POLICY FORUM: DEMOGRAPHY

Broken Limits to Life Expectancy

Jim Oeppen and James W. Vaupel*

Is life expectancy approaching its limit? Many—including individuals planning their retirement and officials responsible for health and social policy—believe it is. The evidence suggests otherwise.

Consider first an astonishing fact. Female life expectancy in the record-holding country has risen for 160 years at a steady pace of almost 3 months per year [Fig. 1 and suppl. table 1

(1)]. In 1840 the record was held by Swedish women, who lived on average a little more than 45 years. Among nations today, the longest expectation of life—almost 85 years—is enjoyed by Japanese women. The four-decade increase in life expectancy in 16 decades is so extraordinarily linear [$r^2 = 0.992$; also see suppl. figs. 1 to 5 (1)] that it may be the most remarkable regularity of mass endeavor ever observed. Record life expectancy has also risen linearly for men ($r^2 = 0.980$), albeit more slowly (slope = 0.222): the gap between female and male levels has grown from 2 to 6 years (suppl. fig. 2).

In addition to forewarning any looming limit to the expectation of life, trends in best-practice life expectancy provide information about the performance of countries. The gap between the record and the national level is a measure of how much better a country might do at current states of knowledge and demonstrated practice. Although rapid progress in catch-up periods typically is followed by a slower rise, life-expectancy trajectories do not appear to be approaching a maximum (Fig. 2).

The linear climb of record life expectancy suggests that reductions in mortality should not be seen as a disconnected sequence of unrepeatable revolutions but rather as a regular stream of continuing progress (2, 3). Mortality improvements result from the intricate interplay of advances in income, salubrity, nutrition, education, sanitation, and medicine, with the mix varying over age, period, cohort, place, and disease (4). Before 1950, most of the gain in life expectancy was due to large reductions in death rates at younger ages. In the second half of the 20th century, improvements in survival after age 65 propelled the rise in the length of people's lives. For Japanese females, remaining life expectancy at age 65 grew from 13 years in 1950 to 22 years today, and the chance of surviving from 65 to 100 soared from less than 1 in 1000 to 1 in 20 (1). The details are complicated but the resultant straight line of life-expectancy increase is simple.

World life expectancy more than doubled over the past two centuries, from roughly 25 years to about 65 for men and 70 for women (4). This transformation of the duration of life greatly enhanced the quantity and quality of people's lives. It fueled enormous increases in economic output and in population size, including an explosion in the number of the elderly (5, 6). Although students of mortality eventually recognized the reality of improvements in survival, they blindly clung to the ancient notion that under favorable conditions the typical human has a characteristic life-span. As the expectation of life rose higher and higher, experts were unable to imagine its rising much further. They envisioned various biological barriers and practical impediments. The notion of a fixed life-span evolved into a belief in a looming limit to life expectancy.

Ultimate Expectations of Life

In 1928, Louis Dublin quantified this consensus (7). Using U.S. life tables as a guide, he estimated the lowest level to which the death rate in each age group could possibly be reduced. His calculations were made "in the light of present knowledge and without intervention of radical innovations or fantastic evolutionary change in our physiological make-up, such as we have no reason to assume." His "hypothetical table promised an ultimate figure of 64.75 years" for the expectation of life both for males and for females. At the time, U.S. life expectancy was about 57 years. Because Dublin did not have data for New Zealand, he did not realize that his ceiling had been pierced by women
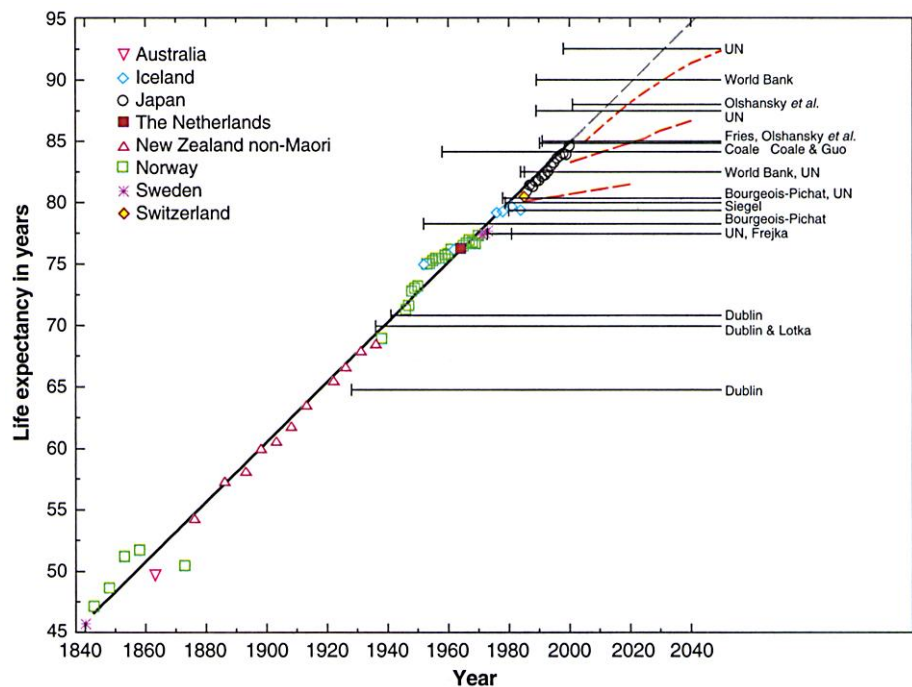

Fig. 1. Record female life expectancy from 1840 to the present [suppl. table 2 (1)]. The linear-regression trend is depicted by a bold black line (slope = 0.243) and the extrapolated trend by a dashed gray line. The horizontal black lines show asserted ceilings on life expectancy, with a short vertical line indicating the year of publication (suppl. table 1). The dashed red lines denote projections of female life expectancy in Japan published by the United Nations in 1986, 1999, and 2001 (1): It is encouraging that the U.N. altered its projection so radically between 1999 and 2001.

J. Oeppen is with the Cambridge Group for the History of Population and Social Structure, Cambridge University, Cambridge, CB2 3EN, UK. He is associated with, and J. W. Vaupel is at, the Max Planck Institute for Demographic Research, Doberaner Strasse 114, D-18057 Rostock, Germany.

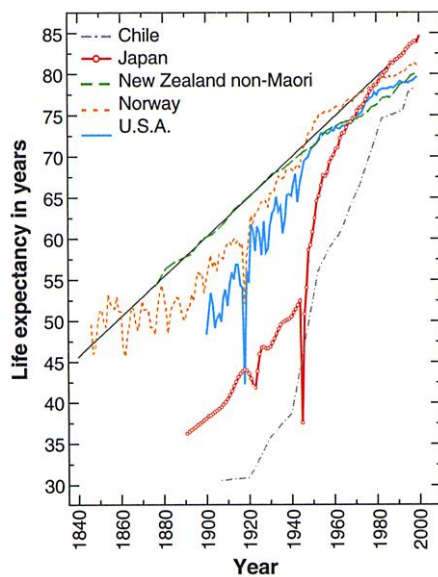*To whom correspondence should be addressed. E-mail: jwv@demogr.mpg.de

Fig. 2. Female life expectancy in Chile, Japan, New Zealand (non-Maori), Norway, and the United States compared with the trend in record life expectancy.

there: in the non-Maori life table for 1921, female life expectancy is 65.93 years [Fig. 1 and suppl. tables 1 and 2 (*1*)].

Marshalling methods and arguments strikingly similar to Dublin's, Olshansky *et al.* in 1990 and again in 2001 assess the life expectancy that could be attained if age-specific death rates could be reduced by amounts that are not "implausible," "overly optimistic," and "highly unlikely" (*8, 9*). In 1990, they asserted that life expectancy "should not exceed ... 35 years at age 50 unless major breakthroughs occur in controlling the fundamental rate of aging." This cap, however, was surpassed by Japanese females in 1996.

Other scholars tried various stratagems to seize life expectancy heights that they could not conceive of being surmounted (*1*). Although some of the more recent ostensible limits have not yet been exceeded, those from Dublin in 1928 to Olshansky *et al.* in 1990 have been broken, on average 5 years after publication (Fig. 1 and suppl. table 1).

Better Forecasts
The ignominious saga of life-expectancy maxima is more than an exquisite case for historians intrigued by the foibles of science. Continuing belief in imminent limits is distorting public and private decision-making. Forecasts of the expectation of life are used to determine future pension, health-care, and other social needs. Increases in life expectancy of a few years can produce large changes in the numbers of the old and very old, substantially augmenting these needs (*5, 6*). The officials responsible for making projections have re-

calcitrantly assumed that life expectancy will increase slowly and not much further (*10*). The official forecasts distort people's decisions about how much to save and when to retire. They give politicians license to postpone painful adjustments to social-security and medical-care systems (*11*).

Officials charged with forecasting trends in life expectancy over future decades should base their calculations on the empirical record of mortality improvements over corresponding spans of the past (*2, 3*). Because best-practice life expectancy has increased by 2.5 years per decade for a century and a half, one reasonable scenario would be that this trend will continue in coming decades. If so, record life expectancy will reach 100 in about six decades. This is far from eternity: modest annual increments in life expectancy will never lead to immortality. It is striking, however, that centenarians may become commonplace within the lifetimes of people alive today (*12*).

Life expectancy can be forecast by considering the gap between national performance and the best-practice level (Fig. 2). The U.S. disadvantage varied from a decade in 1900 to less than a year in 1950 and about 5 years in 2000 (Fig. 2). If the trend in record life expectancy continues and if the U.S. disadvantage is between a year and a decade in 2070, then female life expectancy would be between 92.5 and 101.5, considerably higher than the Social Security Administration's forecast of 83.9 published in 1999 (*1*). An alternative method for forecasting life expectancy is to analyze the rapidity of improvement in age-specific death rates over many decades and then to use this information to project death rates over coming decades (*2, 3*). The official Japanese forecast, issued in 1997, of life expectancy (for males and females combined) in 2050 is 82.95 (*1*). Projections based on the decline in death rates in Japan since 1950 result in a life expectancy some 8 years longer, 90.91, with a 90% confidence range from 87.64 to 94.18 (*3*).

Declines in mortality might be systematically slower than in the past. On the other hand, biomedical research may yield unprecedented increases in survival. Given the extraordinary rise in best-practice life expectancy and the demonstrated near-sightedness of expert vision, the central forecast should be based on the long-term trend of sustained progress in reducing mortality.

In their quest to impose a cap on average longevity, students of mortality ignored essential research questions. Major changes in life expectancy hinge on improvements in survival at advanced ages,

but comprehensive analysis of the substantial reductions since the mid–20th century in death rates after age 80 first flourished in the 1990s (*1, 13*). Hypothesized biological barriers to longer life-spans also first received systematic attention (and refutation) a decade ago (*1, 14–16*). The impact of continuing mortality improvements on life expectancy attracted empirical (*12*) and theoretical attention (*17*) in the late 1980s, with refined methods developed over the past decade (*1–3*).

Three Findings
This mortality research has exposed the empirical misconceptions and specious theories that underlie the pernicious belief that the expectation of life cannot rise much further. Nonetheless, faith in proximate longevity limits endures, sustained by ex cathedra pronouncement and mutual citation (*1, 8, 9*). In this article we add three further lines of cogent evidence. First, experts have repeatedly asserted that life expectancy is approaching a ceiling: these experts have repeatedly been proven wrong. Second, the apparent leveling off of life expectancy in various countries is an artifact of laggards catching up and leaders falling behind. Third, if life expectancy were close to a maximum, then the increase in the record expectation of life should be slowing. It is not. For 160 years, best-performance life expectancy has steadily increased by a quarter of a year per year, an extraordinary constancy of human achievement.

References and Notes
1. Supplemental material—including data sources and additional references—is available on *Science* Online at http://www.sciencemag.org/cgi/content/full/296/5570/1029/DC1. Life expectancy is the mean age at death under current mortality conditions.
2. R. D. Lee, L. Carter, *J. Am. Stat. Assoc.* **87**, 659 (1992).
3. S. Tuljapurkar, N. Li, C. Boe, *Nature* **405**, 789 (2000).
4. J. Riley, *Rising Life Expectancy: A Global History* (Cambridge Univ. Press, Cambridge, 2001), 243 pp.
5. L. G. Martin, S. H. Preston, *Demography of Aging* (National Academy Press, Washington, DC, 1994).
6. R. W. Fogel, D. L. Costa, *Demography* **34**, 49 (1997).
7. L. I. Dublin, *Health and Wealth* (Harper, New York, 1928), 361 pp.
8. S. J. Olshansky, B. A. Carnes, C. Cassel, *Science* **250**, 634 (1990).
9. S. J. Olshansky, B. A. Carnes, A. Désesquelles, *Science* **292**, 1654 (2001).
10. N. Keilman, *J. Offic. Stat.* **12**, 245 (1997).
11. J. W. Vaupel, *Washington Q.* **23**, 197 (2000).
12. J. W. Vaupel, A. E. Gowan, *Am. J. Public Health* **76**, 430 (1986).
13. V. Kannisto, J. Lauritsen, A.R. Thatcher, J.W. Vaupel, *Pop. Dev. Rev.* **20**, 793 (1994).
14. J. R. Carey, P. Liedo, D. Orozco, J. W. Vaupel, *Science* **258**, 457 (1992).
15. J. W. Curtsinger, H. H. Fukui, D. Townsend, J. W. Vaupel, *Science* **258**, 461 (1992).
16. J. W. Vaupel *et al.*, *Science* **280**, 855 (1998).
17. J. W. Vaupel, *Pop. Stud.* **40**, 147 (1986).
18. Funded by the Max Planck Society and the U.S. National Institute on Aging (AG-08761). We thank V. Kannisto, P. Laslett, S. Horiuchi, R. D. Lee, S. Leek, H. Maier, M. Luy, R. Rau, Y. Saito, S. Tuljapurkar, K. W. Wachter, and J. R. Wilmoth for their assistance.