February 28, 2006

A DECOMPOSITION OF LIFE EXPECTANCY LEVELS AND TRENDS

John Bongaarts
Population Council
New York

Correspondence:
John Bongaarts
Population Council
1 Dag Hammarskjold Plaza
New York, NY, 10017
jbongaarts@popcouncil.org

Abstract:
Since 1800 life expectancy at birth has doubled from about 40 to near 80 years in high income countries. Pessimists expect these improvements to end soon because we are approaching biological limits, but optimists predict continued rapid improvements with no limits. To shed light on this controversy, past trends in the juvenile, background and senescent components of life expectancy are examined in 16 high income countries. Large increases in conventional life expectancy before 1950 are found to be primarily attributable to reductions in juvenile and background mortality. After 1950 the rate of improvement in life expectancy slowed because declines in juvenile and background mortality slowed, but senescent mortality fell more rapidly than before, thus becoming the main cause of rising life expectancy at birth. The role of smoking in the past half century is also quantified. In the future, background mortality and juvenile mortality will have little or no impact on longevity because they have reached very low levels. There is however no evidence of approaching limits and life expectancy will likely improve at a rate of approximately 1.5 years per decade due to continued declines in senescent mortality.

One of the most notable achievements of modern societies is a large rise in human longevity. Since 1800 life expectancy at birth has doubled from about 40 to near 80 years. The causes of this massive decline in mortality include improvements in standards of living, nutrition and education, the implementation of wide-ranging public health measures and more effective and accessible medical care (Riley, 2001). Recent mortality trends are well established, but there is considerable disagreement among demographers and biologists about what lies ahead. Pessimists believe we are approaching limits to life expectancy while optimists expect continued rapid improvements with no limits. Much is at stake: improvements in longevity are a key cause of skyrocketing costs of pensions and healthcare for the elderly.

After a brief review of the controversy about future trends, this study examines past trends in the components of life expectancy at birth. The projection of these components can provide the basis for assessing plausible future trends in longevity. The focus throughout will be on high-income countries with low levels of mortality.

Background: From pessimism to optimism

Reliable historical estimates of mortality are available for a small number of countries. Figure 1a plots past estimates of life expectancy at birth for females in 16 high-income countries: Austria, Belgium, Canada, Denmark, England and Wales, Finland, France, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, USA (Human mortality database, 2005).[1] The longest plotted time series start in 1850 and end in 2000 and the shortest are from 1950 to 2000. Trends for male life expectancy at birth in Figure 1b are broadly similar, although males live, on average, a few years less than females. In all sixteen countries large increases in life expectancy occurred. The only significant interruptions in this overall upward trend are attributable to the global influenza epidemic in 1918-1919 and two World Wars. Differences between these countries have narrowed considerably over time, leaving most countries today with life expectancies close to the average for the group, regardless of historical patterns. In recent decades, countries have moved in tandem within a narrow range to reach an average in 2000 of 81.5 years for females and 75.8 for males. This remarkable convergence is presumably due to a reduction in disparities among countries in standards of living, nutrition and public health measures, and increasingly rapid diffusion of advances in medical treatment, drug therapy and life style among countries. Another notable development evident in Figure 1 is that the pace of improvement in female life expectancy is less rapid in recent decades than in the century before the 1950s and male life expectancy stalled in the 1950s and 1960s. The future implications of these recent trends are the subject of a contentious debate.

Pessimists believe that future life expectancy has an upper limit of about 85 years and they provide biological and demographic evidence in support of this view (Fries 1980; Olshansky et. al. 1990). The biological argument considers mortality after the reproductive ages to be beyond the reach of Darwinian forces of natural selection. As a result, an "intrinsic" biologically determined age pattern of senescent mortality is said to exist which rises steeply with age after about age 30 in humans. This pattern is "expected to remain invariant unless the genome itself is modified" (p.252, Carnes et al. 1996). The pessimists' demographic argument claims that improvements in life expectancy at birth can only result from declines in "premature" mortality among children and young adults. In contrast, senescent mortality at older ages is considered largely immutable, because at the end of the natural lifespan "everything comes apart at once and repair is impossible" (p.135, Fries, 1980).

Up to the 1980s this pessimistic perspective was accepted by many demographers. For example, Bourgeois-Pichat (1978) proposed "biological" limits for life expectancy of 80.3 years for females and 73.8 years for males. Population projections prepared by the United Nations at various times from the 1950s to the 1980s included a maximum. This pessimism led to the consistent underestimation of future improvements in longevity in projections made before the 1990s (Keilman, 1997).

Several developments during the 1990s led to the demise of this pessimism. First, many proposed past limits to life expectancy were broken, often soon after they were introduced (Oeppen and Vaupel, 2002). This continuous need for an upward revision of supposedly fixed limits is most clearly evident in the past record of the UN projections, which raised their maximum life expectancy several times before the mid-1980s. The more recent UN projections have abandoned the practice of imposing limits. Second, age specific death rates at the oldest ages show no evidence of leveling off. On the contrary, these rates exhibit steady declines (Lee and Carter, 1992; Kannisto et al. 1994). Third, the pace of improvement in old age mortality shows no relationship to the level of old age mortality (Wilmoth, 1997). If limits exist, one would expect countries close to the limit to experience smaller and slower improvements than countries that are farther from the limit. Finally, the claim that mortality at the oldest ages is not subject to the forces of natural selection is being questioned (Lee, 2003). Moreover, it is doubtful that a biological argument can contribute insight into the potential future impact of medical interventions, even if it explains the exponential rise with age in post reproductive age mortality.

In their recent writing, the pessimists seem to have made a concession. Instead of being immutable, the limits to life span are now referred to as "a mortality schedule, that *in the absence of medical improvements* cannot further be reduced" (italics added, p.505, Olshanski, et. al. 2002). Any such improvements "manufacture survival time by saving the lives of people who would otherwise die" (p. 505). This language represents a significant change in position, or at least in the position as interpreted by many readers of the earlier work of Olshansky and his colleagues. It is quite possible, indeed likely, that most improvements in mortality at older ages in the future will be "manufactured" through medical interventions, but if that is the case the net result will still be a life expectancy beyond the proposed limits of about 85 years. As noted by Wilmoth (2001), the difference of opinion between Olshansky and Carnes, and other demographers about likely future trends in life expectancy now appears to be smaller than is widely presumed.

A recent panel report of the National Research Council concludes that if any limits exist, they are far above current levels, and that projections therefore should not impose ceilings (National Research Council, 2000). This view is now widely held in the demographic community. There is, however, no agreement about most plausible future trends. Optimists such as Oeppen and Vaupel (2002) observe that best-practice life expectancy has increased by 2.5 years per decade for the past century and a half and they conclude that a "reasonable scenario" would be for this trend to continue in future decades. Manton et al. (1991) also anticipate much higher levels of life expectancy in the future, due to the development of interventions to address chronic disease at advanced ages. This view is not shared by most national and international agencies that are responsible for preparing official country projections. Their projections are considerably more conservative even if they do not impose limits. For example, projections for the next half century made by the UN in 2004 (without a life span limit), expect female life expectancy in the US to increase at a rate of 1.1 years per decade (United Nations, 2005). Similarly, the US Social Security Administration assumes a rise in life expectancy of only 0.8 years per decade over the same period (Board of Trustees OASDI, 2005). These projected rates of future improvement are less than half the rate considered reasonable by Oeppen and Vaupel (2002). The question of what lies ahead is still unsettled.

Components of life expectancy levels and trends

The disagreement about future trends is in part attributable to different interpretations of past trends. To make progress it is therefore necessary to arrive at a better understanding of the past. To this end a procedure for decomposing life expectancy is proposed. This decomposition divides the level of life expectancy at a given point in time into three components which quantify the roles of juvenile, background and senescent mortality.

-*Juvenile mortality*. Past increases in life expectancy at birth (denoted LE) are in part due to declines in mortality at the youngest ages. For present purposes all mortality under age 25 will be considered "juvenile".[2] To quantify the role of juvenile mortality, a variant of the conventional life expectancy at birth is calculated. This variant, called "life expectancy without juvenile mortality" (denoted LE_J), equals the average age at death for a newborn as calculated with a mortality life table in which all newborns are assumed to survive to age 25. In more conventional demographic terminology LE_J equals life expectancy at age 25 plus 25. It is a measure of adult mortality over age 25.

-*Background mortality*. Past studies of age patterns of adult mortality have often distinguished between background and senescent mortality (Carnes and Olshansky, 1996; Gravilov and Gravilova, 1991; Horiuchi and Wilmoth, 1998; Makeham, 1860). The distinction between these two components of adult mortality is very useful for describing age patterns of death rates, and models using it provide an extremely good fit to empirical data (Bongaarts, 2005; Thatcher, 1999). The risks of some causes of death (e.g., cardiovascular disease and cancer) rise strongly with age and therefore are considered part of senescent mortality. Other causes of death do not show a strong age pattern (e.g., accidents, violence, and some infectious diseases) and they are considered part of background mortality which is assumed age invariant in the models. A complete mapping of causes of death to the background and senescent components is difficult and will not be attempted here. Instead, background mortality is estimated with an empirical method proposed by Bongaarts (2005). As shown next, this estimate permits the calculation of the contribution of background mortality to levels and trends in life expectancy.

-*Senescent mortality.* Senescent mortality rises rapidly with age due to the deterioration of physiological processes at the cellular and systemic levels. Estimates of senescent mortality by age are obtained by subtracting background mortality from the observed total death rate at each age. To summarize the resulting age pattern of senescent mortality, a third longevity measure called “senescent life expectancy” is introduced. Senescent life expectancy (denoted LE_S) is defined as the mean age at death for a newborn, on the assumption that all newborns survive to age 25 and are not subjected to background mortality. That is, LE_S equals the life expectancy obtained with a conventional life table in which senescent mortality is the only cause of death.

Once these three longevity measures LE, LE_J and LE_S are known, the roles of juvenile and background mortality are readily calculated. The effect of juvenile mortality on life expectancy (denoted J) is estimated as the difference between LE and LE_J :

$$J = LE_J - LE$$

and the role of background mortality is quantified as the difference between senescent life expectancy and life expectancy without juvenile mortality:

$$B = LE_S - LE_J$$

These measures lead to a simple equation for decomposing life expectancy:

$$LE = LE_S - B - J$$

The conventional life expectancy at any point in time equals senescent life expectancy minus the longevity reducing effects of background and juvenile mortality.

This equation for the components of the *level* of life expectancy, yields a similar decomposition for the *change* or trend in life expectancy at births between two successive points in time. The change in life expectancy at birth (ΔLE) equals the rise in senescent life expectancy (ΔLE_s) plus the background mortality effect (ΔB) plus the juvenile mortality effect (ΔJ):

$$\Delta LE=\Delta LE_s +\Delta B+\Delta J$$

In this decomposition model changes in the components between times t_1 and t_2 are estimated as $\Delta LE=LE(t_2)-LE(t_1)$, $\Delta LE_s=LE_s(t_2)-LE_s(t_1)$,$\Delta B=B(t_1)-B(t_2)$ and $\Delta J=J(t_1)-J(t_2)$.

Decomposition results: 1850-2000

The longevity measures LE, LE_J and LE_S were calculated for each of the 16 countries for all available years, separately for females and males. Only a partial summary of the voluminous results can be provided here. The focus will be on average trends for females in the five countries with records from 1850 to 2000: Denmark, England and Wales, Netherlands, Norway, and Sweden. Results for males will be included in the figures but will not be discussed in detail.

Figure 2a plots average estimates for females for this subset of five countries from 1850 to 2000 and Table 1 presents results for selected years. Over this period the following changes occurred:

-Life expectancy (LE) from 45.7 to 80.7 years (+35)

-Life expectancy without juvenile mortality (LE_J) from 63.9 to 81.4 years (+17.5)

-Senescent life expectancy (LE_S) from 72.3 to 81.7 years (+9.4)

In 1850 senescent life expectancy exceeded life expectancy at birth by 26.6 years (72.3 vs. 45.7), but by 2000 the difference had narrowed to just 1 year (81.7 vs. 80.7). The cause of this convergence is a large secular decline of juvenile and background mortality to very low levels. As shown in Figures 3 and 4, the effect of juvenile mortality declined from 18.2 to 0.6 years (-17.5) and the background mortality effect declined from 8.4 to just 0.3 years (-8.1).

Life expectancy at birth rose by 35 years between 1850 and 2000. This change can be expressed as the sum of the effects of changes in senescent life expectancy (ΔLE = 9.4 years), background mortality (ΔB =8.1 years) and juvenile mortality (ΔJ =17.5 years): 35 = 9.4 + 8.1 + 17.5. These effects changed considerably over time. Figure 5 presents a decomposition of trends for the periods 1850-1900, 1900-1950 and 1950-2000. Life expectancy at birth rose more rapidly between 1900 and 1950 (+20.1 years) than in the period 1850-1900 (+6.4 years) or 1950-2000 (+8.5 years). The large increase in conventional life expectancy before 1950 was primarily attributable to reductions in juvenile and background mortality. After 1950 the rate of improvement in life expectancy slowed because improvements in juvenile and background mortality slowed, but the pace of increase in senescent life expectancy rose. Between 1950 and 2000, the rise in female senescent life expectancy of 5.6 years actually became the dominant cause of the rise in life expectancy of 8.5 years.

A plausible explanation for the recent acceleration of the improvement in senescent life expectancy is that medical treatment became more effective around the middle of the twentieth century with the widespread use of antibiotics and the ability to treat cardiovascular and other chronic diseases (Costa, 2005; Crimmins, 1981; Riley, 2001). Apparently, the factors that brought about massive declines in juvenile and background mortality before 1950 (i.e., improvements in standards of living and nutrition, and the introduction of public health measures), had only little impact on senescent mortality.

Gender differences in senescent life expectancy and the role of smoking: 1950-2000

Aside from the well-established fact that longevity is slightly shorter for males than for females, the long-range trend in senescent life expectancy for males is broadly similar to that for females. As was the case for females, male LE_s increased little before 1950 but accelerated in recent decades (see Figure 2 and Table 1). The main difference between sexes is that male LE_S stagnated during the 1950s and 1960s while improvement continued for females.

A plausible partial explanation for the stalling of male life expectancy in the 1950s and 1960s is smoking behavior (Pampel, 2002; Peto et al., 1994). Cigarette smoking rose substantially in the first half of the 20th century and the resulting excess mortality was observed after a delay of a few decades. Figure 6 plots the proportion of all deaths attributed to smoking by sex for the developed world (Peto et al. forthcoming). This proportion is much higher for males than for females, reflecting the earlier adoption and higher prevalence of smoking among males. The smoking impact among males peaked in 1990 at 25 percent of all deaths. The subsequent decline is the delayed mortality response to the decline in smoking among males that followed the discovery of the link between smoking and lung cancer in the 1960s. In contrast, female proportion of death due to smoking rises steadily. As a result, smoking is the main reason for the widening of sex differentials in mortality in the middle of the 20th century and for the subsequent narrowing of this differential in recent years (Pampel, 2002).

The impact of smoking on life expectancy can be estimated by using the age and sex specific proportion of death attributed to smoking from Peto et al. (forthcoming). The removal of smoking mortality from the life table calculations results in a variant of senescent life expectancy which will be called "senescent life expectancy without smoking" and denoted LE_{NS}. The difference between senescent life expectancy with and without smoking equals the smoking effect, S:

$$S = LE_{NS} - LE_S$$

Figure 7 and Table 2 present average values of LE_{NS} and LE_S and the smoking effects for all 16 countries used in this study and for males and females. The smoking effect varies over time and differs between sexes. For males it averages 1.1 years in 1950, rises to a peak of 3.0 in 1980 and 1985, and declines slightly to 2.4 years in 2000. For females the effect is very small in 1950 but rises steadily to 1.0 years by 2000. Without the smoking effect males still have lower life expectancy than females but the difference has narrowed at every point in time. Country specific estimates of LE_{NS}, LE_S and S in 1950 and 2000 are presented in Table 3. These results will not be discussed here but Peto et al. (forthcoming) present a review of smoking mortality levels and trends in developed countries.

The removal of the smoking effect changes the trend in average senescent life expectancy between 1950 and 2000. Without smoking, LE_{NS} rises by an average of 6.9 years for males (from 73.3 to 80.2 years) and by a slightly higher amount, 8.2 years, for females (from 75.6 to 83.8 years). These increases are larger than with smoking for females (7.2 instead of 8.2 years) and in particular for males (5.6 instead of 6.9 years). The trend in male senescent life expectancy without smoking is more linear than with smoking and it is broadly similar to that for females. The stall in the 1950s and 1960s in male LE_S has disappeared.

Figure 8 compares male and female senescent life expectancy without smoking for each of the 16 high income countries from 1950 to 2000. In contrast to trends in life expectancy, these trends are roughly linear for both sexes. Differences among countries are remarkably small: the standard deviation for males and females are both just 1.0 year in 2000. The steady pace of increase and the similarity of trends for males and females makes this longevity indicator more suitable for making projections than conventional life expectancy.

Conclusion

Life expectancy has risen in the past due to declines in juvenile, background and senescent mortality. The steady upward trend in senescent life expectancy in recent decades confirms the optimists' view that there is no evidence of approaching limits to longevity. However, the pace of this improvement has been below the optimistic estimate of 0.25 per year by Oeppen and Vaupel (2002). After trends in juvenile, background and smoking mortality are removed, the average rate of increase in senescent life expectancy over the past 50 years was 0.15 years per year (male-female average). Since senescent life expectancy has increased almost linearly since 1950 it is plausible to assume that this trend will continue for a few more decades. This implies that life expectancy is likely to increase by an average of about 7.5 years over the next fifty years, plus any—probably minor—effects of further declines in juvenile, background and smoking mortality. There is no reason to believe that advances in biotechnology, preventive and curative medicine and drug treatment will be less effective in reducing senescent mortality in the future than in the past.

The pessimists are correct in their claim that past life expectancy improvements are largely driven by non-repeatable reductions in mortality among children and young adults. Declines in juvenile and background mortality indeed have reached such low levels that they can make little or no contribution to further increases in longevity. This is one of the main reasons why life expectancy rose more slowly in recent decades than in the century before 1950. However, declines in senescent mortality, which were minimal before 1950, have been substantial since then, and they should result in continuous advances in life expectancy in future decades.

Endnotes

1. This database provides mortality estimates for a number of Eastern Europe countries, but these are not included in this study, because this region has experienced recent fluctuations in mortality from extraordinary social, economic and political changes. West Germany was also excluded because its time series starts in 1956. Estimates for the US before 1959 are taken from the Berkeley Mortality Databank. In a few countries, estimates for 2000 were taken from OECD (2005), because the database information ended in 1999 or 1998.

2) The selection of age 25 as the upper age for this component insures that juvenile mortality includes the slightly elevated mortality observed in the late teens and early twenties, much of which is attributable to accidents and violence.

References

Berkeley Mortality Database, 2002. Data downloaded from www. demog.Berkeley.edu in January 2002.

Board of trustees of OASDI trust funds. 2005. "The 2005 annual report of the board of trustees of the federal old-age and survivors insurance and disability insurance trust funds." U.S. government printing office. Washington: 2005.

Bongaarts John. 2005. "Long-range trends in adult mortality: Models and projection methods," *Demography* 42(1): 23–49.

Costa, Dora, L. 2005. "Causes of improving health and longevity at older ages: a review of the explanations," *Genus* 61(1): 21-38.

Bourgeois-Pichat, Jean. 1978. "Future outlook for mortality decline in the world," *Population Bulletin of the United Nations*. 11: 12-41.

Crimmins, Eileen. 1981. "The changing pattern of American mortality decline, 1940-1977, and its implications for the future," *Population and Development Review* 7(2): 229-254.

Carnes, Bruce, S. Jay Olshansky and Douglas Grahn. 1996. "Continuing the search for a law of mortality," *Population and Development Review*, 22(2): 231-264.

Fries, James F., M.D. 1980. "Aging, natural death, and the compression of morbidity," *The New England Journal of Medicine*. 303(3): 130-135.

Gavrilov, Leonid A. and Natalia S. Gavrilova. 1991. *The Biology of Life Span: A Quantitative Approach*. V.P. Skulachev (ed.). Chur, Switzerland: Harwood Academic Publishers.

Horiuchi, S. and J.R. Wilmoth. 1998. "Deceleration in the age pattern of mortality at older ages," *Demography* 35 (4): 391-412.

Human mortality database, 2005. Data downloaded from www. mortality.org in July 2005.

Kannisto, Vaino, Jens Lauritsen, A. Roger Thatcher, and James W. Vaupel. 1994. "Reductions in mortality at advanced ages: Several decades of evidence from 27 countries." *Population and Development Review*, 20(4) (Dec.), 793-810.

Keilman, N. 1997. "Ex-post errors in official population forecasts in industrialized countries." *Journal of Official Statistics* (Statistics Sweden) 13: 245-277.

Keyfitz, N. 1991. "Experiments in the projection of mortality." *Canadian Studies in Population* 18(2): 1-17.

Lee, Ronald D. and Lawrence R. Carter. 1992. "Modeling and forecasting U.S. mortality." *Journal of the American Statistical Association,* 87(419): 659-671.

Lee, Ronald D. 2000. "Long-term population projections and the US Social Security System," *Population and Development Review*, 26 (1): 137–143.

Lee, Ronald. 2003. "Rethinking the evolutionary theory of aging: Transfers, not births, shape senescence in social species," *Proceedings of the National Academy of Sciences,* 100 (16): 9637-9642

Makeham. W.M. 1860. "On the law of mortality and the construction of annuity tables," *Journal of the Institute of Actuaries*. 6:301-310.

Manton, Kenneth, Eric Stallard and Dennis Tolley. 1991. "Limits to human life expectancy: Evidence, prospects and implications," *Population and Development Review.*17(4): 603-637.

National Research Council. 2000. *Beyond Six Billion*. J. Bongaarts and R. Bulatao, editors. Washington DC: National Research Council.

OECD. 2005. *OECD Health Data*, June 2005. Estimates of life expectancy for 2000 downloaded from OECD database www.oecd.org/document/16/0,2340,en_2825_495642_2085200_1_1_1_1,00.html

Olshansky, S. Jay, Bruce A. Carnes, and Christine Cassel. 1990. "In search of Methusaleh: Estimating the upper limits to human longevity," *Science* 250**,** pp. 634-640.

Olshansky, S. Jay and Bruce A. Carnes. 2001. *The Quest for Immortality: Science at the Frontiers of Aging.* New York: Norton

Olshansky, S. Jay, Bruce A. Carnes, and Jacob Brody. 2002. "A biographic interpretation of life span," *Population and Development Review*, 28(3):501-513.

Oeppen, Jim and James Vaupel. 2002. "Broken limits to life expectancy" *Science* , 296: 1029-1031.

Pampel, Fred C. 2002. "Cigarette use and the narrowing sex differential in mortality," *Population and Development Review,*28(1): 77-104.

Peto, R. et al. 1994. *Mortality from smoking in developed countries 1950-2000*. Oxford: Oxford University Press.

Peto, R. et al. forthcoming. *Mortality from smoking in developed countries 1950-2000*. Oxford: Oxford University Press. (data available at http://rum.ctsu.ox.ac.uk/~tobacco/)

Pollard, J.H. 1987. "Projection of age-specific mortality rates." *Population Bulletin of the United Nations*. Nos. 21-22. New York: United Nations. Pp. 55-69.

Riley, James. 2001. *Rising life expectancy: A global history.* New York: Cambridge.

Siegel, Jacob S. [*NIH Publ. 80-969* (National Institutes of Health, Bethesda, MD, 1980), pp. 17-82].

Thatcher, A. R. 1999. "The long-term pattern of adult mortality and the highest attained age." *Journal of the Royal Statistical Society* 162 Part 1, pp. 5-43.

Tabeau, E., A. Jeths, and C. Heathcote. 2001. *Forecasting Mortality in Developed Countries.* Dordrecht, the Netherlands: Kluwer Academic Publishers.

Technical Panel on Assumptions and Methods. 2003. Report to the Social Security Advisory Board, Washington DC. www.ssab.gov/documents/2003TechnicalPanelRept_000.pdf

Tuljapurkar, S., N. Li, and C. Boe. 2000. "A universal pattern of mortality decline in the G7 Countries." *Nature* 405: 789-792 (letter).

Wilmoth, John R. 1997. "In search of limits." In Kenneth W. Wachter and Caleb E. Finch (eds.), *Between Zeus and the Salmon: The Biodemography of Longevity*. Committee on Population, National Research Council. Wash. DC: National Academy Press, pp. 38-64.

Wilmoth, John R. 2001. "How long can we live?" A review essay. *Population and Development Review*, 27(4): 791-800.

Wilmoth, John R. 2005. "Some methodological issues in mortality projection, based on an analysis of the U.S. social security system." *Genus* 61(1):179-212.

Kevin M. White. 2002. "Longevity advances in high-income countries, 1955-96" *Population and Development Review*, 28,(1): 59-76

United Nations. 1958. *The Future Growth of World Population*. Population Studies, no. 28. New York: United Nations.

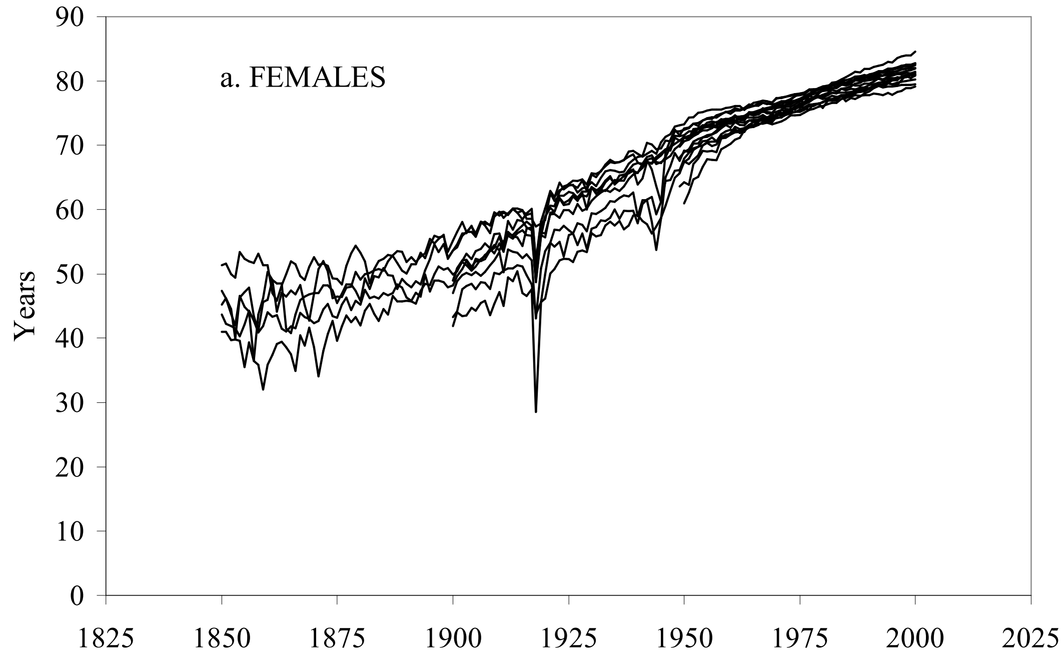
United Nations. 2005. *World Population Prospects: The 2004 Revision.* New York: United Nations.

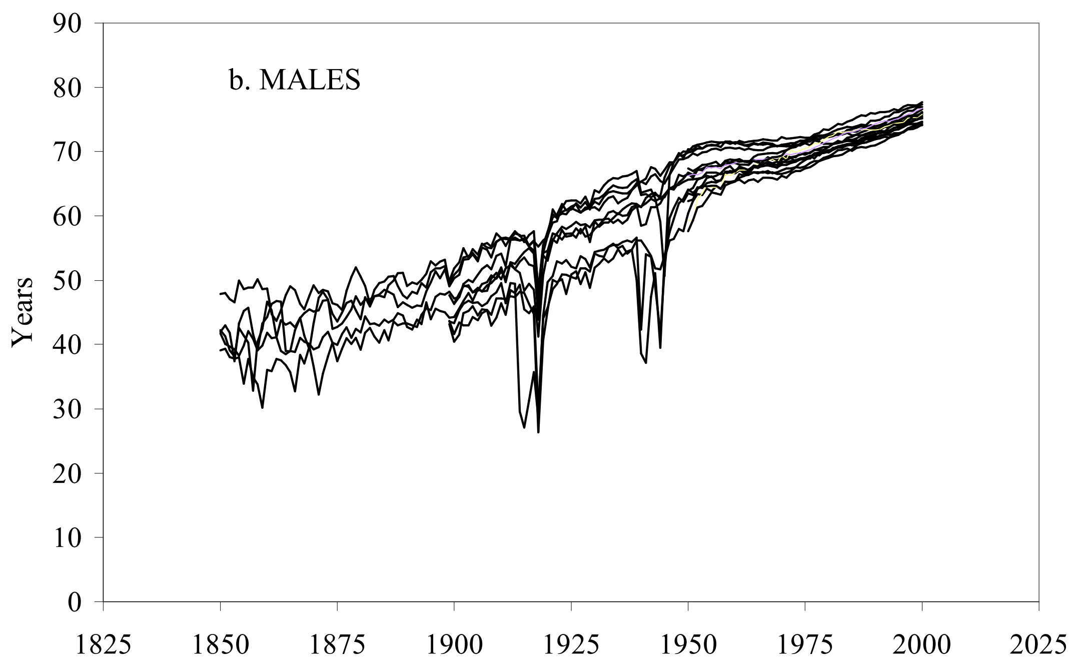
Vaupel, James W. 1986. "How change in age-specific mortality rates affect life expectancy," *Population Studies* 40: 147-157

Acknowledgements:

This research was funded in part through NIA grant no. R03 AG024083-01A1. Paul Demeny and Griffith Feeney provided helpful comments on an earlier version of this paper

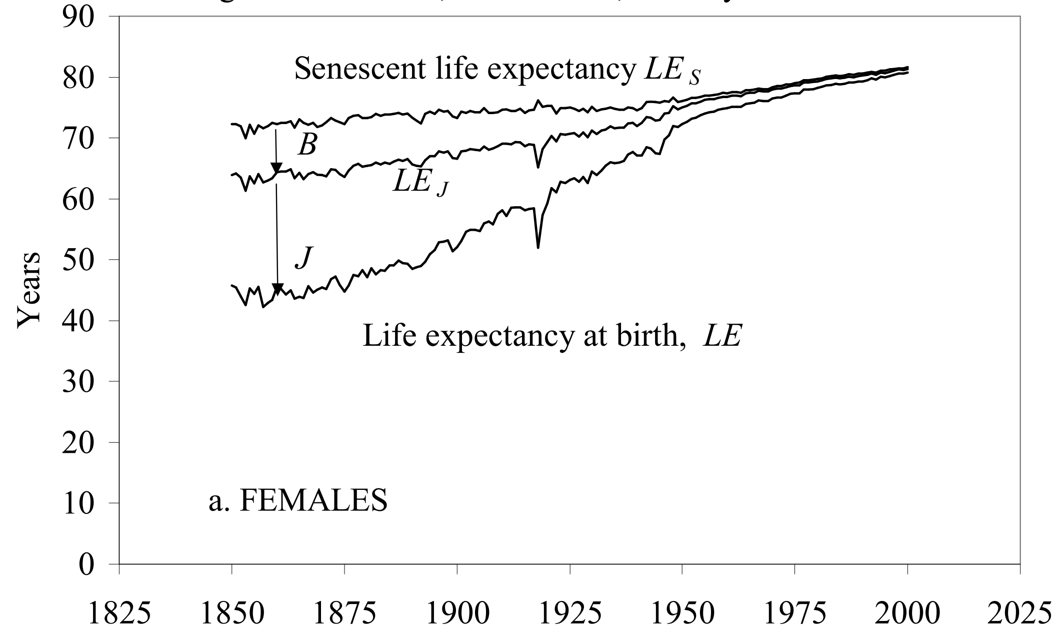
Figure 1: Life expectancy at birth in 16 high income countries

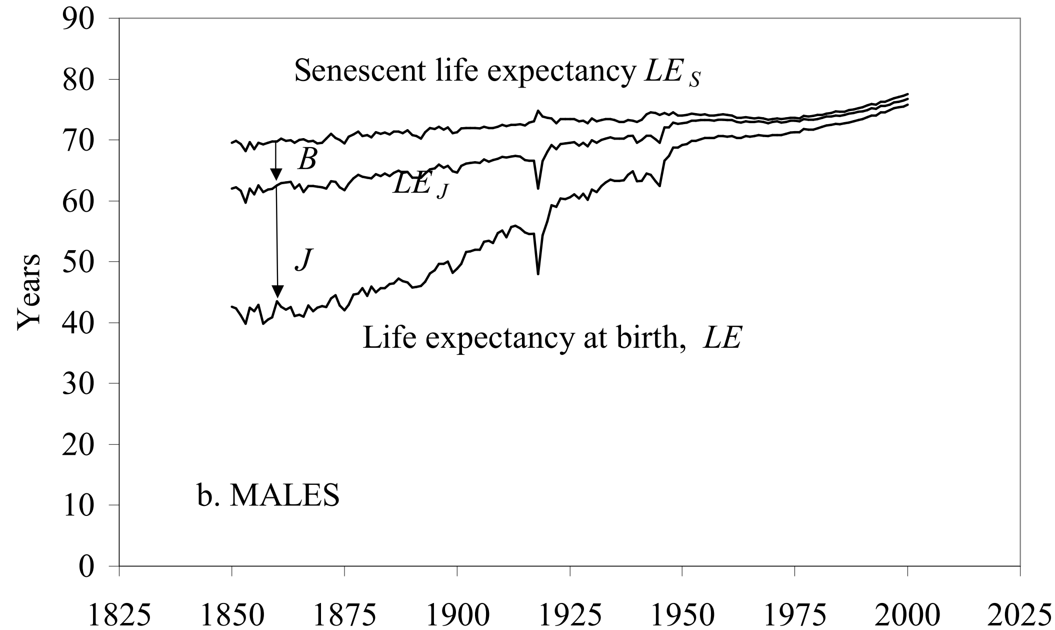




Source: Human Mortality Database (2005)

Figure 2: Three longevity measures, 1850-2000, averages for Denmark, England and Wales, Netherlands, Norway and Sweden.





Source: Human Mortality Database (2005) and estimates by author.

Figure 3: Juvenile mortality effect on life expectancy, averages for Denmark, England and Wales, Netherlands, Norway and Sweden

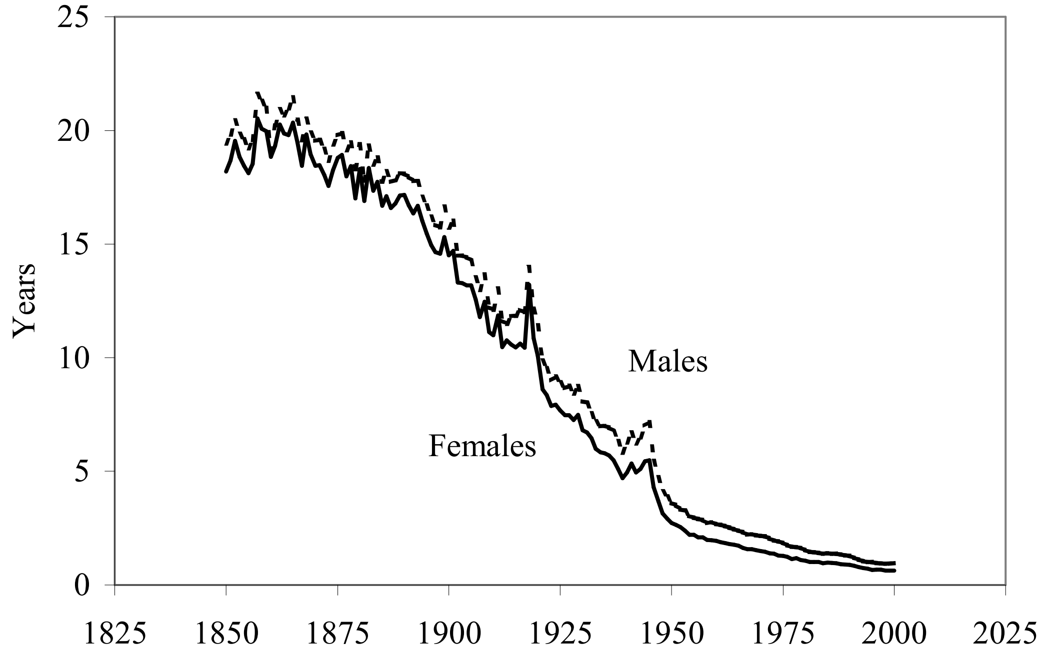
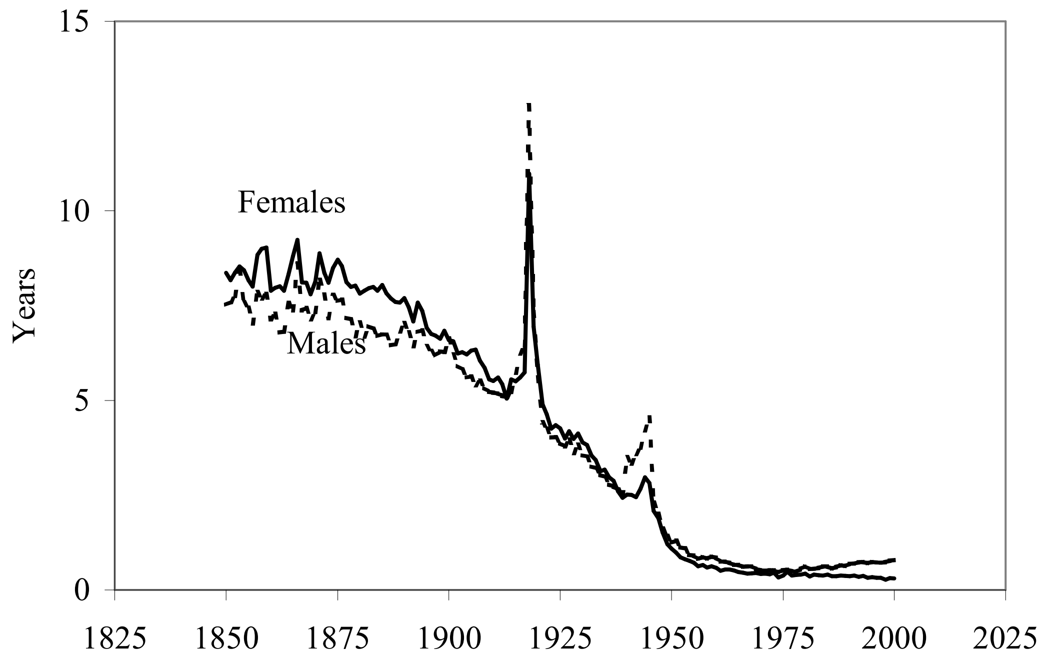


Figure 4: Background mortality effect on life expectancy, averages for Denmark, England and Wales, Netherlands, Norway and Sweden



Source: Human Mortality Database (2005) and estimates by author.

Figure 5: Decomposition of changes in life expectancy at birth
1850-1900, 1900-1950 and 1950-2000

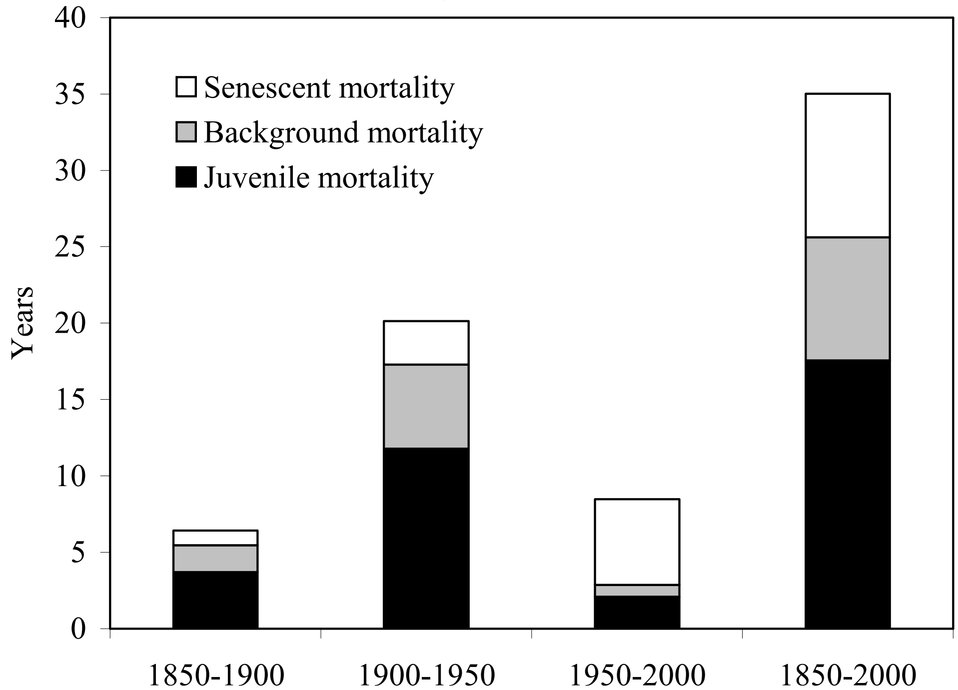
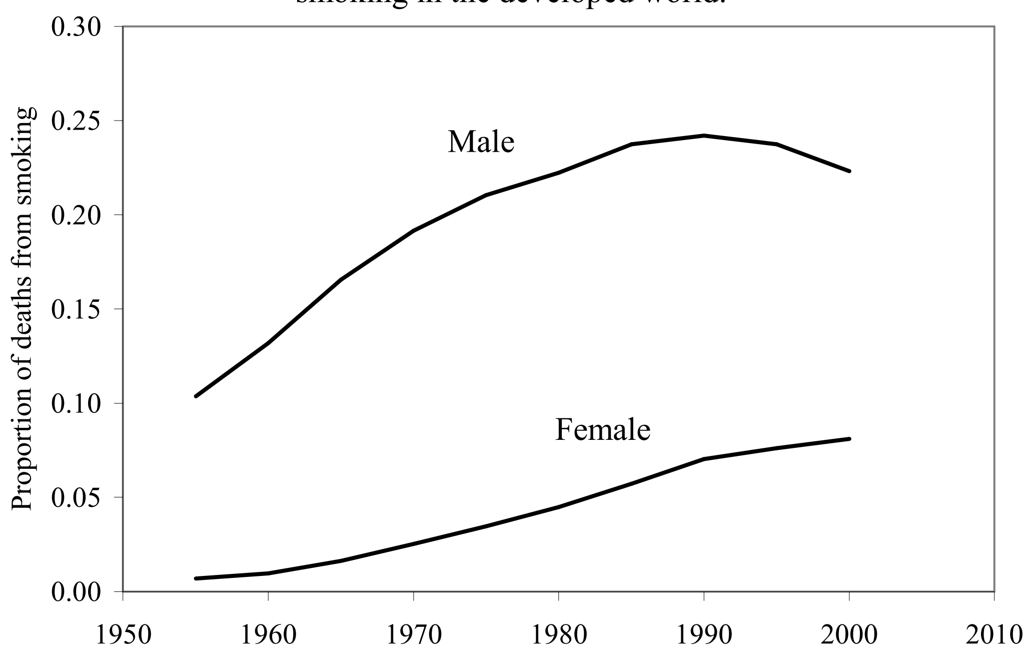


Figure 6: Proportion of all deaths attributed to
smoking in the developed world.



Source: Peto et al. (2005)

Figure 7: Senescent life expectancy with and without smoking, average 16 countries

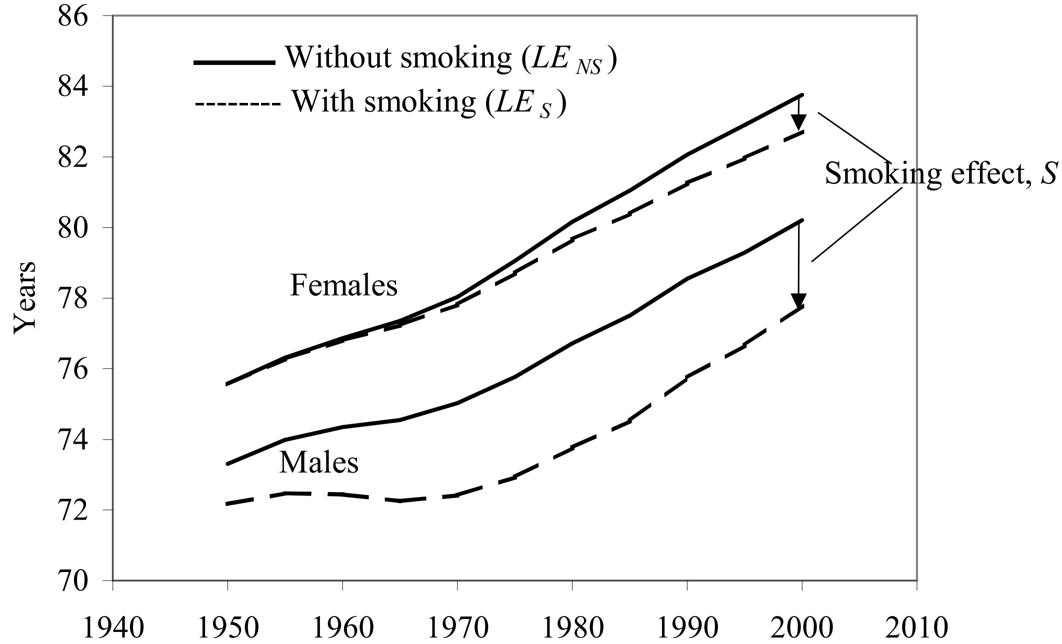


Figure 8: Senescent life expectancy without smoking in 16 countries

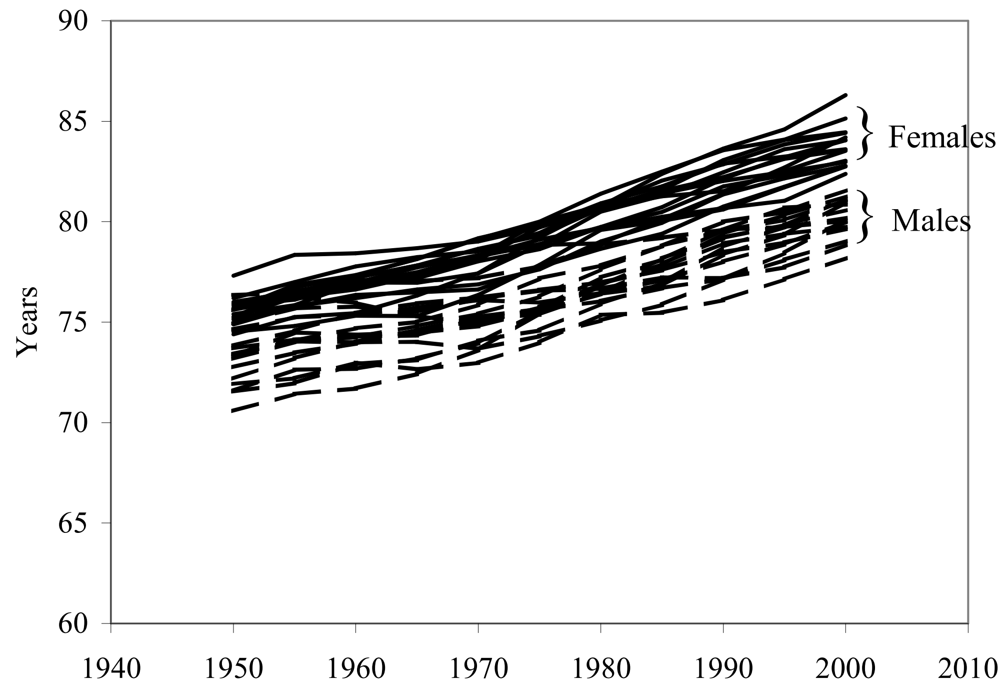


Table 1: Estimates of life expectancy at birth, life expectancy without juvenile mortality and senescent life expectancy, averages for Denmark, England and Wales, Netherlands, Norway and Sweden, 1850-2000

	Year				Trend			
FEMALES	1850	1900	1950	2000	1850-1900	1900-1950	1950-2000	1850-2000
Life expectancy at birth, *LE*	45.7	52.1	72.2	80.7	6.4	20.1	8.5	35.0
LE without juvenile mortality, LE_J	63.9	66.6	75.0	81.4	2.7	8.3	6.4	17.5
Senescent life expectancy, LE_S	72.3	73.2	76.0	81.7	1.0	2.8	5.6	9.4
Juvenile mortality effect, *J*	18.2	14.5	2.7	0.6	-3.7	-11.8	-2.1	-17.5
Background mortality effect, *B*	8.4	6.6	1.1	0.3	-1.8	-5.5	-0.8	-8.1
MALES								
Life expectancy at birth, *LE*	42.6	48.9	69.1	75.8	6.3	20.3	6.7	33.2
LE without juvenile mortality, LE_J	62.0	64.6	72.8	76.8	2.6	8.1	4.0	14.8
Senescent life expectancy, LE_S	69.5	71.2	74.0	77.6	1.7	2.8	3.5	8.0
Juvenile mortality effect, *J*	19.4	15.7	3.6	1.0	-3.7	-12.1	-2.6	-18.5
Background mortality effect, *B*	7.5	6.6	1.2	0.8	-0.9	-5.4	-0.5	-6.7

Table 2: Senescent life expectancy, with and without smoking, average 16 countries, 1950-2000

	1950	2000	1950-2000
FEMALES			
With smoking (LE_S)	75.6	82.7	7.2
Without smoking (LE_{NS})	75.6	83.8	8.2
Smoking effect (*S*)	0.0	1.0	
MALES			
With smoking (LE_S)	72.2	77.8	5.6
Without smoking (LE_{NS})	73.3	80.2	6.9
Smoking effect (*S*)	1.1	2.4	

Table 3: Senescent life expectancy without smoking effect, 1950 and 2000, 16 countries						
	Senescent life exp. no smoking LE_{NS}			Smoking effect (*S*)		
FEMALES	1950	2000	1950-2000	1950	2000	1950-2000
Austria	74.9	82.8	7.9	0.1	0.5	0.4
Belgium	75.1	82.8	7.7	0.0	0.5	0.5
Canada	75.6	85.1	9.5	0.0	2.1	2.1
Denmark	75.3	82.4	7.1	0.0	2.4	2.4
England	76.0	83.0	7.0	0.3	1.8	1.5
Finland	74.5	82.7	8.2	0.0	0.4	0.4
France	75.9	84.5	8.5	0.0	0.3	0.3
Italy	75.9	84.1	8.1	0.0	0.5	0.5
Japan	74.4	86.3	11.9	0.0	0.5	0.5
Netherlands	76.2	83.0	6.8	0.0	1.1	1.1
New Zealand	75.8	84.2	8.4	0.0	1.5	1.5
Norway	77.3	83.5	6.2	0.0	1.0	1.0
Spain	75.9	84.1	8.2	0.0	0.0	0.0
Sweden	75.7	83.6	7.9	0.0	0.8	0.8
Switzerland	75.4	84.4	9.0	0.0	0.5	0.5
USA	75.2	83.6	8.4	0.0	2.5	2.5
All	75.6	83.8	8.2	0.0	1.0	1.0
MALES						
Austria	73.4	79.0	5.6	2.5	2.2	-0.2
Belgium	72.8	80.6	7.8	1.6	3.7	2.1
Canada	73.2	81.6	8.4	0.9	2.7	1.7
Denmark	74.9	78.8	3.9	0.8	2.8	2.1
England	73.8	79.6	5.8	2.8	2.4	-0.4
Finland	71.9	78.2	6.3	2.5	1.9	-0.7
France	71.5	80.0	8.5	0.7	2.6	1.9
Italy	73.7	81.3	7.6	0.5	2.7	2.2
Japan	70.6	81.1	10.5	0.0	1.9	1.9
Netherlands	76.4	80.2	3.8	1.4	3.0	1.7
New Zealand	73.3	81.0	7.7	1.0	2.1	1.1
Norway	75.6	80.1	4.5	0.1	1.7	1.6
Spain	72.2	80.9	8.7	0.4	2.9	2.5
Sweden	74.6	80.0	5.4	0.3	1.1	0.8
Switzerland	73.4	81.1	7.7	1.4	1.9	0.6
USA	71.6	79.7	8.2	1.3	3.0	1.6
All	73.3	80.2	6.9	1.1	2.4	1.3