Extended Abstract: Deceleration in Age-Related Mortality Increase: An Analysis by Cause of Death for the United States and an International Comparison for the Oldest-Old

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Abstract

The exponential increase in mortality is levelling off at advanced ages. Differential selection effects in heterogeneous populations are one way to explain this decelerated mortality development: while the force of mortality on the individual level may continue to increase exponentially, frailer members of the population are dying on average younger resulting in a slowing down in the age-related mortality increase on the observed level. In our paper, we investigate two predictions based on this heterogenity hypothesis as formulated by Horiuchi and Wilmoth (1998). (1) Due to general improvements in mortality over time, the population is less selected and, consequently, the observed deceleration in mortality shifts to later ages in more recent periods. (2) Most major causes of death should show a levelling off and, assuming independence of causes of death, the pattern of deceleration should be more pronounced for causes of death with higher death rates than with lower death rates due to the higher selection. We test those two predictions using two sources of data. The first hypothesis is scrutinized employing mortality data for eight selected countries for the oldest-old (80–100) from the Kannisto-Thatcher Database. The second hypothesis is analyzed by combining cause of death data for the United States from the National Center for Health Statistics with population data from the Human Mortality Database. We only find full support for the first hypothesis: the deceleration, which is observed for both sexes in all eight countries, appears to be shifted towards later ages. The second prediction, though, is only partly supported by our results: on the one hand, we find a deceleration for most causes of death. On the other hand, however, we can not find evidence that causes of death with high death rates have a more pronounced deceleration pattern.

Introduction

Throughout most of adult lifespan mortality increases exponentially and is well approximated by Gompertz' equation $\mu(x) = \alpha e^{\beta x}$, where x indicates age. Eventually, the log-linear increase levels off at higher ages. Following Horiuchi and Wilmoth (1998), there are at least two explanations for this levelling-off if data quality issues can be excluded: (a) the heterogenity hypothesis and (b) the individual-risk-hypothesis.

In our paper, we focus on (a). The heterogeneity hypothesis explains the levelling-off as an outcome of compositional change: some individuals are frailer than others and are dying on average at younger ages than their more robust peers. This implies that the population becomes less frail on average at advanced age and *observed* mortality increases more slowly—even if the *individual* mortality hazards continue to grow exponentially (Vaupel et al., 1998, 1979; Vaupel and Yashin, 1985).

According to Horiuchi and Wilmoth (1998), the deceleration can be also explained by the individual-risk-hypothesis: from a physiological point of view, slower rates in mortality increase with age maybe the outcome of a slower rate of living as measured by the metabolic rate, for instance.

Our aim is to test two of the predictions Horiuchi and Wilmoth (1998) based on the heterogeneity hypothesis.[1]

Prediction A: The deceleration should occur for most major causes of death. And, assuming independence of causes of death, "the deceleration should be less pronounced for CODs with lower death rates, which eliminate vulnerable individuals more slowly" (p. 392).

Prediction B: With general improvements in survival over time, populations should be less selected in recent periods than in the past. Consequently, selection effects and thereby deceleration should occur at later ages.

Data and Method

Data

For our analyses, we have two separate data sources. For prediction A, we are using deaths counts for the United States for the years 1959–2002. These data, published by the National Center for Health Statistics, were matched with the corresponding exposures obtained from the Human Mortality Database (University of California, Berkeley (USA), and Max Planck Institute for Demographic Research, Rostock, (Germany), 2007).

Death counts and population estimates for the oldest-old (ages 80 and higher) were obtained from the Kannisto-Thatcher Database on Old-Age Mortality, hosted by the Max Planck Institute for Demographic Research (http://www.demogr.mpg.de).

[1]Horiuchi and Wilmoth (1998) actually made three predictions. The one missing here states that "the deceleration should start at younger ages for more "selective" causes of CODs" (p. 392)". We did not want to include this hypothesis at the current stage due to the lack of "well-established criteria [. . .] for assessing and comparing the selectivity of major CODs" as pointed out by Horiuchi and Wilmoth.

Method

The age-related increase in mortality and its possible deceleration can be measured in a variety of ways. It appears to be a consensus nowadays that plotting mortality on a log-scale against age to detect deviations from a straight line is not the best approach (see, for example, Horiuchi and Wilmoth, 1997). One possibility, for instance, is to use the estimated slope parameter of a Gompertz curve, as done by Horiuchi et al. (2003).[2] We measure the age-related increase in mortality and its possible deceleration by the *life-table aging rate*. As introduced by Horiuchi and Coale (1990) and denoted by $k(x)$ for age x, it is defined as:

$$k(x) = \frac{d \ln \left(\mu\left(x\right)\right)}{dx},$$

where $\mu(x)$ represents the instantaneous death rate.[3]
For the estimation of $k(x)$ for the oldest-old, we followed Kannisto (1996). Basically, Kannisto (1996) used 5-year moving averages over 5-year age periods for survival probabilities (p. 62).[4] For our analysis by cause of death, we followed the suggestion of Horiuchi and Coale (1990) and estimated $k(x)$ by

$$\widehat{k(x)} = \ln(M(x,1)) - \ln(M(x-1,1)),$$

where $M(x,1)$ is the central death rate at age x. However, we do deviate from their approach in their two-fold smoothing approach, (1) the smoothing of the mortality curve and (2) the subsequent smoothing of $k(x)$.
For the analysis of cause-of-death data from the United States, we graduated mortality in a generalized additive model framework (Hastie and Tibshirani, 1990). We modeled the age-specific numbers of death (assuming a Poisson distribution) via the canonical log-link by (1) the known (log-)exposures entered as an offset and by (2) a smooth function of age. (2) was modeled as a non-parametric smooth term using the GLASS approach of Eilers and Marx (2002).
The smoothing of the $k(x)$ curve has been conducted using a non-parametric scatterplot smoother based on penalized B-splines (Eilers and Marx, 1996).
Although many smoothing methods exist, we decided to use these aforementioned non-parametric smoothers because these models do not impose any structure upon the results.

Results

Tables 1 and 2 display our results for the oldest old for women (Table 1) and men (Table 2). Each table lists for the eight selected countries the life table aging rate as estimated

[2]To be precise, Horiuchi et al. (2003) use a linear regression model for the age-specfic death rates measured in 5-year intervals.

[3]Also called the force of mortality or the mortality hazard.

[4]For the estimation of $k(x)$ for the oldest-old according to Kannisto (1996), I used a testing version of software developed by Eugeny Soroko.

by Kannisto (1996) for five different age intervals. A value of 0.1 indicates that mortality increased by 10% from one age to the next. A constant life table aging rate for a given country, sex, and decade would indicate that mortality increases exponentially (or linearly on a log-scale). However, our results show that the life table aging rate decreases with age. This means that the age-related increase in mortality is slowing down at more advanced ages—a development which can be observed in the large majority of our data. Tables 1 and 2 support the prediction as formulated by Horiuchi and Wilmoth (1998) that deceleration should be postponed to later ages: during later periods of time, given values of the life table aging rate are found at higher ages than previously. For example, an increase of 10.5% in the slope of mortality has been measured for French women at ages 83–88 during the decade 1960–70 (0.1051); two decades later, a comparable life table aging rate (0.1058) was found for ages 88–93. For the same time period and age-group, the life table aging rate is steeper for women than for men. This result, which has been also found by Kannisto (1996), can probably be interpreted by the lower average death rate of women implying less selection for women than for men.

Figures 1 and Figure 2 present the life table aging rate for women and men for ages 65 to 95 for single years from 1959 to 2002 for selected causes of death. Different time periods have been plotted by different shades of grey. Later periods are indicated by brighter colors, whereas the darkest color was used for the first year of analysis (1959). Despite employing a different methodology than for the oldest-old, we obtain similar results for all-cause mortality (upper-left panels) if we concentrate only at ages 80 and higher: for the same ages the life-table aging rate became larger over time. Or—seen from a different angle—the same life-table aging rate is now found at later ages than in the past. Both perspectives support the prediction that due to general improvements in mortality, the deceleration in the age-related increase in mortality will shift to later ages. We find also support for the other prediction: a deceleration should be observable for most major causes of death. Although the actual shape is differing across the various categories, most of the causes show signs of deceleration. The other part of the prediction—"the deceleration should be less pronounced for CODs with lower death rate, which eliminate vulnerable individuals more slowly" (Horiuchi and Wilmoth, 1998, p. 392)—does not seem to be supported by our data. While digestive diseases or diabetes mellitus have lower death rates than cardiovascular diseases, cerebrovascular diseases or cancers, their associated patterns in $k(x)$ do not appear to be less pronounced.

Conclusion

Our paper deals with the observed deceleration of the age-related increase in mortality. The analysis of oldest-old mortality for eight selected countries and of causes of death for the United States found support for two predictions of the heterogeneity hypothesis as formulated by Horiuchi and Wilmoth (1998): (a) due to improvements in mortality in general, populations at a given age are less selected nowadays than in the past. Consequently, the deceleration shifts to later ages. The results from our analysis by cause of death were partly in accordance with the other prediction (b) that deceleration should oc-

cur for most major causes of death and that the deceleration should be more pronounced for causes of death with higher death rates.
We should keep in mind that the heterogeneity hypothesis is not the only explanation for the deceleration in the age-related increase in mortality. For example, the individual-risk hypothesis, mentioned in the introduction, reaches similar conclusions about the observed outcome based rather on geronotological mechanisms than on compositional effects. Furthermore, Yashin et al. (1994) showed that distinguishing between the two explanations can be very difficult. As proven by the authors, two widely used models to support either one of the two hypotheses turned out to be mathematically equivalent.

The current version of this paper is only an extended abstract. In addition to carefully checking our data and results, we are considering for the final paper to extend the age-range, use more causes of death and/or try alternative methods to compare the results from the United States to results for Japan (Horiuchi and Wilmoth, 1997) and France (Horiuchi et al., 2003).

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Table 1: Life Table Aging Rate, Women, for the Oldest Old in Eight Selected Countries

Country	Decade	Ages				
		83–88	88–93	93–98	98–103	83–98
England & Wales	1950-1960	0.0968	0.0789	0.0765	0.0545	0.0841
	1960-1970	0.0974	0.0846	0.0734	0.0668	0.0851
	1970-1980	0.1002	0.0912	0.0767	0.0676	0.0894
	1980-1990	0.1052	0.0967	0.0786	0.0725	0.0935
	1990-2000	0.1084	0.1053	0.0904	0.0785	0.1014
	2000-2003	0.1167	0.1072	0.0932	0.0846	0.1057
France	1950-1960	0.1013	0.0862	0.0636	0.0940	0.0837
	1960-1970	0.1051	0.0899	0.0660	0.0786	0.0870
	1970-1980	0.1106	0.0972	0.0776	0.0676	0.0951
	1980-1990	0.1211	0.1058	0.0823	0.0735	0.1031
	1990-2000	0.1319	0.1170	0.0971	0.0896	0.1153
	2000-2003	0.1367	0.1246	0.1002	0.0947	0.1205
Germany (West)	1960-1970	0.0990	0.0851	0.0712	0.0935	0.0851
	1970-1980	0.1039	0.0889	0.0792	0.0618	0.0907
	1980-1990	0.1113	0.0968	0.0785	0.0596	0.0955
	1990-2000	0.1202	0.1092	0.0877	0.0723	0.1057
	2000-2004	0.1233	0.1128	0.0921	0.0749	0.1094
Italy	1960-1970	0.1007	0.0874	0.0722	0.0441	0.0867
	1970-1980	0.1063	0.0933	0.0812	0.0617	0.0936
	1980-1990	0.1149	0.0993	0.0818	0.0660	0.0987
	1990-2000	0.1232	0.1108	0.0918	0.0742	0.1086
	2000-2003	0.1264	0.1154	0.0950	0.0798	0.1123
Japan	1950-1960	0.0915	0.0841	0.0691	0.0359	0.0816
	1960-1970	0.0966	0.0853	0.0741	0.0496	0.0854
	1970-1980	0.1084	0.0952	0.0739	0.0579	0.0925
	1980-1990	0.1206	0.1048	0.0844	0.0636	0.1033
	1990-2000	0.1280	0.1186	0.0932	0.0794	0.1133
	2000-2004	0.1278	0.1189	0.1029	0.0897	0.1165
Spain	1950-1960	0.0870	0.0504	0.1055	0.0215	0.0810
	1960-1970	0.0944	0.0686	0.0892	0.0445	0.0840
	1970-1980	0.1016	0.0854	0.0656	0.0175	0.0842
	1980-1990	0.1159	0.0987	0.0718	0.0325	0.0955
	1990-2000	0.1272	0.1134	0.0895	0.0532	0.1100
	2000-2004	0.1374	0.1136	0.0901	0.0653	0.1137
Sweden	1950-1960	0.0979	0.0870	0.0755	0.0751	0.0868
	1960-1970	0.1037	0.0848	0.0728	0.0775	0.0871
	1970-1980	0.1081	0.0934	0.0846	0.0746	0.0953
	1980-1990	0.1197	0.1034	0.0855	0.0725	0.1029
	1990-2000	0.1248	0.1173	0.0964	0.0774	0.1128
	2000-2004	0.1344	0.1212	0.0997	0.0674	0.1185
USA	1960-1970	0.0993	0.0857	0.0666	0.0208	0.0839
	1970-1980	0.1007	0.0932	0.0760	0.0429	0.0900
	1980-1990	0.1052	0.0992	0.0861	0.0644	0.0968
	1990-2000	0.1071	0.1075	0.0944	0.0753	0.1030
	2000-2003	0.1094	0.1054	0.0959	0.0752	0.1036

Table 2: Life Table Aging Rate, Men, for the Oldest Old in Eight Selected Countries

Country	Decade	Ages				
		83–88	88–93	93–98	98–103	83–98
England & Wales	1950-1960	0.0895	0.0735	0.0760	0.0499	0.0796
	1960-1970	0.0842	0.0728	0.0679	0.0809	0.0750
	1970-1980	0.0795	0.0766	0.0717	0.0627	0.0759
	1980-1990	0.0825	0.0775	0.0673	0.0518	0.0758
	1990-2000	0.0902	0.0900	0.0791	0.0694	0.0864
	2000-2003	0.1010	0.0918	0.0851	0.0643	0.0926
France	1950-1960	0.0922	0.0768	0.0463	0.0619	0.0718
	1960-1970	0.0893	0.0796	0.0491	0.0948	0.0726
	1970-1980	0.0892	0.0820	0.0626	0.0724	0.0779
	1980-1990	0.0939	0.0884	0.0677	0.0644	0.0833
	1990-2000	0.1054	0.0991	0.0749	0.0773	0.0931
	2000-2003	0.1134	0.0931	0.0952	0.0690	0.1005
Germany (West)	1960-1970	0.0878	0.0813	0.0716	0.0555	0.0802
	1970-1980	0.0812	0.0805	0.0716	0.0493	0.0777
	1980-1990	0.0854	0.0793	0.0616	0.0635	0.0754
	1990-2000	0.0938	0.0954	0.0760	0.0659	0.0884
	2000-2004	0.0919	0.0827	0.0905	0.0707	0.0884
Italy	1960-1970	0.0925	0.0835	0.0754	0.0607	0.0838
	1970-1980	0.0871	0.0830	0.0714	0.0658	0.0805
	1980-1990	0.0883	0.0824	0.0733	0.0669	0.0813
	1990-2000	0.0996	0.0935	0.0783	0.0733	0.0905
	2000-2003	0.1044	0.0979	0.0789	0.0699	0.0937
Japan	1950-1960	0.0818	0.0782	0.0475	-0.0160	0.0692
	1960-1970	0.0821	0.0715	0.0540	0.0654	0.0692
	1970-1980	0.0909	0.0791	0.0675	0.0439	0.0792
	1980-1990	0.0955	0.0837	0.0724	0.0595	0.0839
	1990-2000	0.1026	0.0953	0.0789	0.0741	0.0923
	2000-2004	0.1018	0.0952	0.0848	0.0785	0.0939
Spain	1950-1960	0.0833	0.0434	0.0944	-0.0190	0.0737
	1960-1970	0.0855	0.0618	0.0869	0.0099	0.0781
	1970-1980	0.0855	0.0741	0.0409	-0.0012	0.0668
	1980-1990	0.0939	0.0829	0.0585	0.0135	0.0784
	1990-2000	0.0999	0.0930	0.0804	0.0277	0.0911
	2000-2004	0.1130	0.0908	0.0806	0.0477	0.0948
Sweden	1950-1960	0.1009	0.0852	0.0723	0.1270	0.0861
	1960-1970	0.0945	0.0886	0.0766	0.0592	0.0866
	1970-1980	0.0901	0.0832	0.0755	0.0790	0.0829
	1980-1990	0.0939	0.0867	0.0771	0.0725	0.0859
	1990-2000	0.1042	0.0974	0.0839	0.0649	0.0951
	2000-2004	0.1151	0.1050	0.0933	0.0686	0.1045
USA	1960-1970	0.0821	0.0723	0.0521	-0.0051	0.0688
	1970-1980	0.0789	0.0747	0.0631	0.0121	0.0722
	1980-1990	0.0832	0.0790	0.0722	0.0424	0.0781
	1990-2000	0.0908	0.0906	0.0814	0.0614	0.0876
	2000-2003	0.0934	0.0864	0.0858	0.0611	0.0886

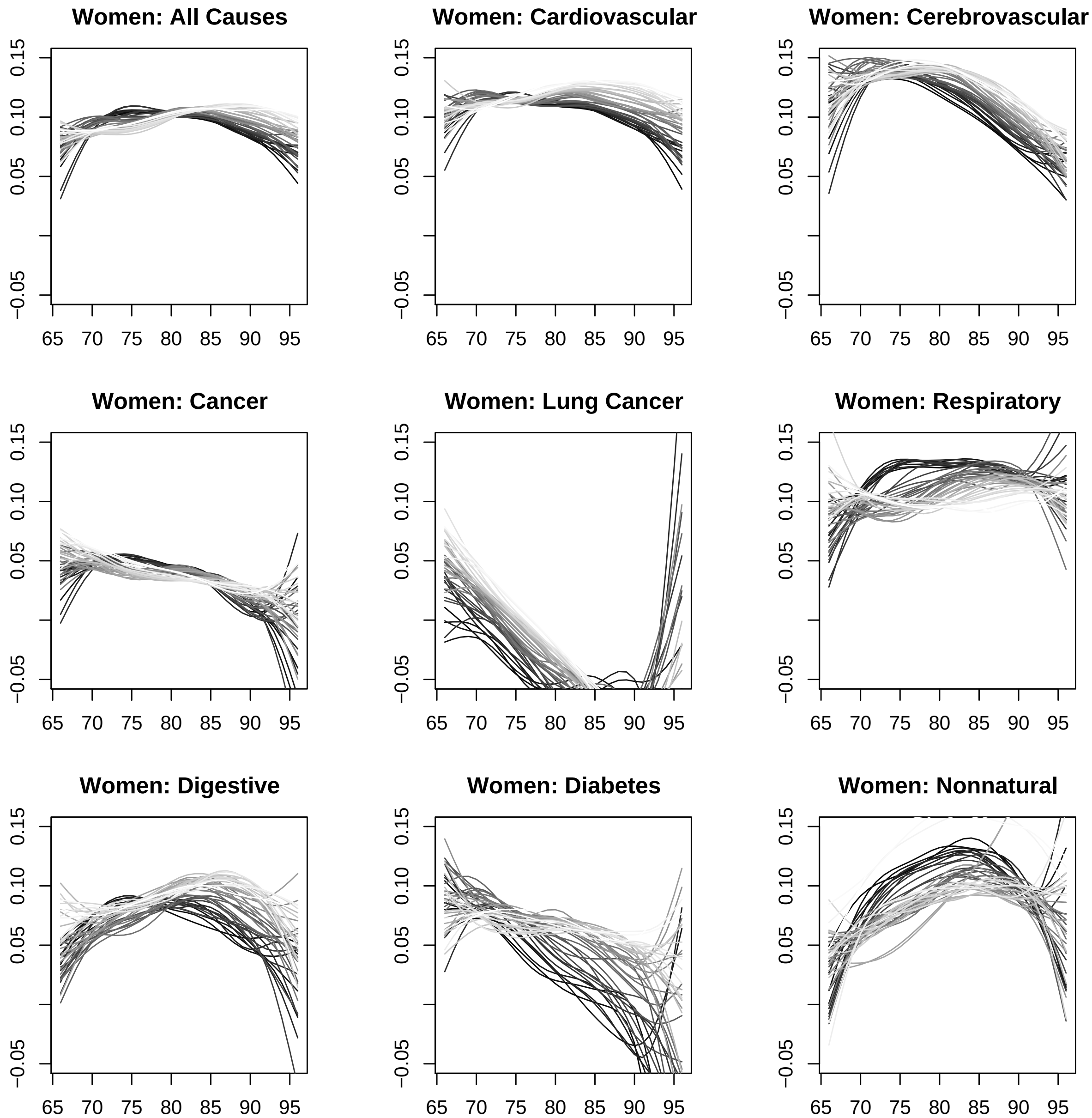

Figure 1: Life Table Aging Rate for Women in the United States, Aged 65–95, from 1959–2002 by Cause of Death. Increasing brightness indicates later years. The darkest shade of grey represents the year 1959.

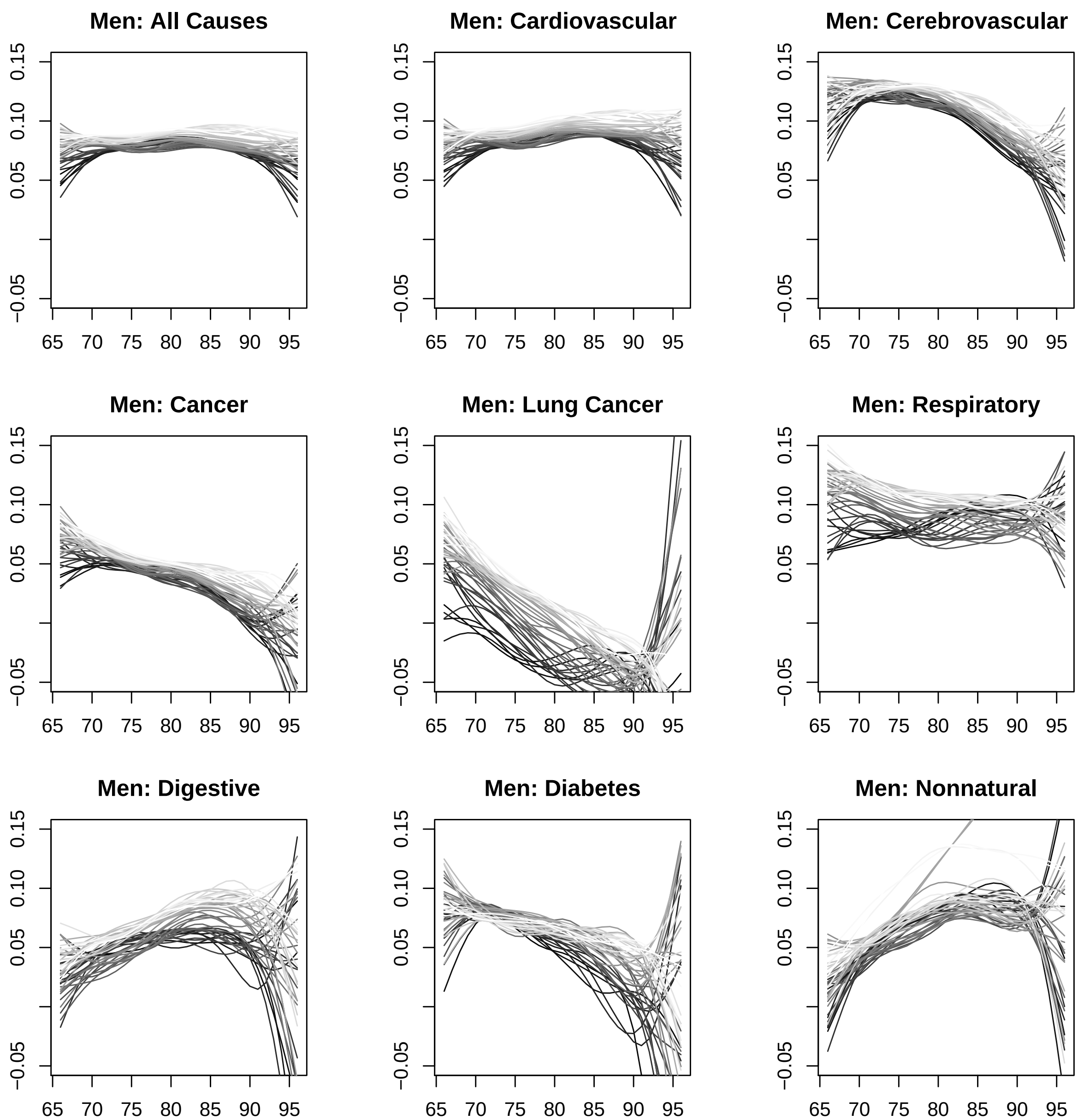

Figure 2: Life Table Aging Rate for Men in the United States, Aged 65–95, from 1959–2002 by Cause of Death. Increasing brightness indicates later years. The darkest shade of grey represents the year 1959.