hispanic white females, non-Hispanic black females, and Hispanic females (table A.2). The number of education groupings for which we could produce reliable estimates varied by race and ethnicity. For white males and females, we developed separate life tables for individuals who did not complete high school ("less than high school," or LTHS), who completed high school but did not complete a four-year college degree (HS+), and who completed four years of college (COL). For black males and females, we did not have a sufficient number of observations to reliably estimate separate life tables for individuals with a college degree. Therefore, the Feldstein-Liebman and Liebman papers (chapters 7 and 1, respectively) used two education subgroups for blacks: individuals who did not complete high school ("LTHS"); and high school graduates, including those who completed college ("HS+"). Brown (chapter 10) used a slightly different approach. For black high school graduates who did not complete college, he estimated a life table that corresponded to that population. Then, for black college graduates he assumed that the ratio of mortality between black college graduates and other blacks was the same as the ratio for whites. The Hispanics samples were not large enough to develop reliable estimates with any variation by education level. Thus, we generate a total of twelve different life tables (six for whites, four for blacks, and two for Hispanics).

The NLMS data file that is available to researchers outside of the U.S. government contains roughly half the observations in the full NLMS. This sample was not sufficient for us to produce precise estimates for all of our groups, so instead we used summary tabulations produced by a Census Bureau employee from the full NLMS that contained nonparametric mortality rates for each age-by-sex-by-ethnicity-by-education group cell from age twenty-five to eighty-four. For example, the nonparametric sample estimate for the mortality rate of sixty-five-year-old college-educated white males is the number of sixty-five-year-old college-educated white males in the NLMS matched to a death record from the NDI before age sixty-six,

2. In addition to the demographic variables, the NLMS includes a CPS-based measure of annual family income. While recent research by Deaton and Paxson (2001) has shown that income has an impact on mortality even when race and education are controlled for, we chose not to incorporate income into our analysis. It is difficult to establish causality when examining correlations between contemporaneous income and mortality, because of the possibility that negative health shocks affect both measures.

3. Some individuals do, of course, obtain additional education after age twenty-five, the initial age used in our analysis.

Table 10A.1 **Relative Mortality Rates for Males Aged 25–100 by Race, Ethnicity, and Education: Ratio of Subgroup Male Mortality to General Population Male Mortality**

	White			Black		Hispanic
Age	LTHS	HS+	COL	LTHS	HS+	All
25	1.038637	0.880302	0.719848	3.955698	1.655740	2.734350
26	1.056137	0.881084	0.707339	3.913315	1.673879	2.646963
27	1.073668	0.882054	0.694940	3.868796	1.691346	2.558439
28	1.091155	0.883218	0.682718	3.822210	1.708028	2.469093
29	1.108517	0.884582	0.670741	3.773642	1.723815	2.379255
30	1.125676	0.886149	0.659077	3.723197	1.738603	2.289268
31	1.142551	0.887921	0.647796	3.670994	1.752293	2.199477
32	1.159065	0.889897	0.636961	3.617167	1.764794	2.110232
33	1.175142	0.892075	0.626637	3.561860	1.776026	2.021876
34	1.190709	0.894452	0.616884	3.505232	1.785916	1.934746
35	1.205698	0.897022	0.607757	3.447445	1.794407	1.849165
36	1.220047	0.899778	0.599307	3.388671	1.801450	1.765438
37	1.233700	0.902711	0.591579	3.329082	1.807010	1.683851
38	1.246605	0.905811	0.584612	3.268853	1.811065	1.604665
39	1.258721	0.909067	0.578441	3.208154	1.813603	1.528113
40	1.270009	0.912466	0.573091	3.147154	1.814625	1.454403
41	1.280443	0.915995	0.568585	3.086016	1.814145	1.383712
42	1.290000	0.919640	0.564936	3.024894	1.812183	1.316186
43	1.298666	0.923387	0.562155	2.963932	1.808773	1.251945
44	1.306431	0.927220	0.560244	2.903267	1.803954	1.191078
45	1.313294	0.931124	0.559202	2.843021	1.797774	1.133645
46	1.319259	0.935084	0.559022	2.783308	1.790286	1.079683
47	1.324334	0.939085	0.559694	2.724226	1.781547	1.029204
48	1.328532	0.943113	0.561204	2.665864	1.771621	0.982198
49	1.331870	0.947151	0.563533	2.608297	1.760572	0.938636
50	1.334368	0.951187	0.566664	2.551589	1.748464	0.898471
51	1.336049	0.955206	0.570571	2.495793	1.735367	0.861644
52	1.336936	0.959194	0.575233	2.440950	1.721345	0.828080
53	1.337057	0.963139	0.580622	2.387094	1.706465	0.797696
54	1.336438	0.967026	0.586713	2.334248	1.690792	0.770403
55	1.335107	0.970844	0.593479	2.282425	1.674387	0.746102
56	1.333091	0.974580	0.600891	2.231633	1.657312	0.724694
57	1.330417	0.978223	0.608922	2.181873	1.639623	0.706073
58	1.327113	0.981759	0.617543	2.133139	1.621376	0.690137
59	1.323204	0.985179	0.626728	2.085421	1.602620	0.676780
60	1.318716	0.988471	0.636447	2.038704	1.583406	0.665899
61	1.313671	0.991622	0.646674	1.992969	1.563777	0.657391
62	1.308093	0.994622	0.657382	1.948194	1.543777	0.651157
63	1.302003	0.997459	0.668543	1.904357	1.523443	0.647102
64	1.295420	1.000122	0.680130	1.861430	1.502812	0.645132
65	1.288362	1.002599	0.692117	1.819387	1.481916	0.645157
66	1.280847	1.004878	0.704476	1.778200	1.460786	0.647093
67	1.272891	1.006948	0.717182	1.737841	1.439451	0.650857
68	1.264506	1.008797	0.730207	1.698282	1.417935	0.656370

(*continued*)

Table 10A.1 (continued)

	White			Black		Hispanic
Age	LTHS	HS+	COL	LTHS	HS+	All
69	1.255708	1.010413	0.743524	1.659495	1.396264	0.663559
70	1.246509	1.011784	0.757105	1.621453	1.374459	0.672350
71	1.236920	1.012898	0.770923	1.584131	1.352542	0.682675
72	1.226954	1.013745	0.784948	1.547505	1.330532	0.694468
73	1.216621	1.014312	0.799153	1.511553	1.308451	0.707664
74	1.205934	1.014589	0.813506	1.476254	1.286316	0.722201
75	1.194905	1.014568	0.827979	1.441593	1.264148	0.738019
76	1.183546	1.014240	0.842540	1.407556	1.241967	0.755056
77	1.171874	1.013599	0.857159	1.374131	1.219795	0.773252
78	1.159905	1.012640	0.871804	1.341313	1.197656	0.792549
79	1.147658	1.011361	0.886445	1.309099	1.175575	0.812886
80	1.135157	1.009765	0.901052	1.277492	1.153581	0.834201
81	1.122428	1.007857	0.915595	1.246500	1.131705	0.856433
82	1.109503	1.005646	0.930048	1.216136	1.109984	0.879519
83	1.096419	1.003150	0.944385	1.186421	1.088458	0.903395
84	1.083219	1.000391	0.958587	1.157381	1.067174	0.927993
85	1.069955	0.997400	0.972637	1.129050	1.046183	0.953247
86	1.056685	0.994215	0.986525	1.101471	1.025545	0.979089
87	1.043478	0.990886	1.000248	1.074694	1.005327	1.005450
88	1.030413	0.987474	1.013813	1.048778	0.985603	1.032261
89	1.017579	0.984053	1.027238	1.023793	0.966457	1.059453
90	1.005079	0.980710	1.040552	0.999819	0.947983	1.086959
91	0.993029	0.977549	1.053801	0.976945	0.930286	1.114714
92	0.981558	0.974689	1.067045	0.955273	0.913482	1.142657
93	0.970812	0.972269	1.080364	0.934917	0.897697	1.170727
94	0.960950	0.970445	1.093856	0.916000	0.883071	1.198870
95	0.952149	0.969394	1.107638	0.898660	0.869755	1.227032
96	0.944598	0.969307	1.121844	0.883042	0.857911	1.255159
97	0.938498	0.970394	1.136623	0.869302	0.847711	1.283189
98	0.934057	0.972871	1.152125	0.857596	0.839330	1.311045
99	0.931479	0.976952	1.168491	0.848078	0.832939	1.338615
100	0.930953	0.982838	1.185832	0.840889	0.828698	1.365729

Note: See text for explanation of abbreviations and makeup of education subgroups.

divided by the total number of sixty-five-year-old college-educated white males in the NLMS sample. These tabulations were generously provided to us by Hugh Richards and have been used previously in Richards and Barry (1998).

There are several reasons that we do not use these nonparametric estimates directly. First, the sample sizes for some cells are very small, and therefore some single year of age mortality probabilities have very large standard errors. Consequently, estimates are often not a monotonic function of age for a particular race-gender-education classification, suggesting that some smoothing would be desirable. Second, we needed to construct

Table 10A.2 **Relative Mortality Rates for Females Aged 25–100 by Race, Ethnicity, and Education: Ratio of Subgroup Female Mortality to General Population Female Mortality**

	White			Black		Hispanic
Age	LTHS	HS+	COL	LTHS	HS+	All
25	1.131830	1.042855	0.864270	2.649466	0.711158	1.185041
26	1.138879	1.033564	0.853033	2.681900	0.759445	1.166252
27	1.146161	1.024175	0.841630	2.713179	0.808499	1.146999
23	1.153650	1.014734	0.830117	2.743030	0.858107	1.127352
29	1.161315	1.005292	0.818552	2.771177	0.908037	1.107389
30	1.169120	0.995900	0.807000	2.797344	0.958041	1.087195
31	1.177026	0.986615	0.795528	2.821258	1.007857	1.066864
32	1.184991	0.977492	0.784209	2.842658	1.057211	1.046494
33	1.192969	0.968588	0.773113	2.861297	1.105824	1.026188
34	1.200911	0.959962	0.762316	2.876947	1.153415	1.006053
35	1.208766	0.951668	0.751889	2.889405	1.199706	0.986194
36	1.216484	0.943759	0.741903	2.898496	1.244427	0.966718
37	1.224014	0.936286	0.732426	2.904078	1.287320	0.947730
38	1.231305	0.929294	0.723523	2.906042	1.328144	0.929328
39	1.238307	0.922825	0.715251	2.904318	1.366680	0.911606
40	1.244973	0.916912	0.707664	2.898870	1.402733	0.894650
41	1.251260	0.911586	0.700807	2.889702	1.436135	0.878538
42	1.257127	0.906868	0.694717	2.876854	1.466749	0.863336
43	1.262538	0.902776	0.689426	2.860399	1.494467	0.849103
44	1.267460	0.899317	0.684956	2.840443	1.519212	0.835883
45	1.271865	0.896495	0.681321	2.817122	1.540938	0.823713
46	1.275732	0.894306	0.678527	2.790594	1.559631	0.812615
47	1.279043	0.892741	0.676576	2.761040	1.575300	0.802604
48	1.281783	0.891785	0.675459	2.728658	1.587985	0.793680
49	1.283944	0.891419	0.675163	2.693658	1.597746	0.785839
50	1.285521	0.891619	0.675669	2.656258	1.604664	0.779064
51	1.286514	0.892359	0.676953	2.616684	1.608839	0.773333
52	1.286924	0.893609	0.678987	2.575160	1.610383	0.768617
53	1.286758	0.895336	0.681741	2.531909	1.609422	0.764879
54	1.286022	0.897507	0.685181	2.487152	1.606090	0.762081
55	1.284729	0.900087	0.689271	2.441099	1.600527	0.760178
56	1.282888	0.903041	0.693974	2.393957	1.592875	0.759124
57	1.280515	0.906332	0.699253	2.345918	1.583281	0.758872
58	1.277623	0.909925	0.705068	2.297165	1.571888	0.759371
59	1.274228	0.913786	0.711383	2.247871	1.558841	0.760572
60	1.270345	0.917878	0.718159	2.198195	1.544278	0.762424
61	1.265990	0.922170	0.725359	2.148283	1.528335	0.764878
62	1.261180	0.926627	0.732947	2.098270	1.511143	0.767885
63	1.255929	0.931220	0.740887	2.048281	1.492826	0.771397
64	1.250253	0.935917	0.749147	1.998427	1.473503	0.775369
65	1.244169	0.940690	0.757692	1.948808	1.453286	0.779756
66	1.237690	0.945511	0.766492	1.899516	1.432281	0.784515
67	1.230832	0.950354	0.775515	1.850632	1.410588	0.789605
68	1.223608	0.955194	0.784734	1.802229	1.388299	0.794988

(*continued*)

Table 10A.2 (continued)

	White			Black		Hispanic
Age	LTHS	HS+	COL	LTHS	HS+	All
69	1.216033	0.960008	0.794121	1.754371	1.365503	0.800626
70	1.208121	0.964774	0.803648	1.707115	1.342281	0.806484
71	1.199884	0.969470	0.813292	1.660513	1.318708	0.812530
72	1.191338	0.974077	0.823027	1.614610	1.294857	0.818731
73	1.182495	0.978578	0.832833	1.569445	1.270794	0.825059
74	1.173370	0.982955	0.842686	1.525054	1.246581	0.831488
75	1.163978	0.987194	0.852568	1.481470	1.222277	0.837990
76	1.154333	0.991282	0.862458	1.438720	1.197938	0.844545
77	1.144453	0.995206	0.872340	1.396832	1.173615	0.851130
78	1.134354	0.998956	0.882198	1.355828	1.149360	0.857728
79	1.124055	1.002525	0.892016	1.315733	1.125221	0.864320
80	1.113577	1.005906	0.901782	1.276566	1.101244	0.870894
81	1.102942	1.009098	0.911485	1.238350	1.077476	0.877438
82	1.092175	1.012098	0.921115	1.201104	1.053961	0.883943
83	1.081303	1.014909	0.930667	1.164851	1.030744	0.890404
84	1.070359	1.017537	0.940135	1.129611	1.007872	0.896818
85	1.059375	1.019993	0.949520	1.095409	0.985389	0.903188
86	1.048391	1.022291	0.958823	1.062268	0.963344	0.909521
87	1.037452	1.024452	0.968053	1.030215	0.941787	0.915827
88	1.026606	1.026501	0.977222	0.999281	0.920770	0.922125
89	1.015911	1.028472	0.986350	0.969499	0.900349	0.928440
90	1.005432	1.030411	0.995464	0.940908	0.880586	0.934805
91	0.995245	1.032370	1.004602	0.913552	0.861547	0.941266
92	0.985438	1.034420	1.013814	0.887483	0.843308	0.947881
93	0.976114	1.036646	1.023168	0.862764	0.825954	0.954725
94	0.967396	1.039158	1.032753	0.839468	0.809585	0.961894
95	0.959433	1.042093	1.042685	0.817688	0.794317	0.969514
96	0.952405	1.045627	1.053121	0.797536	0.780291	0.977746
97	0.946537	1.049985	1.064264	0.779154	0.767676	0.986801
98	0.942108	1.055461	1.076390	0.762723	0.756685	0.996955
99	0.939474	1.062435	1.089863	0.748476	0.747586	1.008572
100	0.939091	1.071408	1.105174	0.736714	0.740721	1.022134

Note: See text for explanation of abbreviations and makeup of education subgroups.

out-of-sample estimates of age-specific mortality rates, because mortality estimates for people above age eighty-four are required for our analysis. Third, this methodology yields data for a period mortality table describing the mortality experience of people alive during the NLMS. In contrast, our research projects required cohort life tables representative of people born in a given year.

To smooth the data, we estimated a nonlinear model for age-specific mortality separately for each group. With the proper choice of three parameters, the Gompertz-Makeham survival function can be applied from age twenty-five almost to the end of life (Jordan 1991). The Gompertz-Makeham formula is usually written as

$$l_x = \frac{l_0}{g} s^x g^{c^x} ,$$

where x is age, l_x is the number of people in the population alive at age x, and l_0 is the number of people in the population alive at birth. The parameters to be estimated are c, g, and s. Note that if l_0 is normalized to 1, then l_x is the cumulative probability of survival at age x, and we can define q_x, the mortality rate at age x, as

$$q_x = \frac{l_x - l_{x+1}}{l_x} .$$

Then, rearranging the Gompertz-Makeham formula and solving for q_x yields the equation that we estimate using nonlinear least squares:

$$q_x = 1 - sg^{(c^{x+1} - c^x)} .$$

We estimate the parameters in this equation separately for each of our twelve groups described above. By substituting the nonlinear least squares estimates of c, g, and s into the equation above, fitted estimates of mortality rates for a particular group at age x are formed. This approach guarantees that the fitted mortality rates are a monotonic function of age. Figure A.1 shows the fitted mortality rates and original nonparametric estimates for two of our twelve groups. The fitted values track the original data quite closely.[4]

As we mentioned above, the estimates from the NLMS are period estimates. Our basic approach to producing cohort life tables is to assume that the ratio of age-specific mortality in our disaggregated groups to more aggregated age-specific mortality rates stays constant over time. Then, to generate disaggregated cohort life tables, we can simply apply a ratio of period mortality rates from our data to the more aggregated cohort life tables published by the Social Security Administration or Census Bureau. For example, the cohort age-specific mortality estimates for white female college graduates could be constructed as

$$q_{x,\ \text{white female}}^{\text{cohort, college graduate}} = q_{x,\ \text{female}}^{\text{cohort}} \left(\frac{q_{x,\ \text{white female}}^{\text{fitted, college graduate}}}{q_{x,\ \text{female}}^{\text{fitted}}} \right) .$$

4. This is true for the other ten groups as well.

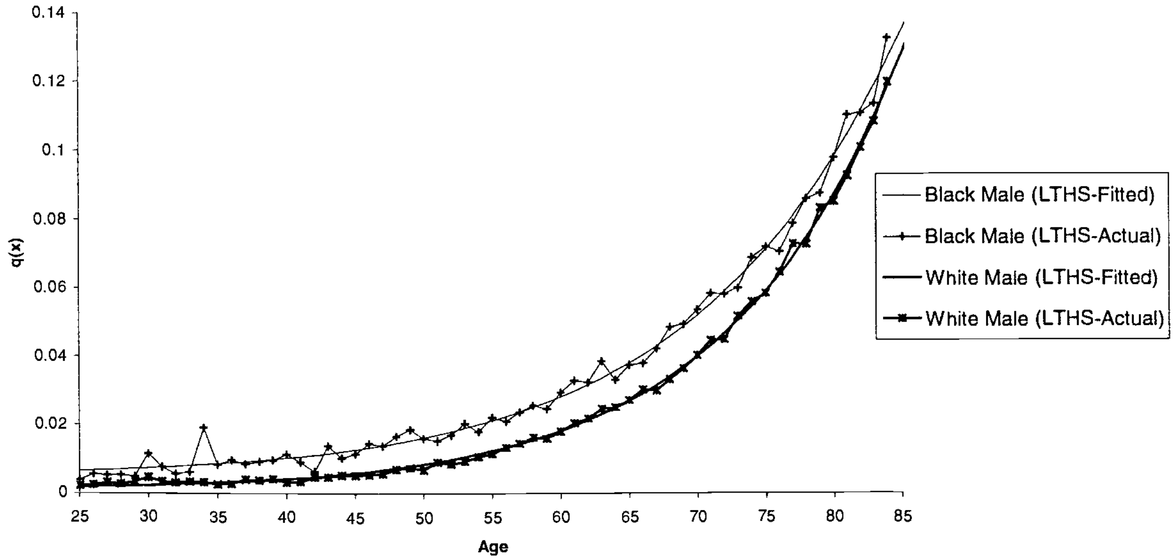

Fig. A.1 Comparison of fitted and nonparametric estimates of mortality rates

The assumption that relative mortality rates stay constant over time is clearly a strong one, though there is some evidence, for example, that differences in mortality rates between socioeconomic groups were not shrinking in the late twentieth century and may actually have been widening (Pappas et al. 1993; Preston and Taubman 1994). Moreover, even if relative mortality rates among demographic subgroups remain constant, changes in the share of the population within each demographic group could alter the relationship between a subgroup's mortality ratio and the aggregate ratio.

Because there has been such significant change in the educational attainment of Americans over the past century, we make one further adjustment to our data. Specifically, we produce aggregate mortality tables from our data weighting the various subgroups to represent the distribution of education rates (within sex-by-race cells) for thirty- to thirty-four-year-olds in the March 1999 CPS. Ratios of subgroup mortality to these aggregates will therefore be appropriate for use with aggregate cohort life tables for cohorts born in the late 1960s and for other cohorts with a similar distribution of educational attainment.[5]

Figure A.2 illustrates the impact of this adjustment for white males. The dashed line displays our unadjusted fitted estimates, which lie almost exactly on top of the published Vital Statistics period life table for white males in 1989–91. The dark line shows our estimate of aggregate white male mortality under the counterfactual assumption that the educational shares of the population had remained constant over time at rates like those for recent cohorts. Because recent cohorts have a larger share of individuals in the high-education (and therefore low-mortality) groups than the older cohorts in the NLMS did, this reweighted aggregate estimate shows lower mortality rates than the estimates based on the actual period data do.

Table A.1 contains the estimated ratios of subgroup age-specific mortality rates to aggregate mortality rates for males. Table A.2 contains the identical data for females.

One last issue requires discussion. Table A.2 indicates that mortality estimates for college-educated white males above age eighty-seven are higher than mortality rates for white males with less education at similar ages. A similar phenomenon appears at age ninety among white females. Because our summary tabulations from the NLMS do not contain data for ages above 84, the fitted estimates for ages 85 to 100 are heavily dependent on the relatively noisy raw data at slightly younger ages. Hence, it is possible that this crossover in the mortality estimates is simply the product

5. We used the late 1960s birth cohorts in creating our weights because they were the youngest for whom we could safely assume that nearly all members of the cohort had completed their educations.

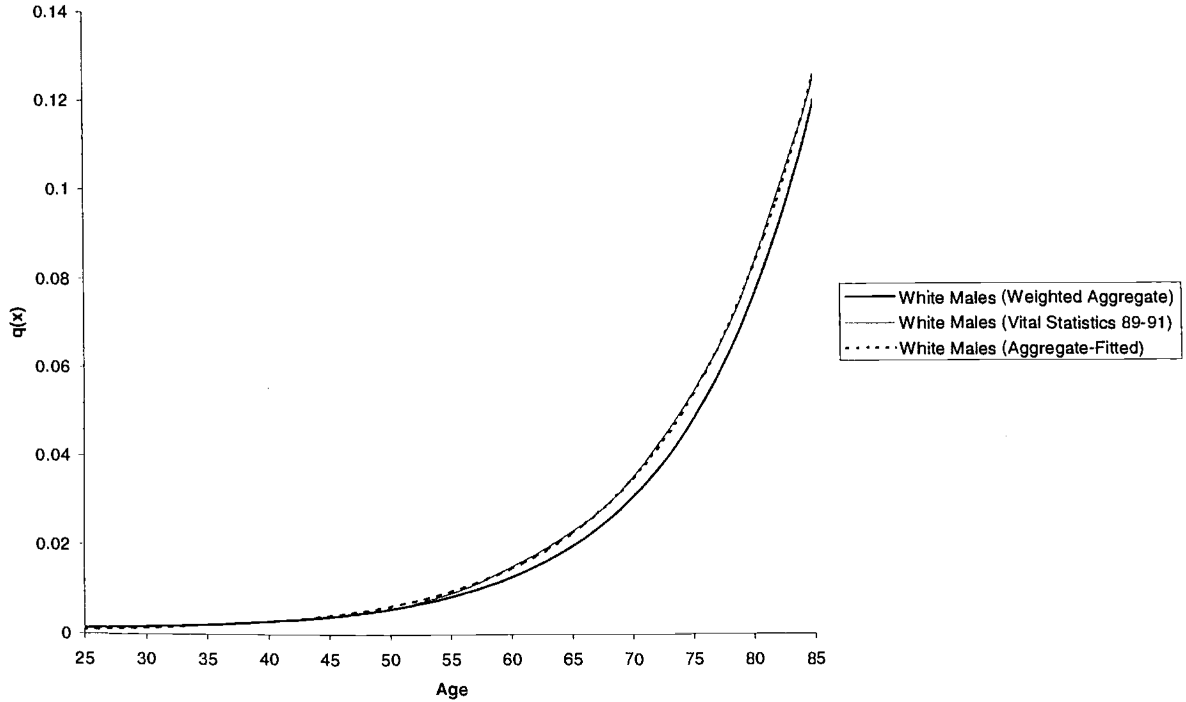

Fig. A.2 **The impact of adjusting mortality rates for changes in education shares**

of measurement error in the NLMS data combined with the functional form assumptions implicit in the Gompertz-Makeham formula. However, it is also possible that the crossover is a real phenomenon. In particular, if it is assumed that there exists a maximum age of survival, then at some very high age we would necessarily observe a crossover.[6]

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6. See Preston et al. (1996) for a discussion of the racial crossover in mortality.