FORECASTING U.S. LIFE EXPECTANCY IN AN AGE OF UNCERTAINTY

Justin T. Denney and Robert McNown

March 4, 2008

ABSTRACT

We employ model schedules and time series analysis to forecast future life expectancy to the year 2055. Our results show limited improvements in life expectancy for males and females in the United States: between the years 2005 and 2055, life expectancy at birth will increase 4.2 years for males, from 73.9 years to 78.1 years, and just 2.9 years for females, from 79.4 years to 82.3 years. These improvements are much lower, for example, than the approximately 70-year life expectancies at age 30 that some researchers have optimistically suggested. Minimal gains in life expectancy suggest that negative health behaviors in the U.S. greatly contribute to stagnant improvements in length of life. The increasing severity of the obesity epidemic, a substantial lack of health insurance coverage and stability in levels of smoking, for example, may be cumulatively reaching critical levels. These results underscore the importance of policy and health initiatives aimed at improving the nation's health and reveal important insight into possible limits to mortality improvement over the next five decades.

Researchers and policy makers must fully understand past and present mortality trends in order to accurately determine future ones. Such forecasts have direct substantive importance because they inform us about population aging and changing sex differences in life expectancy, and policy relevance because they provide needed information for such national programs as Medicare and Social Security. Although the Social Security Administration (SSA) has regularly underestimated future gains in life expectancy (see Oeppen and Vaupel 2002), past underestimation does not guarantee substantial future gains in life expectancy; more conservative estimates may prove more precise at some future date. It is important to employ a technique that can produce accurate life expectancy forecasts for all age and sex groups, because researchers and policy makers are interested in better understanding future mortality at all ages. Indeed, U.S. males and females are living longer than ever before. But for decades, the U.S. has consistently declined in worldwide rankings of life expectancy. At the same time, Americans have increased their numbers of obese and uninsured individuals and maintained a significant proportion of smokers (Rogers, Hummer, and Nam 2000; Committee on the Consequences of Uninsurance 2002; Flegal et al. 2005). Based on these now lasting negative trends, researchers must investigate the potential impacts on future length of life. We employ model schedules and time series analysis to forecast future life expectancies at birth for males and females to the year 2055.

Historical Trends in Life Expectancy

In 1900, U.S. life expectancy at birth for the total population was just 47.3 years; by the year 2003, it had jumped to 77.6 years. In the first half of the twentieth century these increases were uneven and were punctuated by periodic dramatic reductions in life

expectancy owing to infectious diseases; for example, between 1917 and 1918, life expectancy at birth plummeted 11.8 years because of the influenza epidemic. The second half of the twentieth century witnessed gains that were slower and less variable.

Optimistic researchers expect substantial gains in life expectancy, comparable to some of the dramatic gains of the past. The Epidemiologic Transition Theory argues that previous reductions in mortality have been realized through far-reaching medical breakthroughs, public health advances, and increases in quality of life (including warmer clothes, better housing, and higher overall incomes) (Omran 1977; Tuljapurkar et al. 2000). Public health advances in the nineteenth and twentieth centuries include chlorination, pasteurization, and refrigeration (see Omran 1977). New public health interventions – including improved traffic safety; efforts to provide cleaner air, water, and land; and increases in immunizations – have further lowered mortality. Koch's 1882 isolation of the tubercule bacillus led to practical application of the germ theory of disease, and Fleming's 1928 discovery of penicillin led in the 1940s to the use of antibiotics (Wilmoth 1998). Recent medical breakthroughs include improved treatment for heart disease and cancer, kidney dialysis, and organ transplants (see Fogel and Costa 1997; Rogers et al. 2005).

There are reasons to be guarded about future gains in life expectancy, including persistent risky behaviors, external causes of death, and the law of diminishing returns (see Wong-Fupuy and Haberman 2004). We have seen periods of stagnation if not deterioration in life expectancy. Ironically, past progress hinders future gains (Vaupel 1986). It is much easier to reduce infectious diseases than such complex chronic and degenerative diseases as heart disease, cancer, Alzheimer's disease, and AIDS (Tuljapurkar et al. 2000). Further, we must consider the Taeuber Paradox (Keyfitz 1977):

especially at older ages, diseases are interrelated, so that the elimination of one disease may not substantially reduce overall mortality (Tuljapurkar and Boe 1998). Although cancer contributes to about one-quarter of all deaths in the U.S., the large majority of these deaths occur at older ages, so its elimination might add just a little over three years to life expectancy at birth (Anderson 1999). Similarly, because survival at younger ages is already so high and cannot improve much further, future gains in life expectancy must be realized among older ages where fewer person-years are added (Bongaarts 2005). Vaupel (1986) estimates improvements in age-specific mortality at ages proximal to a population's life expectancy at birth generally translate into the greatest gains in overall life expectancy. Gene therapy, heralded as the next major medical breakthrough, may be some years off, may affect a small proportion of the population, and may more directly affect morbidity and disability than mortality. Thus, whereas public health measures and medical treatments will continually improve survival, future survival improvements may need to target increasingly older ages and may increase at a decreasing rate.

Life expectancy could remain stable or even deteriorate due to stress, risky behaviors, infectious diseases, a lack of health insurance coverage, and human-made and environmental hazards. Life expectancy could also decline due to pollution, terrorist attacks, and such natural disasters as earthquakes, tornados, mudslides, and floods (Lave and Seskin 1973; Rogers et al. 2005). Although we have conquered or diminished the effects of many infectious diseases, old infectious diseases could re-emerge, new drug-resistant strains could develop, and new infectious diseases could arise, further increasing mortality (Olshansky et al. 1997). Some suggest that increased risky behaviors coupled with declining mortality due to other factors has ushered us into a new stage of the epidemiologic transition, where behavioral factors are the leading cause of death

(McGinnis and Foege 1993; Olshansky et al. 2005; Rogers and Hackenberg 1987). Individuals continue to overeat and to remain inactive even in the midst of an obesity epidemic; they continue to smoke, drink excessively, and use drugs despite cautions and even prohibitions; and they continue to engage in violence, unprotected sexual intercourse, and reckless driving even with knowledge of their potential life-shortening effects.

Researchers are interested not only in changes in overall mortality, but also in the shape of the mortality curves and in differences by sex. The sex gap in life expectancy at birth, which was relatively low but variable in the early 1900s, widened to its highest levels in 1975 and again in 1979, at 7.8 years. Since 1979, the sex gap in life expectancy has gradually closed to 5.3 years by 2003, the narrowest level in 55 years.

Both males and females have enjoyed substantial long-term increases in survival, but with gains that differ by period. For example, females experienced substantial gains in survival between 1930 and 1950, with smaller gains between 1950 and 1970. Males, while they have lower survival than females in every period, experienced small gains between 1950 and 1970, with some of their greatest survival gains between 1970 and 1990. Thus, large survival gains for males, especially over the last three decades, contribute to converging male and female survival rates (Preston 2005).

Forecasting Life Expectancies

Techniques for forecasting mortality vary in accuracy and complexity: expert opinion; forecasts of age-, sex-, and sometimes cause-specific mortality rates; survival rates; and life expectancies. More complex methods do not necessarily result in more accurate forecasts. At the same time, simple methods may be illustrative but misleading.

The Social Security Administration (SSA) regularly publishes low, intermediate, and high projected period life expectancies at birth. The 2005 report states that by 2050 life expectancy at birth will rise to 79.4 years for males and 83.2 years for females, based on intermediate estimates. The high cost estimates are slightly higher: 82.4 for males and 85.9 for females (Board of Trustees 2005). Social Security and other official forecasts rely heavily on subjective expert opinion, often reflect the optimistic or pessimistic climate of the times, and over the past century have generally underestimated actual life expectancy (Lee and Miller 2001).

Oeppen and Vaupel (2002) hold that although more sophisticated techniques are available, linear projections of life expectancies are reasonable and relatively accurate. Employing international data from the years 1840 through 2000, they use the highest female and male life expectancy at birth that is reported for any country in that year. Based on these record-holding countries, they present a linear relationship between the 160-year period and female life expectancy at birth. They argue that more developed countries can expect unprecedented increases in life expectancy – indeed, that in about 60 years, life expectancies at birth could reach 100 years. Further, they assert that the linear life expectancy trend "may be the most remarkable regularity of mass endeavor ever observed" (2002, p. 1029).

A linear pattern in life expectancy should hold for different time periods and countries, including the U.S. But a forward linear trend based on the first half of the twentieth century for the U.S. would vastly overestimate present life expectancies. And a backward linear projection would quickly lead to severe life expectancy underestimates. Oeppen and Vaupel (2002) find a larger slope for females than for males, state that the sex gap in life expectancy has increased over time, and thus claim that the sex gap in life

expectancy will constantly continue to widen over time. But the U.S. has witnessed a substantial and consistent closing of the sex gap in life expectancy over the last 24 years (Arias 2004; Hoyert et al. 2005). Thus, although Oeppen and Vaupel's (2002) linear method is direct and instructive, it does not work for all periods and countries and does not represent current trends in the sex gap.

Olshansky et al. (2005) argue against extrapolative methods for forecasting life expectancy, stating that the past may not reflect future gains or losses. They also suggest, contrary to many demographers' advice, that SSA should *not* increase their forecasts, even though it has had a tendency to underestimate in the past. Although no extrapolative method can completely forecast human behavior (such as obesity rates), political effects (such as war and genocide), or pandemics (Olshansky et al. 2005), extrapolating past trends has been tested and produces reasonable forecasts (Lee and Miller 2001). Furthermore, historical extrapolation is less prone than other methods to subjective biases and common assumptions, such as the existence of a biological maximum lifespan (Preston 2005).

Forecasting Mortality Rates. British actuary Benjamin Gompertz (1925) first proposed a mathematical law of mortality by modeling mortality rates for humans aged approximately 20 to 60 with a simple exponential equation. This function accurately describes age-specific mortality for humans and other species at select ages. When Gompertz developed the equation, mortality above age 80 (or age 60 or 70 for that matter) was of little concern (Olshansky and Carnes 1997). However, at older ages, mortality does not continue to increase in an exponential fashion but instead shows a deceleration in the rate of aging and increases linearly through at least age 105 and possibly 110 (Wilmoth 1995). Heligman and Pollard (1980) and others have expanded

Gompertz's equation to fit mortality at all ages and to allow for deceleration of mortality at the older ages.

Researchers and policy makers may be interested in age-specific mortality rates, as well as aggregated measures such as life expectancy. Recently, investigators have converted age- and sex-specific mortality rates into model schedule parameters and have then used time series analysis to project the parameter estimates (for reviews, see Tuljapurkar and Boe 1998, and Wong-Fupuy and Haberman 2004).

Lee and Carter (1992) developed a method for forecasting mortality based on the equation

$$\text{Ln}(m_{x,t}) = a_x + b_x * k_t + \varepsilon_{x,t} \quad (1)$$

where $m_{x,t}$ is the central death rate for age x at time t, a_x and b_x are parameters dependent only on age that represent age effects and age pattern of mortality change, respectively, k_t is a temporal factor representing level of mortality, and $\varepsilon_{x,t}$ is the error term. Lee and Carter's method is renowned for its simplicity; there is only one temporal parameter to model, and its error term is relatively easy to calculate (Lee 2000).

Lee and Miller (2001) evaluate the Lee-Carter method and find that when compared to observed data, both Lee and Carter's (1992) projections and hypothetical historical projections are quite accurate. In each case, however, life expectancies were systematically underestimated (though to a lesser degree than Social Security projections, Lee and Miller note). Seventy-four of 78, or 95%, of historical Lee-Carter projections were below actual values. Actual values also fell outside of the 95% probability intervals 15% of the time. Although this seems to imply that the Lee-Carter method underestimates error, every case where the actual values fell outside of the interval occurs with projections of greater than fifty years. When considering estimates from five different

countries (all with starting points less than fifty years other than the U.S.), Lee and Miller find only 3% of actual values fell outside of the intervals (the problem of underestimation, however, persisted with each country). The confidence intervals were, in fact, too broad for projections of forty years or less and too narrow for fifty years or greater.

Although the Lee-Carter method produces fairly accurate but slightly underestimated life expectancy projections, it does not allow for variations in the age pattern of mortality declines over time, and may not accurately reflect the shape of mortality. Because b_x, which defines the age pattern, is not a time-dependent term, Lee and Carter (1992) assume that the age pattern of mortality decline is fixed (Bongaarts 2005; Lee and Miller 2001). But Lee and Miller (2001) show that the age pattern in the second half of the twentieth century is substantially different from the first half: improvements in infant and childhood mortality were proportionally larger in the early part of the century, whereas gains in late middle-aged and elderly mortality were proportionately greater in later periods. The fixed age pattern problem will be exacerbated during periods where substantial age pattern changes occur and may partly explain the systematic underestimation of life expectancy (Lee and Miller 2001).

Bongaarts (2005) uses a shifting logistic model to project adult mortality. He first fits mortality data to a three-parameter logistic model. Next, he fixes the slope parameter to its average value, refits the mortality data to the three-parameter logistic model, and then extrapolates the remaining two parameters. Although extrapolation is straight-forward, the trends over time in at least one of the parameters is not steady, and therefore may be better captured by other nonlinear techniques (Bongaarts 2005). Bongaarts presents results for ages 25-100 and acknowledges that the model will not work for

younger ages because there are too few parameters to model mortality among infants, children, and young adults during the accident peak. Although the focus on ages 25-100 is important, it does not provide a complete picture of mortality trends. Nevertheless, Bongaarts (2005) finds that compared to projections to the year 2100 with his model, the Lee-Carter method produces large mortality improvement in ages 60-80, but very small mortality improvement in older ages (90-100), which suggests that the Lee-Carter method does not fully incorporate mortality improvement among older ages.

McNown and Rogers (1989) use a parameterized time series approach to forecast mortality. The McNown-Rogers method begins with the eight-parameter Heligman-Pollard (1980) mortality model:

$$q_x = A^{(x+B)^c} + De^{(-E(\ln x - \ln F)^2)} + \frac{GH^x}{(1+GH^x)} \qquad (2)$$

It then employs univariate and multivariate time-series techniques to forecast the eight parameters into the future.

The Heligman-Pollard model of mortality can be decomposed into three broad age groups. Parameters A, B and C focus on childhood mortality, D, E, and F young adult mortality, and G and H older age mortality. The Heligman-Pollard model of mortality, despite its complexity and estimation of eight separate parameters, has been shown to produce consistent and accurate estimates. To address complexity in the model, some have suggested reducing the number of parameters thereby eliminating the volatility due to infant and early childhood mortality and the so-called "accident peak" during young adult years (McNown 1992). Indeed, considering mortality only for adults over the age of 20 or 30 can reduce the Heligman-Pollard function from eight to five or even two parameters (parameters A-C and possibly D-F can be dropped). However, once again,

these models are then inherently incomplete as they cannot estimate mortality across the lifespan. Rather, we propose examining the patterns of the full eight-parameter model over time for all ages. Doing so may provide insight into the fluctuations and stability of the parameters, allowing some parameters to be held at a constant value in the equation.

METHOD

Data Sources

Comparatively little attention has been paid to the data used in various examinations and forecasts of United States mortality. This is, in part, because of a historical lack of consistency in the computation and sources of death rates, life expectancies, and other measures of mortality in the United States (see Smith and Bradshaw 2006). Indeed, it is vitally important to 1) know the computational and organizational history of data used to investigate mortality trends and 2) come as close as possible to a central consistent source of mortality data for the U.S. The Human Mortality Database (HMD), a joint venture between The University of California – Berkeley and the Max Plank Institute (HMD [http://www.mortality.org]), has gone a long way toward addressing these concerns, especially recently.

We use United States death data compiled by the HMD for the years 1933 to 2004. The year 1933 marked the completion of an initiative to admit states into a death registration system for the entire United States. This was the beginning of an all inclusive effort to compile deaths by year and, thus, data on United States deaths are considered to be complete and of acceptable quality since this time.

Improvements of and additions to the United States death data housed and managed by the HMD will undoubtedly improve upon mortality examinations in the

coming years. Using standard and acceptable procedures, the HMD provides a relatively robust set of United States death data spanning over 70 years, unlike any other single source. Even so, available data on U.S. deaths since 1933 have not been consistently compiled and deserve consideration. From 1933 to 1958, for some age ranges, the total number of deaths were assembled by 5-year age groups rather than by single years of age. For example, deaths for these years are available for individuals 80 to 84 years of age rather than age 80, age 81 and so on. To allow examinations of death by single year of age across these years, the HMD interpolates deaths for the five-year age groups using a cubic spline procedure (for a complete description, see the Methods Protocol for the HMD 2007).

Furthermore, data on deaths for the years 1933 to 1952 include an open age range of age 100+. To provide some consistency with later years of death data, the HMD uses the Kannisto model of old age to extrapolate deaths by single year to age 110+ for the years 1933 to 1952 (again, for a complete description, see the Methods Protocol for the HMD 2007). However, because our ultimate intention is to extrapolate death rates to come up with forecasts 50 years into the future, it would be inappropriate to use data for ages greater than 99, since age at death past age 99 is itself extrapolated. Therefore, we use ages 0 to 99 for the years 1933 to 2004 to predict mortality estimates and then forecast 50 years into the future.

Model Fitting

We fit q_x values to the eight-parameter Heligman-Pollard model with the *Table Curve 2D* program, which accommodates user-defined functions. We started with the first year, 1933, and identified the best fit for the eight parameters, then sequentially fit each

subsequent year. The advantage of using *Table Curve 2D* is that it provides an objective way to determine the best fit.

We identified three parameters, B, E, and F that could be held at a constant value in the equation. Parameter B addresses early life mortality, especially for the first year of life (Heligman and Pollard 1980). Parameter B fluctuated very little over the 70 years of observed data. Parameters E and F address young adult mortality. Specifically, parameter E measures the spread of the accident hump while parameter F approximates the modal age of the accident hump (Heligman and Pollard 1980). Parameter E fluctuated erratically at times over the 70 year period causing some potential unnecessary noise to the overall model. Similar to parameter B, parameter F showed very little variation over the time span. Consequently we experimented with holding these three parameters at their mean values and re-estimated the models accordingly. The r^2 was over .987 for each year before and after holding the parameters at their constant values. For parsimony, we present most results for 1940 and subsequent 20-year periods through 2055.

Time Series Models of Parameters

Adapting the strategy of McNown and Rogers (1989), we use time series methods to model the temporal patterns of the model schedule parameters in order to project these parameters, and hence the age patterns of adult mortality, into the future. Both univariate and multivariate time series methods are employed to analyze the dynamic behavior of the parameters.

RESULTS

The projections of parameters from 2005 through 2055 are attached to the historical data for 1933-2004, and displayed in Figure 1. For males and females, parameter A declines precipitously during the observed and projected years indicating a steady reduction of mortality in the first year of life. A similar reduction is observed in parameter C, measuring early childhood mortality. Parameter D, measuring the intensity of the "accident hump", shows a marked decline in the first 20 years for females and then levels off. For males, parameter D begins to decline and then peaks during the mid to late 1940's, surely a result of increased young adult male mortality during World War II. After this peak, there is some continued fluctuation and eventual reduction, though the value stays higher for males, reflecting their increased young adult mortality.

The older age mortality parameters, G and H, suggest a continuing convergence of male and female mortality at the oldest ages. In particular, parameter G, indicating the slope of the mortality curve at the oldest ages, begins to converge around 1990 and continues to do so at a steady rate through the remaining historical years and into the projections. Parameter H acts in conjunction with parameter G, that is, as parameter G decreases H increases. Further, parameter H denotes the deceleration of mortality at the older ages and shows male and female variations and even dispersal from the 1960s to the 1980s only to converge starting in the 1990s and leveling off through the projection years.

(Figure 1 about here)

Table 1 provides observed and projected probabilities of death by selected years and selected ages for both males and females. The probability of death at age 0 declines steadily for both sexes, especially from 1980 to 2000. Males experienced a slightly larger reduction, moving from .014 to .0078. Males continue to benefit from this decreased

probability of death at age 0, and in fact, surpass females in the projections by year 2040. By the year 2055, it is estimated that the probability of death for males at age 0 will be .0012 compared to .0019 for females.

U.S. males and females experienced substantial reductions in mortality at ages 30 to 60 from 1940 to 1980. However, after 1980, these reductions in the probability of death began to lessen. That trend carries forward in the projections. Indeed, for males and females, there are modest decreases in the probability of death during these ages. For example, in 2000, the probability of death for males and females was .006 and .003 respectively. By 2055, it is estimated that these probabilities will reduce slightly to .004 for males and .002 for females.

At the oldest ages, the observed data show steady slight improvements in mortality. Again, from 1980 to 2000, these improvements become less prominent. For example, the probability of death for 80 year-old females improves from .059 to .049. A similar, yet slightly more dramatic trend exists for males, moving from .093 to .072. Projecting to the year 2055, males continue to experience a greater reduction in death at age 80, narrowing the sex gap in mortality at the latest ages. Indeed, the probability of death for males in 2055 at age 80 reduces to .061 from .072 in the year 2000. For 80 year-old females, the movement is from .049 in 2000 to .045 in 2055.

(Table 1 about here)

From our forecasted probabilities of death we calculated corresponding life expectancies. These forecasted life expectancies are presented along with observed life expectancies in Table 2. Contrary to gains observed between the earliest and latest observed years, our forecasts produce very modest gains in life expectancy at all ages for

males and females. In addition, life expectancies of males and females continue to converge at a slow but steady rate.

From 2000 to 2055 male life expectancies at age 0 increase almost four years, from 74.28 to 78.09. Females see a more modest gain of less than three years, from 79.56 to 82.27. By stark contrast, from 1940-2000, male life expectancies at birth increased over 13 years and females 14 years. Our forecasts show minimal gain at every stage of life, with slightly larger improvements for males.

Especially at the oldest ages, modest improvements in mortality displayed in Table 1 correspond with small improvements in length of life in Table 2. For example, in 2055 males and females can expect to add 1.5 to 2.0 years of life at age 60 as compared to life expectancies in the year 2000. At age 80 the gain is less than a year for both sexes.

(Table 2 about here)

CONCLUSION

With regard to health and length of life, the U.S. is in an age of uncertainty. In the first half of the 20th century Americans witnessed phenomenal improvements in life expectancy that stayed relatively consistent but began to slow in the second half of the century. But over the last several decades, rates of obesity have continued to rise without many signs of leveling off (Christakis and Fowler 2007). While rates of current smokers have certainly declined since 1960, they have stabilized since the 1990's and even increased for some populations (Nam et al. 1996). Consequently a substantial number of Americans continue to smoke.

Additionally, a growing number of Americans are living without health insurance. There are debates on whether this lack of insurance is a choice made by individuals or

whether employers or governments have an inherent duty to supply insurance. Either way, it is detrimental to live without it (Hadley 2003). If one takes ill and lacks the necessary resources to treat the illness there are undeniable consequences, varying in degree according to the seriousness of the ailment.

The Epidemiologic Transition Theory demonstrates that historical reductions in mortality have come about through public health advances, improvements in quality of life, and new medical technology (see Fogel and Costa 1997; Rogers et al. 2005). But future reductions could be hampered by persistent risky behaviors, stress, environmental risks, and the law of diminishing returns. Most major causes of death today are chronic, progressive, degenerative, multifactorial, and relatively resistant to intervention and treatment: heart disease, stroke, cancer, Alzheimer's disease, and AIDS (Tuljapurkar et al. 2000). We are now at a stage where individual behaviors – cigarette smoking, diet, drinking, drug use, exercise, and sexual activity – can have a profound effect on life expectancies (Rogers and Hackenberg 1987). Life expectancy gains could continue to slow with increases in poverty and income inequality, outbreaks of infectious diseases, environmental and human-made catastrophes, and continued risky behavior (Olshansky et al. 1997, 1998). Indeed, Olskansky et al. (2005) estimate that obesity dampens current U.S. life expectancy by one-third to three-quarters of a year, and with greater prevalence and higher levels, could further reduce life expectancy in future years. Although we agree that obesity has increased for three decades, and that obesity is increasing for children, adolescents, and adults, we also acknowledge that national programs, public health initiatives, and medical intervention could reverse this trend. Moreover, obesity is but one of hundreds of factors that affect life expectancy (Preston 2005).

Life expectancy forecasts have important lifestyle and public policy ramifications. Accurate forecasts are critical to policy decisions that affect tax rates, benefit amounts, and age of receivership. We acknowledge that underestimates of future life expectancy could prove especially problematic for such programs as Social Security and Medicare (Olshansky et al. 2005). The U.S. Social Security program, based on intergenerational transfers, succeeds if the surplus taxes collected from the working population offset the deficit generated by the elderly and other qualifying Social Security recipients who pay little in taxes. Lee and Tuljapurkar (1997) calculate that each additional year of life expectancy requires an increase in tax rates (or a decrease in benefits) by 3.6%. Similarly, individuals need accurate life expectancy estimates to balance work and retirement. Lee and Tuljapurkar (1997) calculate that a population would have to increase earnings (or decrease production) over a lifetime by .8% for each additional year of life expectancy.

Our results suggest that the U.S. population will continue to see improvements in life expectancies but those improvements are minimal and of concern. We should remain mindful that increases can be uneven, slow, and punctuated by periods of rapid increase as well as short-term periods of decline. The more accurately our forecasting methods can capture this unevenness, the better. Overall, our results reveal important insight into U.S. mortality over the next five decades.

REFERENCES

Anderson, R.N. 1999. *U.S. Decennial Life Tables for 1989-91*. Vol. 1, No. 4, United States Life Tables Eliminating Certain Causes of Death. Hyattsville, MD: National Center for Health Statistics.

Benjamin, B., and H.W. Haycocks. 1970. *The Analysis of Mortality and Other Actuarial Statistics*. London: Cambridge University Press.

Board of Trustees. 2005. *The 2005 Annual Report of the Board of Trustees of the Federal Old-Age and Survivors Insurance and Disability Insurance Trust Funds*. Washington, DC: U.S. Social Security Administration.

Bongaarts, J. 2005. "Long-Range Trends in Adult Mortality: Models and Projection Methods." *Demography* 42:23-49.

Bourgeois-Pichat, J. 1952. "Essai sur la Mortalite 'Biologique' de l'Homme." *Population* 7:381-94.

-------. 1978. "Future Outlook for Mortality Declines in the World." *Population Bulletin of the United Nations* No 11.

Christakis, Nicholas A., and James H. Fowler. 2007. "The Spread of Obesity in a Large Social Network over 32 Years." *The New England Journal of Medicine* 357:370-379.

Committee on the Consequences of Uninsurance, Board on Health Care Services. 2002. "Care Without Coverage: Too Little, Too Late." Washington, DC: Institute of Medicine.

Dickey, D.A., and W.A. Fuller. 1979. "Distribution of the Estimators for Autoregressive Time Series with a Unit Root." *Journal of the American Statistical Association* 74(366):427-31.

Elliott, G., T.J. Rothenberg, and J.H. Stock. 1996. “Efficient Tests for an Autoregressive Unit Root.” *Econometrica* 64(4):813-36.

Flegal, Katherine M., Barry I. Graubard, David F. Williamson, and Michael H. Gail. 2005. “Excess Deaths Associated with Underweight, Overweight, and Obesity.” *Journal of the American Medical Association*. 293(15):1861-67.

Fogel, R.W., and D.L. Costa. 1997. “A Theory of Technophysio Evolution, with Some Implications for Forecasting Population, Health Care Costs, and Pension Costs.” *Demography* 34:49-66.

Fries, J.F. 1980. “Aging, Natural Death, and the Compression of Morbidity.” *The New England Journal of Medicine* 303(3):130-35.

Gompertz, B. 1825. “On the Nature of the Function Expressive of the Law of Mortality.” *Philosophical Transactions* 27:513-85.

Hadley, Jack. 2003. "Sicker and Poorer - The Consequences of being uninsured: A review of the research on the relationship between health insurance, medical care use, health, work, and income." *Medical Care Research and Review* 60:3S-75S.

Heligman, L., and J.H. Pollard. 1980. “The Age Pattern of Mortality.” *Journal of the Institute of Actuaries* 107(434):49-80.

Hoyert, D.L., H.-C. Kung, and B.L. Smith. 2005. “Deaths: Preliminary Data for 2003.” *National Vital Statistics Reports* 53(15):1-48.

Human Life-Table Database. UC-Berkeley and Max Planck Institute for Demographic Research. http://www.lifetable.de/. Accessed February 14, 2005.

Human Mortality Database. UC-Berkeley and Max Planck Institute for Demographic Research. http://www.mortality.org. Accessed February 14, 2005.

Johansen, S. 1995. *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press.

Keyfitz, N. 1977. "What Difference Would It Make If Cancer Were Eradicated? An Examination of the Taeuber Paradox." *Demography* 14:411-18.

Lave, L.B. and E.P. Seskin. 1973. "An Analysis of the Association Between U.S. Mortality and Air Pollution." *Journal of the American Statistical Association* 68(342):284-90.

Lee, R.D. 2000. "The Lee-Carter Method for Forecasting Mortality, with Various Extensions and Applications." *North American Actuarial Journal* 4:80-93.

Lee, R.D., and L.R. Carter. 1992. "Modeling and Forecasting U.S. Mortality." *Journal of the American Statistical Association* 87(14):659-71.

Lee, R.D. and T. Miller. 2001. "Evaluating the Performance of the Lee-Carter Method for Forecasting Mortality." *Demography* 38:537-49.

Lee, R.D. and S. Tuljapurkar. 1997 "Death and Taxes: Longer Life, Consumption, and Social Security." *Demography* 34:67-81.

Manton, K.G., E. Stallard, and H.D. Tolley. 1991 "Limits to Human Life Expectancy: Evidence, Prospects, and Implications." *Population and Development Review* 17:603-37.

McGinnis, J.M., and W.H. Foege. 1993. "Actual Cause of Death in the United States." *Journal of the American Medical Association* 270(18):2207-12.

McNown, R. 1992. "Modeling and Forecasting U.S. Mortality: Comment." *Journal of the American Statistical Association* 87:671-72.

McNown, R., and A. Rogers. 1989. "Forecasting Mortality: A Parameterized Time Series Approach." *Demography* 26:645-60.

Nam, Charles B., Richard G. Rogers, and Robert A. Hummer. 1996. "Impact of Future Cigarette Smoking Scenarios on Mortality of the Adult Population in the U.S.: 2000-2050." *Social Biology* 43:155-68.

National Research Council. 1997. *Between Zeus and the Salmon: The Biodemography of Longevity*. Edited by K. Wachter and C. Finch. Washington, D.C.: National Academy Press.

Oeppen, J., and J.W. Vaupel. 2002. "Broken Limits to Life Expectancy." *Science* 296:1029-31.

Olshansky, S.J., and B.A. Carnes. 1997. "Ever Since Gompertz." *Demography* 34:1-15

Olshansky, S.J., B.A. Carnes, and C. Cassel. 1990. "In Search of Methuselah: Estimating the Upper Limits to Human Longevity." *Science* 250:634-40.

Olshansky, S.J., B.A. Carnes, R.G. Rogers, and L. Smith. 1997. "New and Ancient Threats to World Health." *Population Bulletin* 52(2):1-52.

-------. 1998. "The Challenge of Prediction: The Fifth Stage of Epidemiologic Transition?" *World Health Statistics Quarterly* 51(2-4):207-217.

Olskansky, S.J., D.J. Passaro, R.C. Hershow, J. Layden, B.A. Carnes, J. Brody, L. Hayflick, R.N. Butler, D.B. Allison, and D.S. Ludwig. 2005. "A Potential Decline in Life Expectancy in the United States in the 21st Century." *New England Journal of Medicine* 352(11):1138-45.

Omran, A.R. 1977. "Epidemiologic Transition in the United States: The Health Factor in Population Change." *Population Bulletin* 32(2):3-42.

Preston, S.H. 2005. "Deadweight? – The Influence of Obesity on Longevity." *New England Journal of Medicine* 352(11):1135-37.

Preston, S.H., P. Heuveline, and M. Guillot. 2001. *Demography: Measuring and Modeling Population Processes*. Oxford, UK: Blackwell Publishers.

Rogers, R.G., R.A. Hummer, and C.B. Nam. 2000. *Living and Dying in the USA: Behavioral, Health, and Social Differentials of Adult Mortality*. London, UK: Academic Press.

Rogers, R.G., R.A. Hummer, and P.M. Krueger. 2005. "Adult Mortality." *Handbook of Population*, edited by Dudley Poston and Mike Micklin. NY: Springer Publishers.

Rogers, R.G., and R. Hackenberg. 1987. "Extending Epidemiological Transition Theory: A New Stage." *Social Biology*. 34: 234-243.

Siegel, J. S. 1980. "Present and Prospective Demographic Trends for the Elderly Population and Some Implications for Health Care." In S.G. Halnes and M. Feinleib (eds.) *Epidemiology of Aging*. National Institute of Health Pub. No. 80-969. Washington DC: U.S. Government Printing Office.

Smith, D.W., and B.S. Bradshaw. 2006. "Variation in Life Expectancy During the 20th Century in the United States." *Demography*. 43(4):647-57.

TableCurve 2D. Jandel Scientific, 2591 Kerner Blvd, San Rafel, CA 94901.

Thatcher, A. 1999. "The Long-Term Pattern of Adult Mortality and the Highest Attained Age." *Journal of the Royal Statistical Society, Series* A No. 162:5-43.

Tuljapurkar, S., and C. Boe. 1998. "Mortality Change and Forecasting: How Much and How Little Do We Know?" *North American Actuarial Journal* 2(4):13-47.

Tuljapurkar, S., N. Li, and C. Boe. 2000. "A Universal Pattern of Mortality Decline in the G7 Countries." *Nature* 405:789-92.

Vaupel, J. W. 1986. "How Change in Age Specific Mortality Affects Life Expectancy." *Population Studies*. 40: 147-157.

Wilmoth, J. 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.

-------. 1998. “The Future of Human Longevity: A Demographer’s Perspective.” *Science* 280:395-97.

Wilmoth, J.R. and S. Horiuchi. 1999. “Rectangularization Revisited: Variability of Age at Death Within Human Populations.” *Demography*. 36: 475-495.

Wilmoth, J.R., and H. Lundstrom. 1996. “Extreme Longevity in Five Countries: Presentation of Trends with Special Attention to Issues of Data Quality.” *European Journal of Population* 12:63-93.

Wong-Fupuy, C., and S. Haberman. 2004. “Projecting Mortality Trends: Recent Developments in the United Kingdom and the United States.” *North American Actuarial Journal* 8(2):56-83.

Table 1. Observed (Years 1940 Through 2000) and Projected (Years 2020 Through 2055) Sex- and Age-Specific q_x Values, Selected Years, United States.

	Selected Years						
	Observed				Projected		
Age	1940	1960	1980	2000	2020	2040	2055
	A. Female q_x						
0	0.04497	0.02267	0.01127	0.00642	0.00351	0.00241	0.00192
10	0.00073	0.00028	0.00020	0.00012	0.00010	0.00009	0.00008
20	0.00192	0.00063	0.00061	0.00046	0.00044	0.00041	0.00040
30	0.00276	0.00113	0.00077	0.00059	0.00051	0.00045	0.00042
40	0.00459	0.00244	0.00166	0.00145	0.00096	0.00082	0.00075
50	0.00885	0.00565	0.00419	0.00318	0.00257	0.00222	0.00203
60	0.01820	0.01356	0.00982	0.00785	0.00704	0.00620	0.00574
70	0.04410	0.03043	0.02248	0.01914	0.01922	0.01725	0.01617
80	0.10144	0.08188	0.05884	0.04973	0.05142	0.04711	0.04469
90	0.22119	0.19857	0.15480	0.13994	0.13043	0.12223	0.11756
98	0.33557	0.32124	0.27708	0.28083	0.25297	0.24178	0.23531
	B. Male q_x						
0	0.05741	0.02969	0.01404	0.00781	0.00354	0.00186	0.00116
10	0.00102	0.00046	0.00030	0.00018	0.00014	0.00011	0.00009
20	0.00245	0.00180	0.00199	0.00134	0.00123	0.00112	0.00104
30	0.00339	0.00183	0.00189	0.00128	0.00103	0.00086	0.00075
40	0.00593	0.00382	0.00305	0.00258	0.00200	0.00163	0.00141
50	0.01288	0.01055	0.00779	0.00554	0.00497	0.00415	0.00365
60	0.02653	0.02494	0.01882	0.01259	0.01236	0.01059	0.00947
70	0.05652	0.05105	0.04339	0.03001	0.03041	0.02672	0.02435
80	0.12196	0.10999	0.09394	0.07250	0.07286	0.06579	0.06116
90	0.24517	0.22600	0.19480	0.17554	0.16453	0.15303	0.14530
98	0.35578	0.33821	0.31430	0.31358	0.29112	0.27742	0.26805

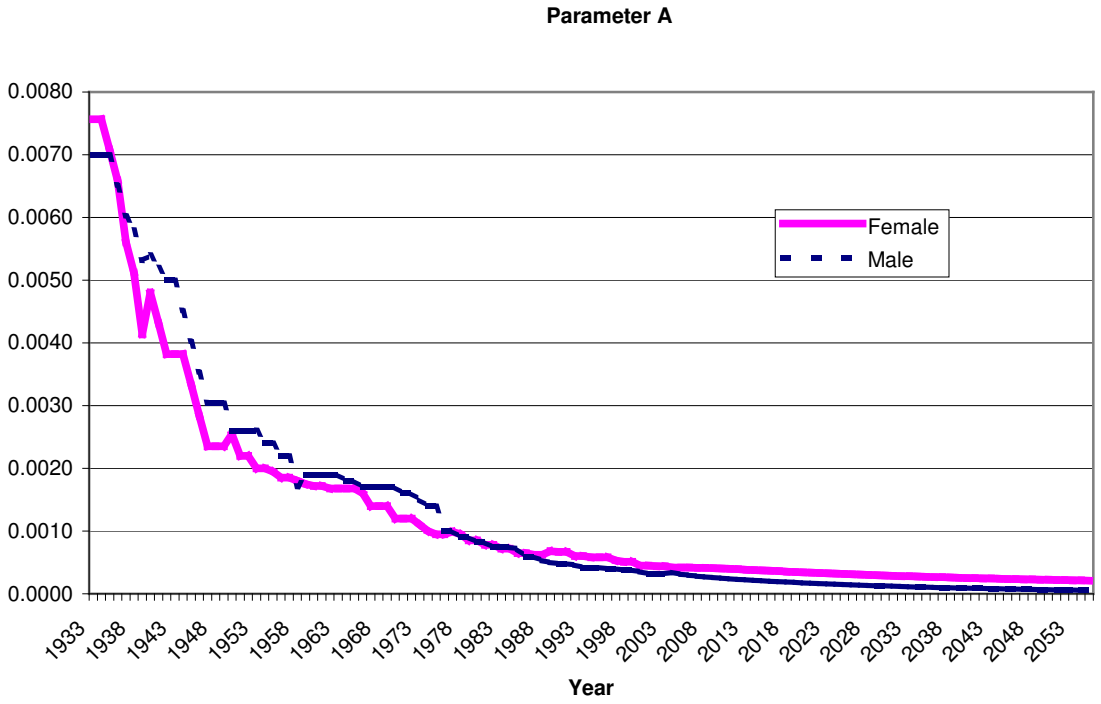
Source: Observed values derived from Human Life-Table Database (2007).

Table 2. Observed (Years 1940 Through 2000) and Projected (Years 2020 Through 2055) Sex- and Age-Specific Life Expectancies, Selected Years, United States.

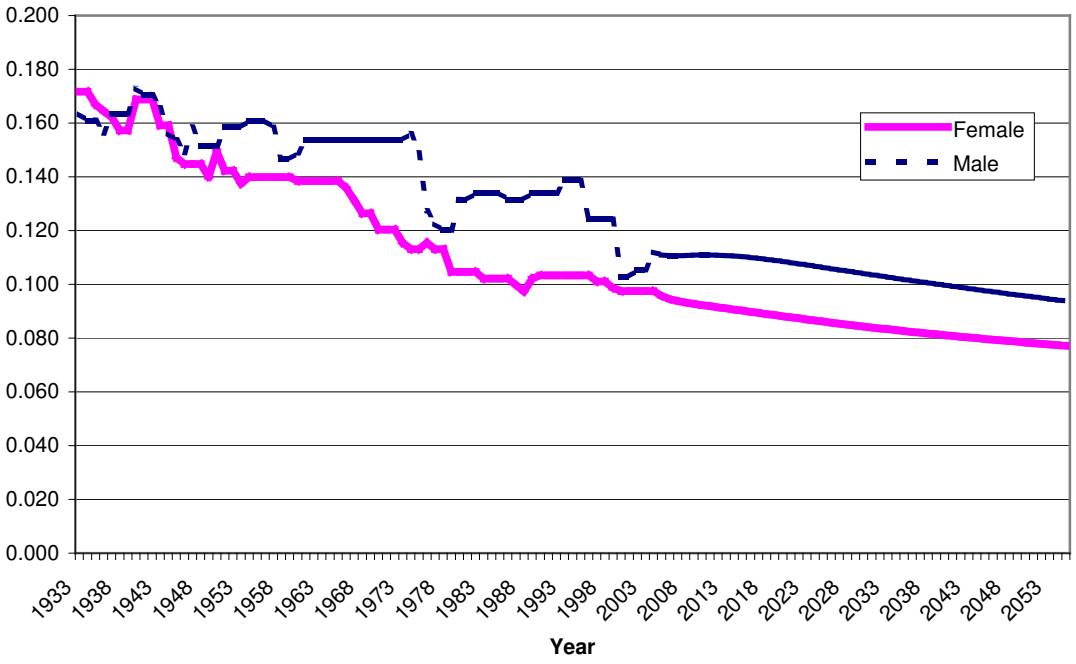
	Selected Years						
	Observed				Projected		
Age	1940	1960	1980	2000	2020	2040	2055
	A. Female e_x						
0	65.58	73.31	77.44	79.56	80.50	81.63	82.27
20	50.30	55.68	58.81	60.39	61.04	62.04	62.63
40	32.60	36.70	39.61	41.08	41.61	42.57	43.12
60	16.86	19.64	22.11	23.17	23.31	24.08	24.54
80	6.06	7.09	8.49	9.08	9.18	9.57	9.80
98	1.16	1.18	1.22	1.22	1.25	1.26	1.26
	B. Male e_x						
0	61.16	66.63	69.98	74.28	75.31	76.98	78.09
20	46.78	49.64	51.77	55.36	55.97	57.46	58.48
40	29.43	31.30	33.54	36.76	37.12	38.47	39.40
60	14.86	15.84	17.36	19.87	19.93	20.93	21.64
80	5.39	6.01	6.65	7.56	7.70	8.15	8.47
98	1.14	1.16	1.19	1.19	1.21	1.22	1.23

Source: Observed values derived from Human Life-Table Database (2007).

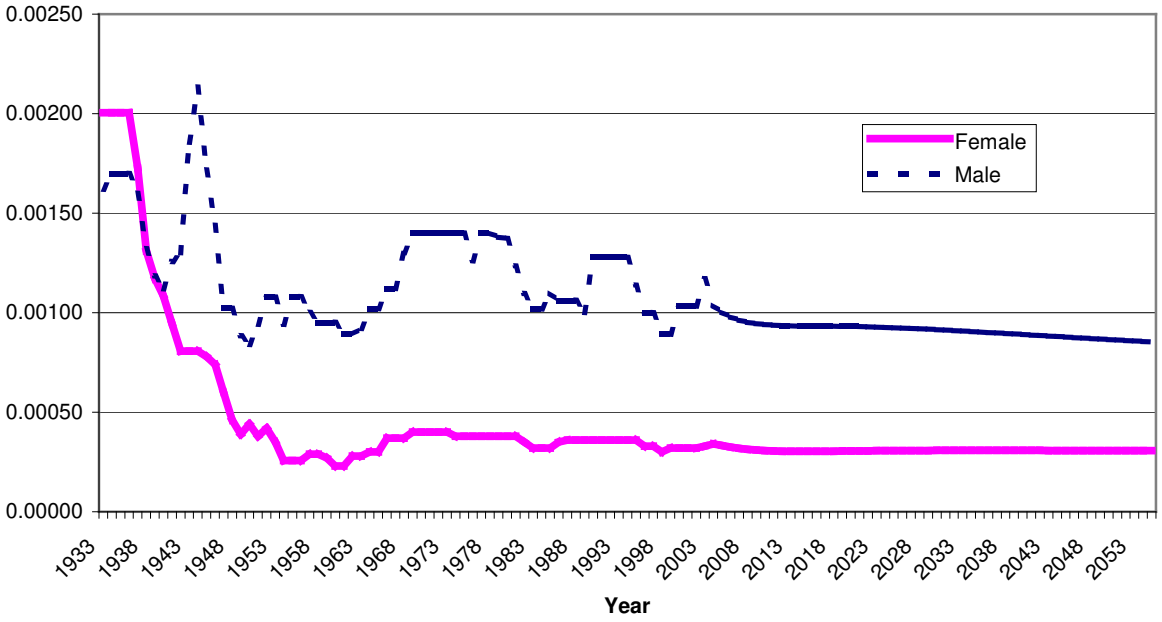
Figure 1. Observed (1933-2004) and Projected (2005-2055) Mortality Parameter Values by Sex, United States



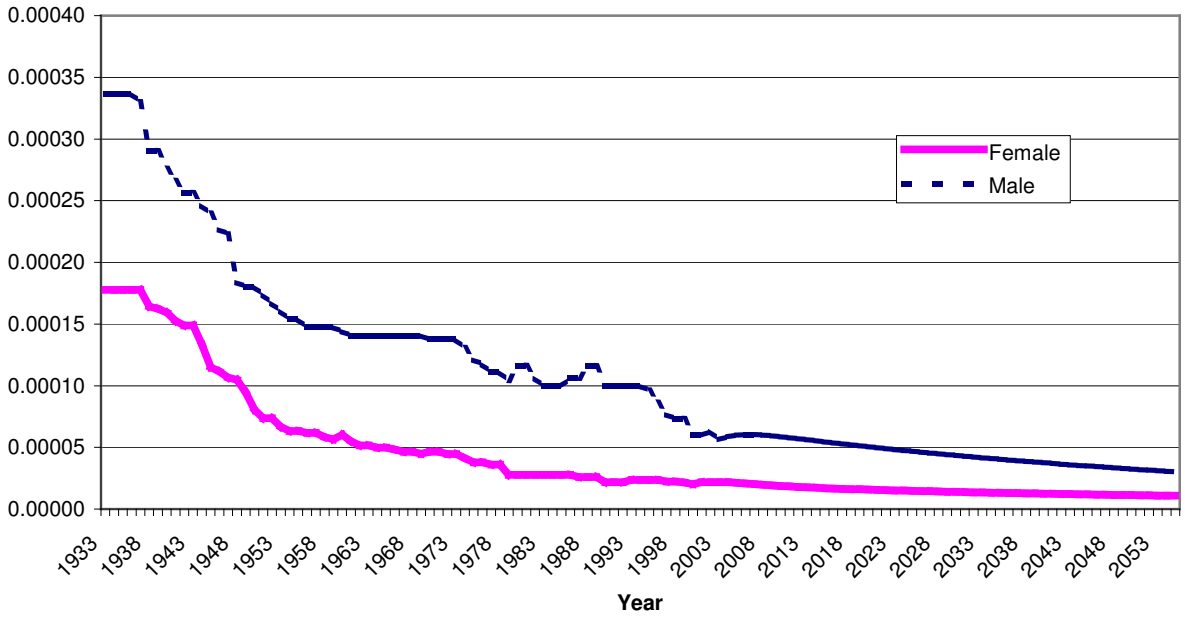
Parameter C



Parameter D



Parameter G



Parameter H