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SCOR Papers

How Long Will We Live? A Demographer's Reflexions on Longevity

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Abstract

How long will men in France who are now 75 live? Or women? Or men or women who are now 60 or 40? Or men and women in Denmark, Germany, Italy, Japan or the United States? What will the lifespans be of newborns in these and other countries with long life expectancies?
The answers to such questions require forecasts for cohorts, i.e., groups of people the same age. Demographers more often make forecasts for periods - e.g., what will life expectancy be 50 years from now? Period calculations pertain to synthetic cohorts - imaginary generations - that live their entire lives at the death rates that prevail in a particular year. Both cohort and period forecasts of longevity are of interest to insurance - and reinsurance - companies, to governments and businesses that have pension obligations, to investors worrying about the solvency of such governments and businesses, and to individuals pondering how much to consume, how much to save and how to plan the time of their lives. For many purposes, cohort forecasts are more useful - but usually period forecasts are easier to make.

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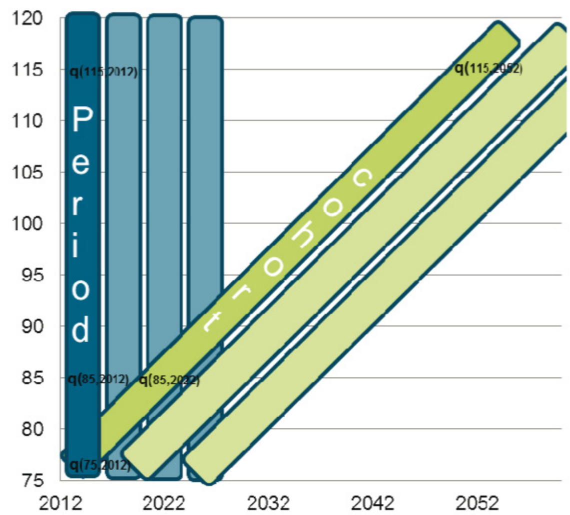
1. Cohort versus Period forecasts

In this paper I reflect on how best to make cohort and period forecasts of longevity. I consider future values of the remaining life expectancy of 75-year-old French males as an example of a period forecast and the average remaining lifespan of the generation of French men who were born 75 years ago as an example of a cohort forecast. I estimate the increase over the next 100 years in the life expectancy of newborn French girls as an example of a period forecast and speculate about the average lifespans of French girls born in 2010 as an example of a cohort forecast. Plotted below is a schematic representation of period versus cohort futures.

Because of concerns about longevity risk, I will consider not only median values of the distribution of uncertain forecasts but also the 99.5 percentile of the distribution, i.e., the forecast that has only half a percent chance of being exceeded. Here I present some reflexions and some preliminary guesstimates: much more thinking is needed.



2. Statistical modeling and/or Experts Judgment?

A cogent argument can be made that the first step in making a longevity forecast should be to extrapolate historical data using methods of time-series analysis [1]. Reasons why the future might be better or worse than the past or more uncertain can then be considered. That is the strategy I will follow. Many factors influence mortality, including economic, social and political conditions, educational levels, diet, smoking and other aspects of personal behavior, epidemics, public health interventions, the quality of health care, the development of more effective pharmaceutical products, improvements in medical treatments and surgical procedures, and revolutionary biomedical breakthroughs. It is so difficult to forecast these factors and their impact on mortality that it is best to extrapolate past trends in mortality or life expectancy. The future may be turbulent but so was the past - consider the 20th century, marked by two world wars, the Spanish Flu epidemic, the ascent and retreat of fascism and communism, the great depression, the AIDS epidemic, etc. Health improvements in the future may be slowed by deleterious trends, e.g., in obesity, but health improvements in the past also were slowed by deleterious trends, e.g., the rise of cigarette smoking. The future may bring biomedical breakthroughs in preventing and treating, e.g., cancer, dementia and perhaps senescence, but the past also was marked by remarkable advances in reducing mortality, e.g., from infectious diseases and from cardiovascular diseases.

Past forecasts of future longevity based on expert judgment have been wrong: the most knowledgeable analysts strongly believed for decades that life expectancy was approaching a looming limit - but life expectancy kept on rising [2]. After a forecast is made based on extrapolation of historical data, consideration then can be given to experts' judgments about how possible changes in various factors might alter the forecast. This should be done with great caution and reserve given the dismal record of experts who forecast longevity based on their notions of how factors affecting longevity would evolve in the future.

Even forecasts based solely on extrapolation of historical data require some expert judgment, e.g., about how much historical data to use - 50 years? 100 years? 150 years? - and about what kind of data to use - life expectancy at birth? age-specific death rates? cause-specific, age-specific death rates? - as well as about whether to use data for females or for males or for the combined population of females and males.

Hence some reliance on expert judgment is necessary. Generally experts' judgments about the nature of the past are much better than their judgments about course of the future. Judgments about whether or not to use life expectancy data for females for the past 170 years are likely to be more reliable than judgments about whether obesity will result in significantly lower life expectancy 50 years from now.

Research on "historical-forecasts", suggests that it is generally judicious to base a forecast of y years into the future on data for at least y years in the past - and if comparable data are available and the time series shows regular persistence of patterns, then 2y or 3y is even better. Forecasts of the future based on data for a few recent years, i.e., for a period considerably less than y years, have generally failed to track future trends -except in a few cases when there was a sea change in conditions. The most notable example is the baby boom following WWII - but this pertains to fertility and was determined by the vagaries of human choice. Mortality trends are much more stable and it is generally reasonable to adhere to the rule: "at least y years of past data to forecast y years into the future".

3. Forecasts are uncertain.

For some purposes, the central forecast is of more interest and is more important than the probability distribution. In some instances a company may be interested in the simple question: is longevity in the future likely to be higher or lower than forecast by our competitors? The answer to this question would help determine whether the company wants to be active in some annuity, life-insurance or reinsurance market. On the other hand, longevity risk is of great interest to many corporations, governmental agencies and investors—and in this regard, forecasts of uncertainty about future longevity are needed. As noted above, the 99.5 percentile of the distribution—an upper estimate such that there is 99.5% chance that the measure of longevity will not exceed this value—is sometimes of particular interest in assessing risk.

One of the major advances in recent years in demographic prognosis has been the development of time-series methods that forecast probability distributions of outcomes. Predictions should include not only a median or mean forecast but also a probability distribution around the central value. Expert judgments about reasons why the future might be different from the past can be used to adjust the central forecast—but only if the judgments seem compelling and even then with trepidation. A more important use of expert judgments is to widen the range of uncertainty estimated by time-series methods. There may be factors in the future that make the future qualitatively different from the past: uncertainty about such factors may suggest that the true uncertainty of an empirically-based forecast is greater than past fluctuations imply. Again, however, experts' opinions have to be treated gingerly: the more recent past differed qualitatively from the earlier past in various ways and the impact of this is captured by the time-series of historical observations. The most important uncertainty, in my judgment, concerns whether biomedical research will produce innovations that slow the rate of senescence, i.e., the deterioration that gets worse and worse with age. Up until now, progress in increasing life expectancy has been achieved by lowering death rates: in the 19th century largely for children and younger adults and since 1950 largely for older adults. With age, individuals suffer cumulative damage to macromolecules and to various physiological processes, resulting in an exponential increase in senescent mortality. No progress has been made in slowing this rate of increase—the progress that has been achieved has lowered the level of mortality but not the slope of increase.

The GOMPERTZ model

The simplest model, due to Gompertz, is that the force of mortality is given by a parameter a multiplied by e raised to the b times x power, where b is a second parameter and x is age. The progress made historically in lowering the force of mortality was progress in reducing a in this model, not b. More complicated models of heterogeneous populations with both senescent and non-senescent causes of death use more complicated formulas, but the basic idea is the same. The level of mortality a has been reduced but the slope b of the increase in the senescent mortality of individuals has not changed [9]. Indeed, if the simple Gompertz model is fit to data on the rise in death rates at older ages, then for most populations the estimated value of b appears to increase rather than decrease.

Many biological research teams, working with such model organisms as yeast, nematode worms, fruit flies and rodents or focusing on cells or components of cells such as mitochondria, are attempting to discover the genetic and physiological factors that regulate the speed of senescence. Their hope is to be able to devise interventions that slow the process of senescence in humans. Suppose the rate of senescence could, starting say at age 20, be cut in half. Then if there were no deaths due to causes other than senescence, remaining life expectancy would double. There are non-senescent deaths so the gain would not be so great, but remaining life expectancy at age 20 might rise from about 65 years to perhaps 110 years and life expectancy at birth might approach 130 years. Cutting the pace of senescent deterioration in half and then in half again would yield a life expectancy at birth of well over two hundred years. If such progress continued, then some of the cohort of newborns alive today might live hundreds and perhaps even thousands of years [10].

What is the chance of this happening? Could the rate of aging be cut by a factor of 2, 4, 10? Could senescent deterioration be halted such that damage with age was fully repaired? These are very difficult questions to assess. Some species age more slowly than others and some species do not seem to age at all [11]. Furthermore much is being learned about the genetics of aging and about cellular mechanisms. So it is not implausible that eventually humans will live much longer than today. But when might the first interventions be implemented that significantly slow senescence? If such interventions can be achieved within the next century, then (1) the average number of years lived by the cohort of babies born in France in 2010 might considerably exceed 100 and (2) period life expectancy at birth a century from today also might be considerably longer than a century. The likelihood of this, it seems to me, is at least half a percent.

4. What should be extrapolated?

Lee and Carter developed a method that forecasts age-specific death rates based on historical trends [3]. Variants of this general approach have been devised by others, with important contributions by Juha Alho [4], Nico Keilman, Shripad Tuljapurkar, Heather Booth and Tiziana Torri.

Some of these variants allow for changes in the trends over time—to capture, e.g., the accelerating improvements in mortality at older ages. Life expectancy can be calculated from the death rates that are forecast. I will call such methods Lee-Alho approaches.

I prefer the more direct method of forecasting life expectancy by extrapolating historical data on life expectancy [2]. Some pioneering research has been done on this approach [5,6], but the strategy needs further development before it can be confidently applied. Furthermore, the approach should be systematically compared with Lee-Alho approaches to determine which is preferable.

Comparing the accuracy of forecasting models

Forecasting models can be assessed by pretending the year is 1960, say, and using alternative strategies to forecast to 2010. Such “historical forecasts” or “ex post forecasts” could be done for various years, e.g. forecasting from 1910 to 1990 or from 1980 to 2005. The forecasts could be for males and females in various countries.

Nico Keilman has pioneered informative research along these general lines [7]. Tiziana Torri has done some pioneering research on forecasting life expectancy directly vs. use of a Lee-Alho method and found that the direct forecasts were better [Ph.D. dissertation]. More research, however, is needed on this issue.

5. A direct approach via the best-practice life expectancy

The basic idea of the direct approach is to take advantage of the remarkable regularity of time trends in period best-practice life expectancy, i.e., period life expectancy in the population with the longest life expectancy (see Fig. 1). For females, best-practice life expectancy has been rising linearly at a pace of about two and a half years per decade —3 months per year, 6 hours per day— since 1840. Using a longer time series and a somewhat different set of populations, Mesle and Vallin fit several linear segments to the trend [8], but their basic results, especially for recent decades, are consistent with the general pattern of increase at a pace of about 3 months per year.

As shown in Fig. 1, particular countries follow more irregular patterns of life expectancy improvement. Patterns for males are somewhat more irregular than for females. It seems reasonable to extrapolate the best-practice trend for females. Then the divergence, from this best-practice trend, of the trajectory for females or males in a particular country can be analyzed using time-series methods. The most appropriate time-series strategies are those such that estimated improvements tend to be small when life expectancy is close to the best-practice level and improvements can be large if life expectancy is far from the best-practice level [6]. Such an approach makes it unlikely that a particular country will fall further and further behind the general trend set by life expectancy in the countries with the highest life expectancies. Hence the approach is best used for countries with long life expectancies and with similarly high levels of economic and social development.

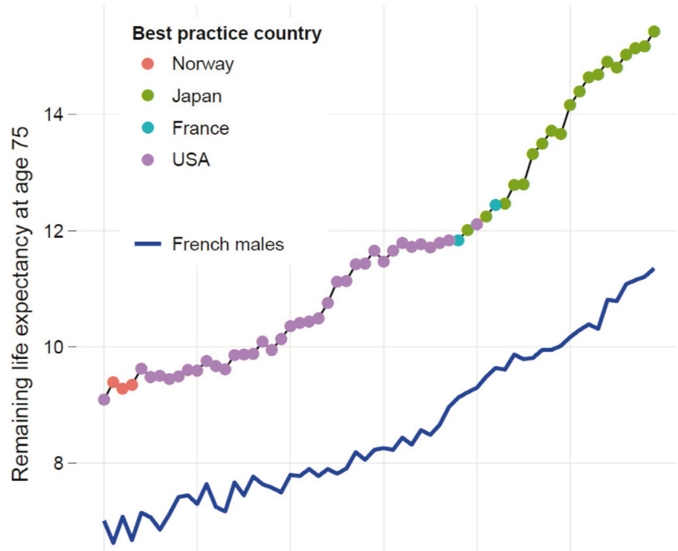


FIGURE 1: Female Life Expectancy from 1840 through 2009. The linear trend summarizes best-practice levels. The curves for France, Germany and the Netherlands illustrate the gaps for specific countries from the best-practice trend.

Best-practice life expectancy forecasts/guessestimates

As shown in Fig. 1, best-practice life expectancy at birth has risen at a pace of about two and a half years per decade since 1840. There are various reasons why this rise may slow in the future and various reasons why the rise might accelerate. A carefully compiled compendium of these reasons with judicious descriptions of what is known about them might be of considerable interest. I have done some preliminary, unpublished research along these lines. In my judgment the overall impact of the various possibilities is, on balance and in view of the great uncertainties about them, neutral. Hence I think that the long-term historical trend, which reflects many positive as well as negative events, can be used as a basis to forecast the future trend. The actual trend in the future may be slower or faster, but an extrapolation of the past trend provides a serviceable middle variant, a median forecast. The forecast then is simple—the mid-point of the distribution of possible best-practice life expectancies a century from now is 25 years longer than now, 111 vs. 86.

Best-practice remaining life expectancy at specific ages, for example age 75, also shows regularity that can be used for forecasting (see Fig. 2). If life expectancy at birth continues to rise at a steady pace, then death rates at older and older ages have to decline sufficiently to permit such progress. Hence, best-practice remaining life expectancy at age 75 can be forecast to improve initially at a pace implied by data in recent decades and subsequently at a faster pace that approaches 3 months per year.

Comparing the accuracy of forecasting models

Forecasting models can be assessed by pretending the year is 1960, say, and using alternative strategies to forecast to 2010. Such "historical forecasts" or "ex post forecasts" could be done for various years, e.g. forecasting from 1910 to 1990 or from 1980 to 2005. The forecasts could be for males and females in various countries.

Hence, when I make them, my period forecasts of future life expectancies of newborn French girls will use data on best-practice life expectancy and French female life expectancy back to 1840. Most 75-year-old French males will die within 15 years and nearly all within 25 years. And the time series of remaining life expectancy at age 75 (Fig. 2) is fairly regular from 1950 on and even more regular from about 1980 on — so I will base my cohort forecast for this population on the past 30-60 years of data.

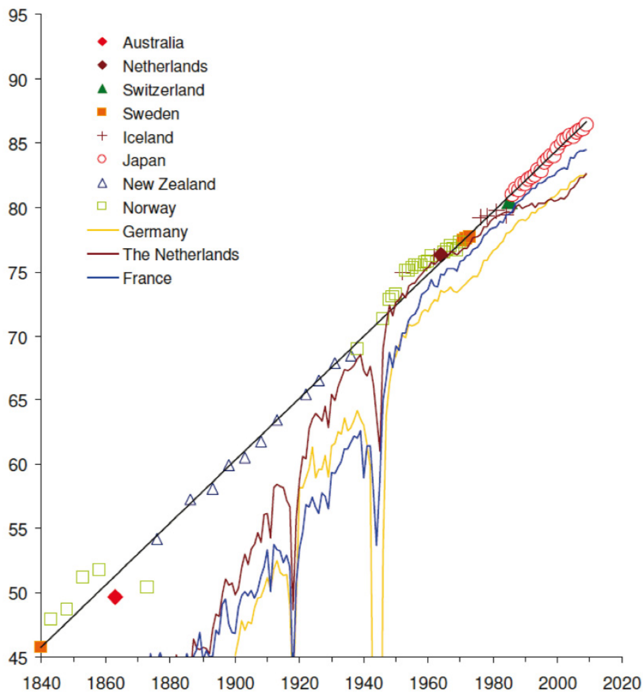


FIGURE 2: Remaining life expectancy at age 75 for French males (blue) compared with remaining life expectancy at age 75 for females in the country doing best, from 1950 through 2009. Data were taken from the Human Mortality Database (www.mortality.org) for countries with populations of more than a million people.

Consider now the very different question of how long 75-year-old French males might live. For a reinsurance company assessing the value of annuities issued by other organizations, this is an important question. More generally, thinking about how to address it sheds light on how to forecast longevity. Fig. 2 shows the trend in period estimates of remaining life expectancy at age 75 for French males. It can be seen that since 1980 this life expectancy has been increasing at a pace of about one year per decade. Extrapolating the trend yields a forecast that remaining life expectancy for 75-year-old French males may increase from 11.35 in 2009 to 14.35 some thirty years later, when almost all will have died. If progress accelerates, which is implied by a steady increase in life expectancy at birth at a pace of 2.5 years per decade and which is also suggested by the increase of about 1.5 years per decade since 1980 in best-practice female remaining life expectancy at age 75, then the remaining life expectancy might increase by an average of 1.5 years per decade and reach 16 or so in 2039. It seems unlikely that radical breakthroughs in slowing senescence will benefit men who are currently 75. So uncertainty about the forecast is modest. If remaining life expectancy rose over the coming decade by 2 years and then by 3 years and by 4 years in the following two decades, remaining life expectancy would rise from 11.35 to 20.35. This might be a reasonable upper bound, a 99.5 percentile.

The remaining years of life for the current cohort of 75-year-old French males is likely to fall between the period values of 11.35 in 2009 and perhaps 14.35 to 16 years (or even 20.35) in 2039. A rough estimate might be 13 or so, an increase of about 15% over the current period value of 11.35. Making more exact estimates is of such interest that more thought and some systematic time-series analysis is warranted. Research on period vs. cohort life expectancy can help inform such analysis [12-14]. Expert judgments may also be relevant, especially forecasts of forthcoming introductions of new drugs and treatments that could reduce death rates among those 75+.

6. Further steps

Let me now turn to a general issue. Given the importance of longevity forecasts, it is astounding how little research is being done to improve the quality of such forecasts. Directions for research include the following:

- The causes of the linear rise in best-practice life expectancy since 1840 are not well understood. The linear pattern may be an artifact of some more complicated process that will not continue to yield a linear rise in the future. Furthermore, if life expectancy is forecast, then a model has to be used to derive age-specific death rates from the overall level of life expectancy. Research is needed on why life expectancy has risen linearly and on how age-specific death rates can be estimated given life expectancy.
- Although period changes in mortality dominate changes on a cohort basis, there are cohort patterns, for instance regarding intensity of cigarette smoking. How can such cohort effects be incorporated in longevity forecasts? Doing so is problematic [15]. Wang and Preston [16] have made a constructive start, but more thinking is needed.
- Extensive data over age, time, population and sex are available on proximate, underlying and contributing causes of death. How can this information be used to improve mortality forecasts? Trends over time in cause-specific age-specific mortality have been complicatedly nonlinear and there have been complex patterns of correlation between trends for different causes. For these reasons, simple forecasting models based on cause-specific data have tended to produce biased forecasts, with estimates of life expectancy generally being too low. At least at the current state of the forecasting art it is advisable not to base mortality or life expectancy forecasts on cause-specific data, unless there is particular interest in specific causes of death. Research is needed on how the wealth of cause-of-death information can be exploited for mortality forecasting.
- Populations are heterogeneous. The frail tend to die first. This probably accounts for the leveling off of human death rates at advanced ages and for some of the convergence (and crossover) of age trajectories of mortality for pairs of populations (such as blacks vs. whites in the United States). So far, however, no feasible, compelling way has been found to model this heterogeneity in forecasting models.
- Bongaarts and Feeney have made a case for tempo effects on mortality, and I have demonstrated that such effects are related to population heterogeneity and do exist. At present, however, it is not clear what the magnitudes of such effects are and how to account or correct for them in mortality forecasts [17].
- Age-specific death rates are highly correlated across ages, between males and females, and among countries. Yet most mortality forecasts are made for either males or females and for a particular country without taking trends for the other sex and for other countries into account. Furthermore, trends are generally forecast for each age separately, perhaps as in the Lee-Carter model for each age relative to the overall rate of improvement. Long-term forecasts that ignore strong age-patterns in the shape of the human mortality trajectory and that fail to consider correlations between males and females and among countries can yield highly implausible predictions. The strategy of forecasting best-practice life expectancy, forecasting the gap from this best-practice forecast for males and females in various countries, and using models to estimate age-specific mortality from life expectancy is one way of addressing these problems—but this strategy needs much more research before it can be widely used. Other ways of coping with correlations across age, between males and females, and among countries merit further research.

- Trends in age-specific mortality are non-linear and if a linear model is used, then resulting forecasts of life expectancy will tend to be too low. It is not yet clear how best to capture the acceleration of mortality progress in a model of the Lee-Alho genre. Furthermore, this kind of model requires forecasts of mortality at ages above 90 and 100: historical data on these ages are sparse and it is difficult to estimate the nonlinear trend in progress in reducing death rates among nonagenarians and centenarians.
- More research is needed on alternative methods for mortality forecasting, including:

--Methods that focus on trends over time and across populations in the modal age at death [18],
--Bayesian methods [19],
--Methods of spatial statistics to model surfaces of mortality over age and time,
--"Vanguard" models in which mortality trends for the highest SES groups are forecast and then the lags of lower SES groups are forecast,
--Simulation methods that combine micro data on individuals with information on macro trends (e.g., MicMac or ProFAMY) to capture trends in smoking behavior, education, obesity, economic conditions, family structure, etc.,
--Use of expert judgments to develop forecasts based on alternative scenarios [20],
--Advanced time-series models, including Markov switching models, co-integration models with more than one time series, and Bayesian versions of time-series models.

7. Conclusions

In conclusion, let me emphasize that at current states of knowledge about methods for predicting future mortality, it is reasonable to base forecasts of longevity, both cohort or period and both at birth or at some older age, on extrapolation of historical data on mortality and life expectancy. A method that forecasts age-specific mortality, in the general Lee-Alho genre, is a good choice. An alternative choice, that I favor but that needs further research before it can be confidently used, is to make forecasts of best-practice life expectancy and of likely discrepancies from this trend for males and females in specific countries and then to estimate age-specific death rates from a model of the pattern of mortality over age. Sometimes expert judgment can provide useful additional information but such judgments should be used with great care and caution and only to modestly adjust time-series extrapolations of central trends and to widen uncertainties around these trends.

In sum, it is likely that life expectancy will continue to rise and it is not impossible that life expectancy might increase to levels well above 100 years. This prognosis has a major implication for long-term governmental and corporate policies regarding ages when people can receive pensions and the sizes of the pensions. Such policies should be flexible enough to accommodate increases and possible large increases in life expectancy. To date, most pension rules have been rather rigid. In addition to immediate reforms to gradually increase pension ages, reforms that radically overhaul pension policies are needed to make such policies sustainable over coming decades of life-expectancy increase.

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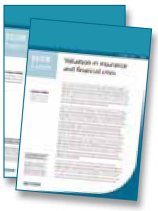

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