Limits to Human Longevity

SAMUEL H. PRESTON and HIRAM BELTRÁN-SÁNCHEZ

Abstract

Longevity has increased sharply in the past century and it is likely to continue increasing. Historical trends in maximum life expectancy at birth show major improvements since 1760. Life expectancy at age 80 has also improved with an accelerating pace in recent years suggesting we are not approaching a biological limit to the length of life. Anticipating the near future of longevity typically relies on extrapolating either longevity itself or age-specific death rates. The principal alternative to extrapolative methods attempts to model factors affecting mortality and to project those factors into the future. In the more distant future, rather than targeting specific diseases, much research would attempt to arrest the aging process itself either through gene therapy or through medicines that replicate the genes' activities. Stem cell technologies may make it possible to create new body organs to replace defective ones. Although discoveries in laboratories will play an important role in determining the future of longevity, many puzzles remain to be worked out in translating individual behaviors into population-level indexes. Quasi-experimental designs may provide a useful approach to investigate systemic determinants of mortality, with implications for the future of longevity. In addition to projections of longevity for national populations, there would also be projections for major groups within populations. Future projections of longevity are likely also to involve much more consideration of the epidemiology of diseases and their interactions. Finally, an attractive approach to longevity is to base projections on birth cohorts instead of, or in addition to, period-specific data.

INTRODUCTION

How long we live has massive implications for individuals and societies. The social effects of longevity include the ratio of older persons to younger persons, which has dramatic effects on the fiscal viability of age-graded social transfer programs. They also include such diverse matters as the social burden of caregiving, the likelihood of having surviving family members, life insurance premiums, and labor force size and industrial composition.

Longevity has increased sharply in the past century and it is likely to continue increasing. How far and how fast it will rise has become a subject of intense interest. Many disciplines are contributing to answering such

Emerging Trends in the Social and Behavioral Sciences. Edited by Robert Scott and Stephen Kosslyn.
© 2015 John Wiley & Sons, Inc. ISBN 978-1-118-90077-2.

questions, and lively controversies have emerged. The approaches range from individual-level studies of molecular, biological, and genetic processes of aging to population-level demographic analysis of mortality rates and survival.

HISTORICAL TRENDS IN LONGEVITY

Several indicators of longevity are used more or less interchangeably in the literature. In this essay, we focus primarily on life expectancy at birth and at age 80. Life expectancy at a given age represents the average number of years to be lived beyond that age if age-specific mortality rates were to remain unchanged. Thus, life expectancy at birth reflects the mortality experience prevailing in the population over the entire age range at a particular time, while life expectancy at age 80 summarizes mortality conditions beyond age 80.

We briefly describe historical trends in these two indicators from 1750 to 2006. Following Oeppen and Vaupel (2002), we focus on the maximum life expectancy observed among national populations, which indicates what could be achieved under the environment of a particular epoch. We focus on trends in longevity among females, the longer lived sex. In recent work, Vallin and Meslé (2009) analyzed time trends since 1750 in female life expectancy at birth and life expectancy at age 80 for 56 countries using a comprehensive set of data sources. Figure 1 shows the maximum female life expectancy in each year that was observed in their data set. Maximum life expectancy at birth remained fairly constant at about 40 years before 1790 and then increased by about 1 year per decade for the next 100 years, reaching 50 years of age by the 1880s, when the germ theory of disease was empirically validated. For the next 70 years, maximum life expectancy increased three times as rapidly as in the previous century. Declines in infectious and parasitic diseases, especially in infancy and childhood, contributed to the bulk of this improvement.

In recent years, increases in maximum life expectancy at birth have slowed from about 3 years per decade to about 2 years per decade. As more people have survived to old ages, trends in life expectancy have come to be increasingly dominated by trends in mortality at those ages. As shown in Figure 2, life expectancy at age 80 has improved at an accelerating pace, increasing by about 5 years in the past half century and 2 years in the past decade alone. This acceleration suggests that we are not approaching a biological limit to the length of life.

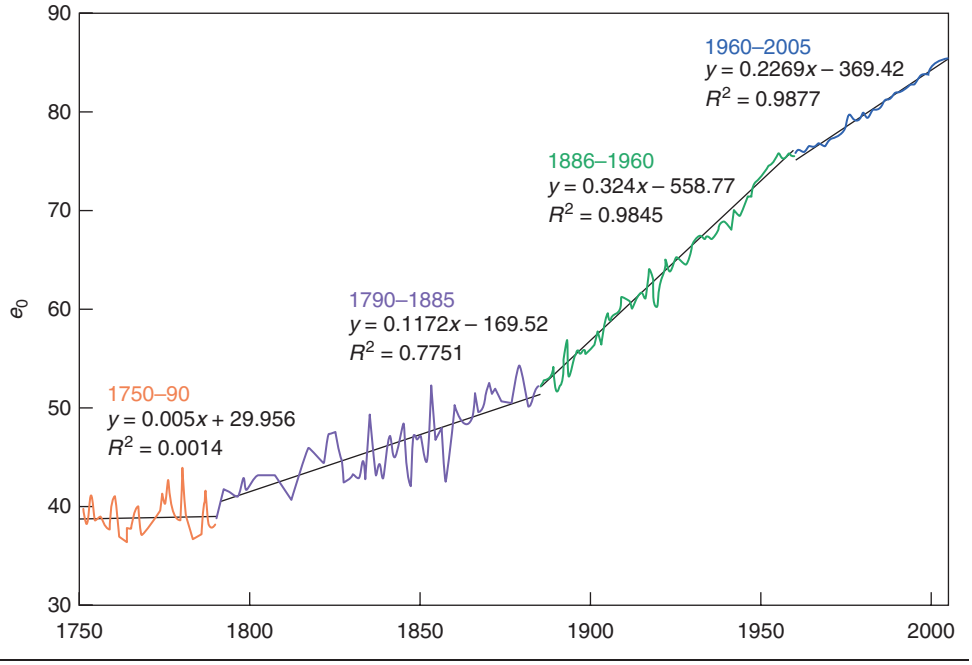

Figure 1 Time trends in maximum female life expectancy at birth. *Source*: Figure 9 reprinted with the permission of Wiley from the paper by Vallin, J and Meslé, F. "The segmented trend line of highest life expectancies," Population and Development Review, 35(1): 159–187.

THE NEAR FUTURE

Over periods of decades, demographers and actuaries are the principal specialists responsible for anticipating the future of life expectancy. The exercise is far from academic. The US Social Security System is required by law to be in actuarial balance over a 75-year period. In simulations performed by Social Security actuaries, the actuarial balance is more sensitive to the future of longevity than it is to any other index except real wages. So projections of longevity have important fiscal implications whose salience is ensured by legislation.

The principal method for projecting longevity over a period as long as 75 years is to observe the past and extrapolate its principal features into the future. More precisely, statistical functions are typically fit to time series data and parameters in those functions are assumed to apply to the future. Figures 1 and 2 illustrate how successful such a strategy can be. For relatively long periods, the rate of change in maximum life span has been roughly constant. Within such periods, extrapolations of rates of change would have been successful. However, when a new period is entered, rates of change in the past will be misleading. Projections made in the 1880s based

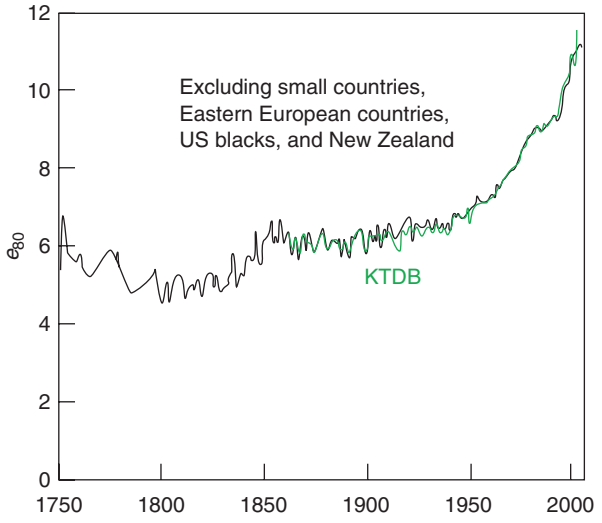

Figure 2 Time trends in maximum female life expectancy at age 80. *Source*: Figure 14, fourth panel reprinted with the permission of Wiley from the paper by Vallin, J and Meslé, F. "The segmented trend line of highest life expectancies," Population and Development Review, 35(1): 159–187. KTDB stands for Kannisto-Thatcher database.

on rates of improvement earlier in the nineteenth century would have been too pessimistic.

Those who extrapolate must also decide what function to extrapolate. Probably the most common method of projecting mortality was developed by Lee and Carter (1992). Their method extrapolates rates of change in age-specific death rates. James Vaupel, on the other hand, has suggested extrapolating rates of improvement in life expectancy itself, which typically gives faster advances. Under most circumstances, a constant rate of improvement in all age-specific death rates would produce slower gains in life expectancy.

Two points of view are resistant to extrapolations, either of longevity itself or of age-specific death rates. One point of view is sometimes explicit in the reasoning of the Social Security Administration. It identifies specific factors that produced past gains in longevity and argues that those factors have already worked their magic and hence cannot be expected to contribute to future improvements. Such reasoning gives rise to a sense that the cupboard is rapidly becoming bare. But many of the institutions that have produced breakthroughs in the past will also be operating in the future. Most importantly, the scientific establishment has enormous incentives to continue producing new medicines, procedures, and therapies that improve health and extend life. And where commercial interests lag, the US government has

stepped into the breach and provided large amounts of funding for research through the National Institutes of Health.

The second source of resistance to methods that extrapolate past changes derives from the notion that there is a strict biogenetic limit to the length of human life, a limit that is fast being approached. The strongest current proponent of this position is Jay Olshansky, but the idea of a fixed life span dates to biblical times. For many years, the idea was a principal underpinning of longevity projections that asymptotically approached an upper limit. As Oeppen and Vaupel show (2002), these supposed limits have almost invariably been shattered, often within a short time after the projection was issued. If rates of decline in death rates at older ages were slowing, the idea that we are approaching a fixed limit would gain credibility. But as noted earlier, death rates at ages above 80 have been falling very rapidly in many countries.

The principal alternative to extrapolative methods attempts to model factors affecting mortality and to project those factors into the future. As shown by Soneji and King (2012), incorporating risk factor data into population projection methods can reduce uncertainty and improve the quality and accuracy of the estimation. Susan Stewart and colleagues (2009) have examined rates of change in smoking and obesity in the United States as well as the connection between those behaviors and mortality. Smoking and obesity are then projected into the future and the mortality consequences examined. Samuel Preston and colleagues (2012) added a cohort-specific component to the smoking and obesity projections and concluded that the combination of changes in these behaviors is likely to speed future US mortality reductions, especially for men.

THE MORE DISTANT FUTURE

Mortality rates at younger ages have reached very low levels in most developed countries, so that any future gains in longevity must result from reductions in old age mortality. Several hurdles will need to be overcome if substantial gains are to be made. A high percentage of older people have multiple morbid conditions, which means that reductions in mortality from one process may increase the prevalence of other morbid conditions and reduce the gains in life expectancy that might otherwise be observed. And some disease processes prominent at older ages have proved very stubborn despite huge control efforts. Mortality rates from cancer, the second leading cause of death, declined by only 12% between 1970 and 2008. Mortality rates from Alzheimer's disease among people aged 65 or older increased by 47% between 2000 and 2006, although some substantial portion of the increase is attributable to better diagnosis.

Rather than targeting specific diseases, much research is attempting to arrest the aging process itself. Recent developments in human gene sequencing and genome analysis (e.g., genome-wide associations) have raised the possibility of identifying longevity genes (Miller, 2012). These genes are thought to enhance an organism's health and extend its life span, either through gene therapy or through medicines that replicate the genes' activities. Research on single-gene mutants has revealed several candidate genes (e.g., SIR2 and clk-1) whose mechanisms have been studied in yeast, worms, and mice. While these candidates are promising, it is not clear whether these genes would achieve similar longevity improvements in humans.

There is also a search for biological agents that can decelerate aging. Rapamycin is a promising contender. Rapamycin is an inhibitor of the mammalian target of rapamycin (mTOR) protein kinase; reducing activity of mTOR is thought to mimic nutrient-limited cellular conditions similar to those of caloric restriction. Studies in mice show significant increases in longevity among those treated with this agent, and suggest that rapamycin may be a modulator of aging and of late-life illnesses, including protection against developing Alzheimer's disease, cancer, and atherosclerosis.

Finally, stem cell technologies may make it possible for new body organs to be created to replace defective ones. Nonetheless, it may not be medically feasible to replace a multitude of organs that typically fail because of the wear and tear that accumulates with increasing age.

Even if medical breakthroughs eventually provide means of slowing the rate of aging, they may not be applied on a wide scale. They may prove to be exceptionally expensive, so that only a small minority may benefit from them. But even if they are inexpensive to use on a personal level, the social costs may be prohibitive. The population aging that is already in store in developed countries, combined with age patterns of public transfers favoring older people, is the basic source of the current financial and political turmoil in Europe, with strong echoes in the United States. The accounts would become even more unbalanced with major advances in longevity. Of course, the longevity improvements could basically pay for themselves IF the population became healthier as well as more longevous, and IF people were willing to convert their greater healthiness into more years of work. The present set of entitlements was established under earlier and more permissive demography, and there is very strong resistance to giving them up.

PROMISING AREAS OF RESEARCH

Although discoveries in laboratories will doubtless play an important role in determining the future of longevity, there is virtually no area of human

activity that does not play a role in fashioning the level of longevity in a population. Personal health behaviors such as smoking, eating, and exercise are reflected not only in personal risks but also in aggregate life expectancy. Many puzzles remain to be worked out in translating individual behaviors into population-level indexes. The observational data that support the identification of risk factors are subject to large potential bias resulting from selection on unmeasured variables, while randomized trials are ethically anathema. Observational data has repeatedly uncovered an "obesity paradox" that is drawing a great deal of attention among epidemiologists. Although obesity sharply increases the risk of acquiring diabetes or heart disease, it appears to be protective once these disease states are reached (Flegal, Kit, Orpana, & Graubard, 2013). Until such puzzles are resolved, they add uncertainty to longevity projections.

Social scientists are alert to these issues and look for opportunities to use quasi-experimental designs in their research. For example, changes in cigarette taxes have repeatedly been studied for their health impacts. Other studies can be addressed to broad social changes. A classic opportunity arose when East and West Germany were unified. Mortality levels at older ages, which had been much higher in East Germany, quickly converged. Health care reform in the United States is providing another opportunity to investigate systemic determinants of mortality, with implications for the future of longevity.

In addition to projections of longevity for national populations, analysts are likely to begin making projections for major groups within populations. As Olshansky and colleagues have shown (2012), the longevity gap among educational groups has rapidly widened in the United States. This raises major issues of social equity. One concrete product of socially differentiated projections would be the possibility of identifying much lower rates of return to Social Security contributions among lower ranking groups.

Future projections of longevity are likely also to involve much more consideration of the epidemiology of diseases and their interactions. Current projection models do not include modules for disease incidence, survival, and impairment. Part of the reason is that we do not have good data on disease incidence apart from cancer, where the national cancer registry provides precise, but not nationally representative, data on cancer incidence and survival. An equivalent system for cardiovascular disease is badly needed. Projection models of longevity that include diseases and impairments would have the additional benefit of providing information about the likely state of future health among the living.

One attractive approach to longevity projection that can be implemented without new data is to base projections on birth cohorts instead of, or in addition to, period-specific data. As Beltrán-Sánchez and colleagues have

shown (2012), mortality rates have been shown to be closely associated with cohort membership. Factors that influence adult mortality, such as childhood diseases and educational attainment, are observable early in the life of a cohort and can be readily transported into the future on a cohort basis. Cohort tendencies to smoke and gain weight are observable by mid-life. Disease incidence, survival, and impairments associated with disease histories play themselves out in cohorts passing through life. These features suggest that cohort processes should become objects of increasingly intense *inquiry in connection* with longevity projections.

REFERENCES

Beltrán-Sánchez, H., Crimmins, E. M., & Finch, C. E. (2012). Early cohort mortality predicts the rate of aging in the cohort: A historical analysis. *Journal of Developmental Origins of Health and Disease*, *3*(5), 380–386.

Flegal, K. M., Kit, B. K., Orpana, H., & Graubard, B. I. (2013). Association of all-cause mortality with overweight and obesity using standard body mass index categories: A systematic review and meta-analysis. *JAMA*, *309*(1), 71–82. doi:10.1001/jama.2012.113905

Lee, R. D., & Carter, L. R. (1992). Modeling and forecasting U.S. mortality. *Journal of the American Statistical Association*, *87*(419), 659–671.

Miller, R. A. (2012). Genes against aging. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *67A*(5), 495–502. doi:10.1093/gerona/gls082

Oeppen, J., & Vaupel, J. W. (2002). Broken limits to life expectancy. *Science*, *296*(5570), 1029–1031.

Olshansky, S. J., Antonucci, T., Berkman, L., Binstock, R. H., Boersch-Supan, A., Cacioppo, J. T., … Rowe, J. (2012). Differences in life expectancy due to race and educational differences are widening, and many may not catch up. *Health Aff (Millwood)*, *31*(8), 1803–1813. doi:10.1377/hlthaff.2011.0746

Preston, S. H., Stokes, A., Mehta, N., & Cao, B. (2012). Projecting the effect of changes in smoking and obesity on future life expectancy in the United States. *National Bureau of Economic Research*, Working Paper No. 18407.

Soneji, S., & King, G. (2012). Statistical security for social security. *Demography*, *49*(3), 1037–1060.

Stewart, S. T., Cutler, D. M., & Rosen, A. B. (2009). Forecasting the effects of obesity and smoking on U.S. life expectancy. *The New England Journal of Medicine*, *361*(23), 2252–2260.

Vallin, J., & Meslé, F. (2009). The segmented trend line of highest life expectancies. *Population and Development Review*, *35*(1), 159–187.

SAMUEL H. PRESTON SHORT BIOGRAPHY

Samuel H. Preston is Professor of Demography and Professor of Sociology at the University of Pennsylvania (http://sociology.sas.upenn.edu/samuel_

preston). The major area of interest throughout his career has been the health of populations, including methods for measuring and analyzing health. He has devoted special attention to cause-of-death patterns across space and time, to the impact of cigarette smoking on aggregate mortality levels, and to the factors that have driven the massive mortality improvements of the past century. He served as Dean of the School of Arts and Sciences at Penn from 1998 to 2004. He is a member of the National Academy of Sciences, the Institute of Medicine, and the American Philosophical Society. He has been president of the Population Association of America and of the Sociological Research Association. He recently completed cochairing an NAS panel addressed to the question of why American longevity lags behind that of many other developed countries.

HIRAM BELTRÁN-SÁNCHEZ SHORT BIOGRAPHY

Hiram Beltrán-Sánchez is a David E. Bell Fellow at the Center for Population and Developments Studies (http://134.174.190.199/centers-institutes/population-development/training/bell-fellowship/bell-fellowship-current-bell-fellows.html) at Harvard University. He obtained a PhD in Demography at the University of Pennsylvania, an MS in Mathematics at Northern Arizona University, and a BS in Actuarial Sciences at the National Autonomous University of Mexico. His research focuses on developing and applying demographic methodologies to studying adult population health at national and individual levels. His research comprises two main areas: (i) national trends in adult morbidity, mortality, and longevity; and (ii) health, health behaviors, and biomarkers in low-income countries with particular focus on the adult Mexican population.

RELATED ESSAYS

Below-Replacement Fertility *(Sociology)*, S. Philip Morgan
Demography and Cultural Evolution *(Anthropology)*, Stephen Shennan
Recent Demographic Trends and the Family *(Sociology)*, Lawrence L. Wu