Age Patterns and Time Sequence of Mortality in National Populations with the Highest Expectation of Life at Birth
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Age Patterns and Time Sequence of Mortality in National Populations with the Highest Expectation of Life at Birth

ANSLEY J. COALE

MORTALITY HAS DECLINED remarkably in the twentieth century. In the countries with the highest life expectancy at birth in 1900, female e_0 had reached about 58 years; by 1990 in these countries and several others with less favorable mortality at the beginning of the century, the female expectation of life had surpassed 80 years. The analysis presented here is a somewhat dissonant contribution to the growing debate about "rectangularization" of survival curves; "compression of mortality," morbidity, and disability; and the continuing speculation about an ultimate limit to the length of life (Fries 1980; Myers and Manton 1984a and 1984b; Manton and Tolley 1991; Wilmoth, Curtsinger, and Horiuchi 1995; Manton and Singer 1994; Preston 1992). In the extensive discussion of "rectangularization" and "compression" there is, as yet, no consensus on a precise definition of these terms (Wilmoth, Curtsinger, and Horiuchi 1995). Furthermore, empirical analyses, frequently involving extensive use of covariates and purporting either to support or refute claims about time trends in the shape of survival curves, have failed to take account of simple macrolevel relations that must constrain any consideration of underlying relations. In this note such constraints are listed and are shown to delineate very low mortality life tables concisely and precisely.

Shape of the human survival curve in populations with very low mortality: Rectangularization

Some recent views of the determinants and the age structure of human mortality seem to imply an increasingly flat curve of the proportion of persons surviving from birth to advancing ages. This phenomenon has been given the name "rectangularization." At high mortality (low levels of life expectancy), the l_x/l_0 curve declines steeply in infancy and early childhood, then less steeply until age 55 or 60 years, and then more steeply at higher ages. When mortality is very low, the survival curve becomes nearly flat from ages 5 to 55. In recent years as mortality has continued to decline, death rates have fallen even at very high ages—over 90 and over 100 years. One result is that the nearly flat survival curve that extends to about age 55 is followed by a curve of lesser steepness than the curve with somewhat higher mortality. Another idea about mortality with much support is that there is an innate maximum age at death that will not be surpassed even after all treatable diseases and causes of disability have been successfully dealt with. Continued reductions in mortality at all ages up to this maximum would produce a survival curve nearly flat until the maximum is approached, followed by a nearly vertical fall. Thus the survival curve would become approximately rectangular. A totally rectangular l_x function would be generated if mortality rates were zero until just short of the maximum age, at which point the death rate would be 1.0. A very low rate (say less than .001) until the maximum age would generate a close approximation to rectangularity.

Support for the idea of a future rectangular curve of survival comes from two qualitative interpretations of observed mortality trends in populations that have attained the lowest death rates at higher ages, and from biomedical ideas about the evolution of mortality. The qualitative interpretations are: first, that substantial reductions in death rates extend to very high ages; and second, that there is a maximum age at death that is unlikely to be surpassed, even with further improvements in medical science.

The biomedical ideas about the evolution of mortality postulate several stages in a human death: becoming susceptible to an ailment, becoming ill (morbid) with the ailment, and dying of the ailment. Vaccinations and healthier life styles have postponed susceptibility and the beginning of morbidity; better curative medicine has shortened the duration of morbidity. Postponement of susceptibility and shortening of the period of morbidity lead to a higher age at death; if innate factors set a limit on the duration of life, the survival curve descends steeply as the limiting age is approached.

The empirical experience of national populations that have achieved the highest levels of expectation of life at birth

Instead of considering hypothetical possibilities of future reductions in mortality, especially among the elderly, I shall examine what has happened in those countries that have to date proceeded the farthest in reducing mortality. The outcome of this examination is that (at least among females) the age patterns of mortality rates in the countries with the lowest mortality have become very similar to one another, and conform closely to model life tables constructed to express the expected age-specific rates at very high e_0.

Two empirical characteristics of mortality are combined in this analysis. They will be discussed in succession. The first relation is found in the experience of national populations that have achieved the large reductions in mortality made feasible by modern advances in medicine and public health. The relation is between the expectation of life at a given moment in one of these populations and the annual rate at which life expectancy is increasing. The relation turns out to be linear: the higher the e_0, the slower the annual increase. The linear relation is very close. It implies an exponentially increasing time path (with a linearly decreasing exponent) for the expectation of life at birth. The current value of e_0 can be placed on the single time path at the current date and estimated future values read from later points on the standard path.

In the 1950s when working with Hoover on population growth and economic development in low-income countries, I needed to project mortality in Mexico to the 1980s. In a projection already made for India, special allowance was made for a rapid decline in mortality rates in malarious areas in the 1950s because the experience in Ceylon showed the large and steep decline that an antimalaria campaign can cause: such a campaign was being started in India. When this campaign was scheduled to end, we expected a gradual further increase in life expectancy because of the widespread contamination of food and water in India and the country's meager health facilities.

Mexico already had a higher expectation of life in the 1950s than we had projected for India in 1980; both in economic wellbeing and the state of public health, Mexico was much further advanced. To estimate the future increases in life expectancy in Mexico, we examined the increase in e_0 between 26 pairs of dates in the experience of 20 countries from the 1930s until the early 1950s. The pairs of tables we used for females had life expectancies ranging from 40 to 74 years (Coale and Hoover 1958).

We next compared in the experience of these countries the average annual increase in e_0 in each interval with the average of e_0 at the two ends of the interval. There was a clear linear relation. The higher the life expectancy, the slower the annual increase. The straight line that fits the points relating annual increase to the level for females is expressed in the equation:

$$e_0(t) = 84.2 - (84.2 - e_0(t_1))e^{-.0303(t-t_1)} \qquad (1)$$

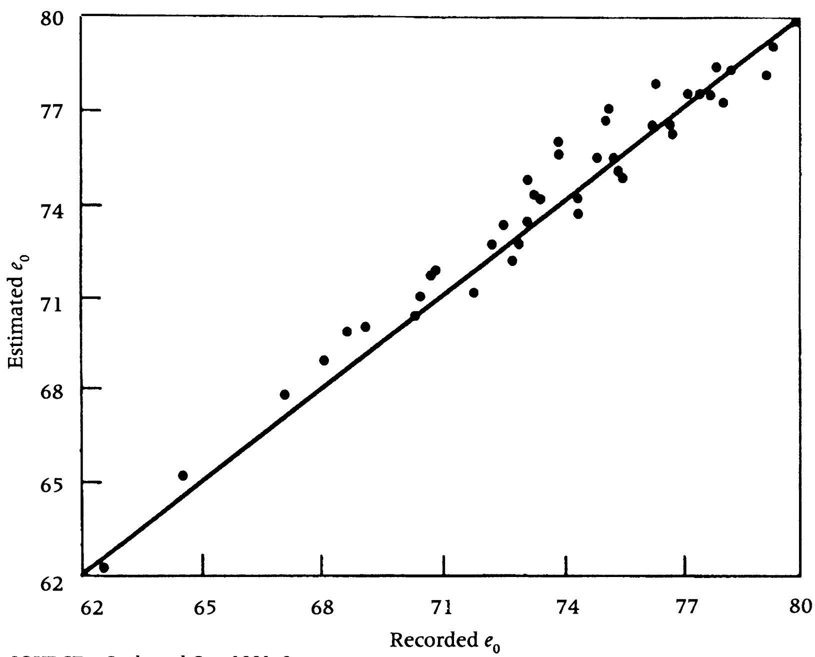
where 84.2 is the expectation of life when the annual increase becomes zero on the extension of the straight-line decrease in delta e_0, and t_1 is the initial year for the estimates.

Evidence that the annual increase in expectation of life at birth decreases linearly as e_0 rises

The linear relation developed for estimating the changes in life expectancy in Mexico starting in 1955 was supported by the validity of the prediction for Mexico implied for 1985: the estimated female e_0 equals 71.4 years in 1985, compared to the UN estimate of 71.5 for the same year, published in 1991 (United Nations 1991). Wider support for the linear relation is provided in Figure 1: values of e_0 in more than 40 life tables over a 35-year interval from 1950 to the early 1980s are very consistent with estimates made with equation (1).

The time path of the increase in expectation of life implied by the equation is not universally followed. Many less developed countries have much more gradual reductions in death rates; India is a conspicuous example. In Eastern Europe and especially in the Soviet Union, expectation of life lagged behind the standard curve, especially in the 1960s and later. In several of these countries the expectation of life for males actually declined. In the United States and England and Wales the rise in e_0 lagged somewhat after about 1960, and in Japan the increase has slightly but persistently surpassed the standard.

FIGURE 1 Actual female e_0 from 1950–54 to 1980–84 compared to estimated e_0 in eight countries



SOURCE: Coale and Guo 1991: 3.

New model life tables at very low mortality

The second line of research that contributes to the understanding of age patterns and time trends of mortality at the highest values of life expectancy is a new set of model life tables (Coale and Guo 1989). These revisions of the Princeton regional life tables (Coale and Demeny 1983) were developed by Coale and Guang Guo in 1989 and published in *Population Index* and in the *Population Bulletin of the United Nations.*

In the late 1980s, it was noticed that the Princeton "Regional Model Life Tables" listed mortality rates at very high ages that were systematically higher than the rates recorded at these ages in the lowest-mortality populations in each region. A factor that contributed to these model excess rates was the assumed exponential increase in mortality rates with age that was used to close out each model table above age 80 (use of the Gompertz function). It had been found that in fact the ratio of the mortality rate at one age to the rate at the next younger age decreased in a linear fashion above age 80 rather than having a fixed value (Horiuchi and Coale 1990; Coale and Kisker 1986; Wilmoth 1995). Following this discovery, new model tables were calculated at very high expectations of life for each of the four regions in the Princeton tables. By analyzing data on death rates by age taken from moderate to low mortality life tables, new models were constructed up to age 80 for each region; above 80 the new models were closed out with mortality rates in which the rate at each age exceeded the rate at the next younger age by an amount that diminished linearly.

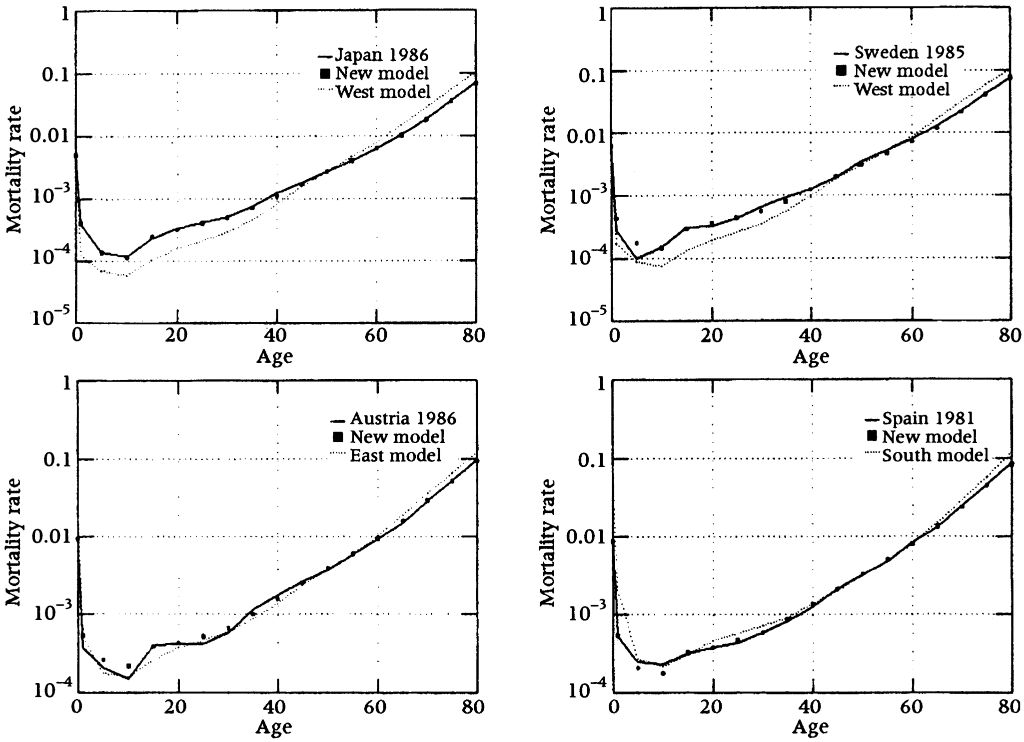
The rate of decline in the rate of increase in mortalities was set to yield an assigned mortality rate at age 110 near to 1.0. The tables calculated for a female e_0 of 80 years were nearly identical in the four regions; the West table was accepted as the sole model at this level. West models at female e_0s of 82.5 and 85.0 were also constructed to be used in all four regions.

Conformity of the life tables in low-mortality populations to the new models

In the 1989 article describing the new model life tables, a figure (reproduced here as Figure 2) showed that the new model tables fitted the schedule of death rates in four populations with the lowest mortality more closely than the previous separate "regional" model tables.

The proportion of females surviving from age 50 to higher ages in the Swedish life tables for 1970 and 1990 is compared in Figure 3 with the survival rates in the new West model tables at e_0 of 77.5 and 80. In the life tables for 1970 and 1990, female e_0 was 77.1 and 80.4; according to equation (1) beginning at 77.1 in 1970 life expectancy should increase to 80.4 in 20 years, exactly what happened to mortality in Sweden from 1970 to

FIGURE 2 Female mortality rates, ages 0–1 to 80–85, compared to the new low-mortality model and to the appropriate family of regional model tables with the same value of l_{65}/l_{10}

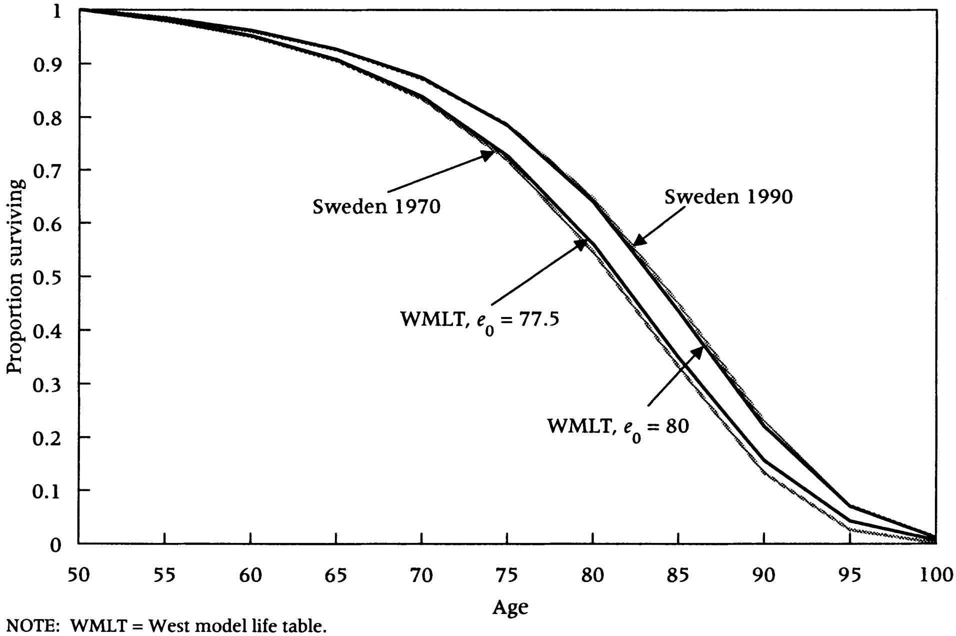


SOURCE: Coale and Guo 1989: 621.

1990. As is evident in Figure 4, the survival rates above age 50 in Sweden at both dates conformed closely to the new model tables. In life tables for the two female populations with the highest e_0 in the early 1990s (Japan and Sweden) the proportion surviving from zero to ages 1, 5, 10, 15, . . . 100 matches the proportion at one level in the new model tables extremely closely. In the Swedish table for 1989–93, the interpolated model level for survival to ages zero to 100 lies between 25.0 and 25.6. The conformity of the female life table for Japan in 1992 to the new model tables is even tighter: the interpolated level at each age from 1.0 to 100 is either 25.8 or 25.9. Populations with different customs and health systems, as they gradually attain very low mortality, have life tables very much like the new models with life expectancy above 80 years. If these populations are approaching a lower limit of death rates, these rates are likely to match the new model with e_0 of about 85, rather than a rectangular survival schedule.

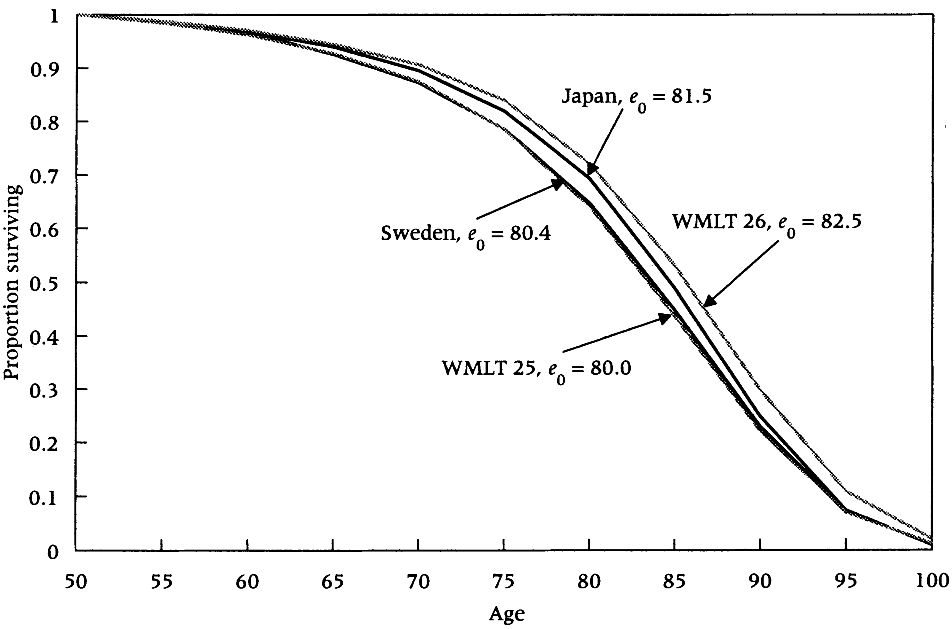
The fact that there is only one set of new model tables at an e_0 of 80 years and higher supports the conjecture that if there is a schedule of mini-

FIGURE 3 Female survival curves above age 50 (l_x/l_{50}) in Sweden compared with the new model life tables



NOTE: WMLT = West model life table.

FIGURE 4 Proportion of females surviving from age 50 to higher ages according to very low mortality life tables for 1990



NOTE: WMLT = West model life table at level specified.

mum death rates at an e_0 of about 85 years, very nearly the same minimum schedule is in store for different populations.

Summary and comments

In populations with the lowest mortality levels reliably recorded (expectation of life at birth over 80 years) the survival rates above age 50 for females are very similar to one another in age structure and closely match the new set of Princeton model life tables. The negative linear relation between the expectation of life at birth and its annual change that was used to project mortality in Mexico from 1955 to 1985 also fits the change in female e_0 for different dates from the 1950s to the early 1980s in a number of countries with high-quality data on mortality. The extension of this straight line until the rate of change is zero implies that female mortality may not continue to decline when e_0 reaches between 84 and 85 years.

Male mortality at the lowest recorded rates does not fall in as regular a pattern as female mortality. It was noted when the first revision of the regional model life tables was undertaken that the intercorrelations between death rates at young adult ages and older ages was systematically lower for males than for females. The source of the lower correlations was a tendency for higher recent male mortality at later adult ages than would be predicted by regressions based on data for early in this century. In other words, mortality for older males was not declining as much as would be expected from the declines for younger males, and from the former association among the mortality rates in these subgroups. Preston showed that the excess mortality for older males in different populations was very closely linked to the per capita consumption of cigarettes (Preston 1970). Hence in the new model tables the death rates for males at very high ages were not estimated independently, but were derived on an assumption of calculable ratios of male-to-female mortality rates within higher age intervals. Thus the upper asymptote for male e_0 is less than 79 years, but the estimate is more uncertain than the asymptote for female mortality.

The irregularity of male mortality rates that has been traced in large part to cigarette smoking implies a qualification of the designation of 84 or 85 years as the likely maximum to be attained by females. When the heavy smokers now in some younger female cohorts reach very old ages, mortality rates may increase. The maximum of nearly 85 years for females represents what might be attainable in the most favorable environment, including optimal health care, rather than what will happen in Sweden or Japan in the next 50 years.

References

Coale, Ansley J. and Edgar M. Hoover. 1958. *Population Growth and Economic Development in Low-Income Countries*. Princeton: Princeton University Press.

Coale, Ansley J. and Paul Demeny with Barbara Vaughan. 1983. *Regional Model Life Tables and Stable Populations*, Second Edition. New York: Academic Press.

Coale, Ansley J. and Ellen Eliason Kisker. 1986. "Mortality crossovers: Reality or bad data?" *Population Studies* 40: 389–401.

Coale, Ansley and Guang Guo. 1989. "Revised regional model life tables at very low levels of mortality," *Population Index* 55, no. 4: 613–643.

———. 1991. "The use of new model life tables at very low mortality in population projects," *Population Bulletin of the United Nations*, No. 30: 1–22.

Fries, James F. 1980. "Aging, natural death, and the compression of morbidity," *New England Journal of Medicine* 303: 130–135.

———. 1989. "The compression of morbidity: Near or far?" *Milbank Quarterly* 67, no. 2: 208–232.

Horiuchi, Shiro and Ansley J. Coale. 1990. "Age patterns of mortality for older women: An analysis using the age-specific rate of mortality change with age," *Mathematical Population Studies* 2: 245–267.

Manton, Kenneth G. and Burton Singer. 1994. "What's the fuss about compression of mortality?" *Chance* 7.

Manton, Kenneth G., and H. Dennis Tolley. 1991. "Rectangularization of the survival curve: Implications of an ill-posed question," *Journal of Aging and Health* 3: 172–193.

Myers, George C., and Kenneth G. Manton. 1984a. "Compression of mortality: Myth or reality?" *The Gerontologist* 24: 346–353.

———. 1984b. "Recent changes in the U.S. age at death distribution: Further observations," *The Gerontologist* 24: 572–575.

Preston, Samuel H. 1970. *Older Male Mortality and Cigarette Smoking*. Berkeley Institute of International Studies.

———. 1992. "Cohort succession and the future of the oldest old," in Richard M. Suzman, David P. Willis, and Kenneth G. Manton (eds.), *The Oldest Old*. New York: Oxford University Press.

Wilmoth, John R. 1995. "Are mortality rates falling at extremely high ages? An investigation based on a model proposed by Coale and Kisker," *Population Studies* 49: 281–295.

———, J. W. Curtsinger, and S. Horiuchi. 1995. "Rectangularization revisited: Survival curves for humans and fruit flies," paper presented at the Annual Meeting of the Population Association of America, San Francisco.

United Nations. 1991. *World Population Prospects 1990*. Population Studies No. 120. New York.