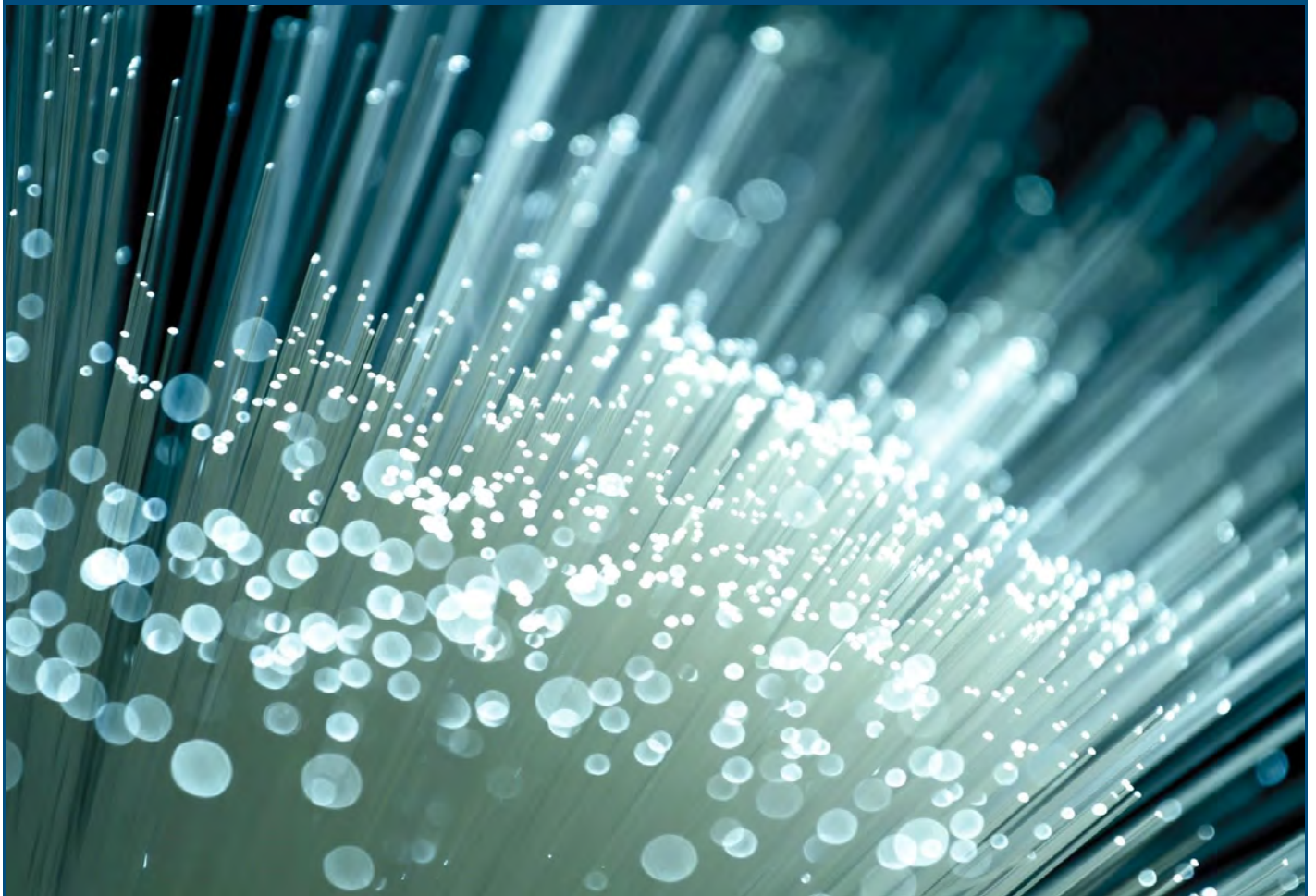


Living to 100

Insights on the Challenges and Opportunities of Longevity
Literature Review 2002–2017





Living to 100

Insights on the Challenges and Opportunities of Longevity

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1. Introduction

Living to 100 is a research initiative featuring triennial international symposia as a means to share knowledge and cultivate innovation. Sponsored by the Society of Actuaries (SOA) with many partners, the symposium brings together a diverse group of scientists and academics to share and discuss their knowledge on longevity. They discuss the latest scientific information on what makes us age and how aging has changed in the recent past; they examine recent trends in survival rates and construct projections for the future; they ponder the consequences for social, retirement, long-term care and health care systems; and they examine the implications of an increasingly elderly workforce and identify private industry innovations that aim to address the challenges of an aging population. There have been six Living to 100 symposia, which were conducted in 2002, 2005, 2008, 2011, 2014 and 2017. Each has produced a lasting body of research (the “symposia material”) that can educate and aid interested parties in understanding longevity and its societal implications.

The SOA commissioned Ernst & Young LLP (EY) to prepare a literature review based on the material presented at the six symposia. The review provides an overview of the technical material related to data sources, validation techniques and methodologies used by leading practitioners to develop mortality rate estimates for past, present and future periods. It also presents discussions regarding business, policy and social implications of increasing longevity. The views presented in this report are exclusively those from Living to 100 symposia authors and panelists. They do not reflect EY views or perspectives.

In particular, this report aims to:

- ▶ Provide an overview of the research and discussions presented at the symposia, highlight areas of consensus or disagreement within the research presented, and identify gaps in knowledge.
- ▶ Present the techniques for modeling mortality and forecasting future mortality exposed in the symposia, followed by applying a subset of those techniques to the U.S. general population data, while also identifying the challenges in applying such techniques and strategies to overcome them.
- ▶ Contribute commentary from interviews in which practicing actuaries discuss the lessons learned from implementing advanced-age mortality models in their work and perspectives on symposia topics.
- ▶ Provide a catalyst to the actuarial community to look beyond the modeling and forecasting aspects of old-age mortality, start conceptualizing the broader implications of increased longevity, and influence policymakers and regulators.
- ▶ Facilitate the content and relevance of symposia materials to the broad professional community and the general public and promote an interdisciplinary focus.

Several other areas within the SOA are also engaged in work related to the implications of long life, but that work is beyond the scope of this literature review. Additional work and research can be retrieved from SOA research committees like the Committee on Post-Retirement Needs and Risks Research and SOA sections such as the Long Term Care Insurance, Pension and Health sections.

The body of the report present various techniques for determining base mortality rates and forecasting older-age mortality. We hope this presentation illustrates the practical applications of these techniques, provides insight into the thought process required prior to implementing these models and facilitates the reflection process when interpreting results.

The Living to 100 symposia have produced a lasting and valuable body of knowledge on the future of longevity and its implications that will help practitioners to better understand competing perspectives on longevity and a societal lens through which to understand its impacts.

This report is divided into two parts. Part 1 focuses on papers that discuss data sources, validation techniques and methodologies that practitioners use to develop and project mortality rates for the past, present and future.

Section 1	Overview
Section 2	Data selection and validation
Section 3	A priori expectations
Section 4	Assessing trends in underlying mortality and morbidity
Section 5	Identifying possible predictors of changes in future improvement patterns
Section 6	Selecting the appropriate projection model

Part 2 focuses on papers that discuss the resulting implications of longevity for industry, society and government.

Section 1	Seniors in the workforce
Section 2	Social security and public support for retirement
Section 3	Challenges for retirement systems
Section 4	Challenges for long-term care systems
Section 5	Challenges for health care systems
Section 6	Innovation within the private industry

Each section highlights important information from the symposia by discussing matters in which experts from industry and academia tend to agree, matters in which they tend to disagree, and any gaps in knowledge that have been identified and may present opportunities for future research.

In each section we include a list of referenced papers, along with links to their full text on the SOA website. Appendices A and B house a full listing of the symposia monographs, with links to their full text on the SOA website and a synopsis of each paper’s content. Papers are referenced throughout this document by the keys [A-XXX] and [B-XXX]; these references are unique to each paper and can be used to find other references to the paper within this report, as well as to find the paper’s summary in appendices A or B. Appendix C contains a heat map developed to organize the symposia academic papers by practice area—retirement, health, long-term care, life and other—and by analytical phase and to provide an overall view of where knowledge has been abundant and lacking in prior symposia.

We note that this review is limited to material presented at the symposia. No effort has been made in this report to do independent research to fill the gaps in what has been presented at prior symposia. However, an effort has been made to identify these gaps to provide direction for future research.

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3. Executive Summary

Actuaries have a professional obligation as stewards of the financial safety nets that governments and individuals have created for themselves to understand and drive thought leadership on longevity—both the technical aspects of projecting longevity and on downstream societal implications.

Robert L. Brown, FSA, ACAS, FCIA, HonFIA,
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Longevity is an important issue. The implications of increasing longevity have far-reaching effects for the world's social programs and financial security as people grow into old age. It is also a trend actuaries are well suited to analyze: Actuaries have unique skills and experience that allow for distilling large volumes of data into key elements that can nourish predictions of future events. Their partnership with other experts will shape the discussion on the implications of increasing longevity. In developing the Living to 100 symposia, the SOA is facilitating the collection of key elements of that discussion and shaping it going forward.

Papers presented at the symposia have been categorized by their scope and area of application within Appendix C. This serves as a means to easily find leading papers specific to the field of interest as well as an overall view of where knowledge has been abundant in prior symposia and what areas require additional research. As one reads the material, a few key threads appear consistently throughout the discussion.

First, the majority of people around the globe are living longer,^[A-62] although the rate of improvement differs across ethnicities, geographies and social status.^[A-155] In particular, females generally have higher life expectancies than males, placing them at a higher risk for challenges associated with longevity. However, the gap between female and male life expectancies has been narrowing in recent years, showing a relative stagnation of female mortality improvement and continuous increases in males.^[A-17]

Second, our understanding of what factors have a material effect on our expected lifetime is growing but is not yet complete (see section 4.1.5.1). There are large gaps in knowledge on how the complex aging process functions as well as on the influence of genetics and its related technology.^{[A-134] [A-172] [A-173] [A-175]} The correlation and evolution of causes of death also present challenges when forecasting longevity.^{[A-17] [A-155]} Our understanding of older age mortality is also limited, in part because the data at older ages are sparse and of varying quality. There are open questions related to the rate of improvement and the ultimate age at which it is appropriate to assume a mortality table should end.^{[A-30] [A-40] [A-157] [A-172] [A-174]}

Third, in many regions there is no broad consensus on the appropriate base mortality rates and improvement factors that should be used to value life-contingent liabilities or on the models to forecast these rates into the future. This creates challenges for practitioners who must develop their own projections; inefficiencies such as the use of different data, assumptions and models leads to different mortality forecasts; and inconsistencies across disciplines—for example, between the pension and insurance communities—as each develops its own independent view of long-term mortality (see section 4.1.4.4). Having said this, the actuarial community has successfully dealt with issues of this magnitude in the past. As evidenced by the material presented in the body of this report, we can use techniques such as stress-testing, backtesting, scenario-testing, risk heat maps and screening systems, among others, to gain insight into pertinent assumptions for base mortality rates and improvement factors.^[B-37]

Last, there are broad socioeconomic implications for governments, employers, social institutions, businesses and individuals that must be addressed as our life-span increases. The systems that exist to support us through our retirement and into our old age are calibrated to a certain expectation of how long we will live, and when and how we will become eligible for support. As those expectations change, our personal and social safety nets will be forced to adapt. In addition, the amount of time we allocate between work and other pursuits is changing significantly. As we grow older, we must work with our governments and employers to identify the best terms on which we leave

the workforce. There are a wide variety of views on longevity's implications and potential solutions, especially around the roles of the public and private sectors (see section 4.2).

There are many areas where practitioners of different disciplines across the globe have come to similar conclusions. These areas include:

- ▶ Limited data points at extreme ages can lead to erratic mortality rates, proving to be a significant hurdle for research. Poor data quality caused by external factors (e.g., overstatement of age, unreported deaths, late reporting of deaths or inaccurate diagnosis of death) is also an obstacle. Analytical and practical solutions are limited but have a range of cost/benefit profiles. (see section 4.1.2)
- ▶ Many sources for mortality/longevity data exist, especially from governments (social insurance, census data), but practitioners need to consider whether the underlying population is consistent with the intended application, which means that life, annuity and pension practitioners need additional sources. Retrieving non-publicly available data sources can be time-consuming due to privacy, ethical and legal considerations. Nonstandard nomenclature between data sources makes reconciling multiple data sources challenging. (see section 4.1.2)
- ▶ Dependencies exist across causes of death, which limits and challenges practitioners when attributing mortality by specific diseases and projecting their interaction in the long term.^{[A-155] [B-44]}
- ▶ Researchers segment mortality data in various ways to understand correlations and establish appropriate subgroupings, where gender and smoking status are standard. In addition, actuaries in government and insurance companies have typically used percent-per-year improvement scales based on tables that vary by aspects such as age and gender. Differences in subgroupings may be driven, in part, by the type of information included in a given database. Commercial and regulatory considerations also affect the type of information available for research. (see section 4.1.2)
- ▶ Determining predictors of mortality and morbidity proves to be challenging, mainly due to long-term lags between underlying behaviors and their mortality consequences, multiple possible interpretations of the patterns in the data, the interaction among multiple pathological and biological processes, limited knowledge of the aging process, and inaccuracies in cause-of-death diagnoses. (see section 4.1.5)
- ▶ Practitioners agree that calibrating the extrapolation to different time periods will lead to significantly different results. Consensus also exists over how different data sources and methodologies can make it difficult to compare life tables and mortality projections between models. (see section 4.1.6)
- ▶ Companies should explicitly or implicitly incorporate the effects of current and recent medical advancements, but major future developments (such as a cure for cancer or increase in mental illnesses) are difficult to predict and model. (see section 4.1.6)
- ▶ Changes in demographics, and the resulting shift in balance between retirees and non-retirees, are increasing social insurance burdens worldwide, resulting in pay-as-you-go programs becoming increasingly difficult to maintain.^{[A-32] [A-102]}
- ▶ Higher life expectancies and different life histories put women at a higher risk of financial distress in late ages than males with lower average pension benefits and higher probability of outliving assets.^{[A-68] [A-106]}
- ▶ Income responsibilities post-retirement are increasingly falling onto the employees as employers reduce pension benefits and shift to defined contribution plans, increasing the demand for financial products with guaranteed income. Retirees face many risks, thus needing better education and the development of comprehensive portfolios of financial security products. However, many consumers do not have adequate resources, so the challenges go far beyond education.^[A-147]

- ▶ There are benefits of integrating seniors into the workforce for the employer, the elderly and the economy. Employers may be rewarded with loyalty and lower employee turnover, the government may collect more income taxes with the elderly continuing to contribute to the gross domestic product (GDP), and seniors may be able to more comfortably finance their postponed retirement. (see section 4.2.1)
- ▶ Rules of thumb that have often been promoted by financial advisors may be misunderstood and applied in the wrong context. Individuals should incorporate their unique needs into developing solutions, rather than depending on generalized advice.^[B-39]
- ▶ Those in need of long-term care should explore alternative housing models to support the funding of long-term care costs, including continuing care retirement communities, universal design communities, co-housing and reverse mortgages on their existing home equity.^{[B-4] [B-9]}
- ▶ Institutional acknowledgement of longevity risk has continued to rise as evidenced by the demand for protection through use of reinsurance, capital market solutions and pension de-risking strategies.^[A-140]

In addition, there is a fundamental need to address the following gaps in knowledge:

- ▶ Are there limits to longevity? At what age should mortality tables end, if at all?^{[A-30] [A-40] [A-157] [A-172] [A-174]}
- ▶ How can the profession improve data collection for insured and annuitant populations? There is a clear, significant difference from the general population, but many companies do not participate in voluntary data submission to SOA/American Academy of Actuaries (AAA) research, resulting in tables that are not necessarily comprehensive of the industry. (see section 4.1.4.4)
- ▶ How can the profession acquire more credible mortality data by cause of death, and what are some viable strategies for resolving privacy and confidentiality concerns?^{[A-17] [A-155]}
- ▶ Where should actuaries add rigor to data scrubbing/analysis processes or to predictive modeling or any other component? In particular, at what extreme age does the quality of data show deterioration?^{[A-30] [A-138] [A-139]}
- ▶ What are some mechanisms for validating key data sources, technical measures and sophisticated, multivariate projections of longevity-related data? (see section 4.1.2.3)
- ▶ What impact will the current obesity epidemic have on mortality rates?^{[A-48] [A-86] [A-131] [A-163]}
- ▶ How can we improve our understanding of the complex aging process and the role genetics plays in longevity?^{[A-134] [A-172] [A-173] [A-175]}
- ▶ How should abnormal mortality improvement rates exhibited by outlier cohorts be treated in projections? What are the causes of these anomalous cohorts?^{[B-1] [B-8]}
- ▶ What are some mechanisms for assessing the utility of finer subgroupings of the populations?^{[A-46] [A-138] [A-138]}
- ▶ What future medical and pharmaceutical breakthroughs will become the main drivers of longevity? Will life expectancy keep on increasing at rates similar to those experienced since the mid-19th century, or will it have a slower increment? How can companies mitigate risks associated with these major technological advances? What are some ways to model these risks?^{[B-8] [B-26] [A-173]}
- ▶ Can we validate a wealth/longevity effect at the oldest ages, especially for disability income and long-term care business?^[B-31]
- ▶ Will individual economic behavior vary as longevity patterns continue to shift, and how can that be incorporated into modeling and planning? (see section 4.1.5)

- ▶ What can other practice areas learn from predictive modeling practices in property and casualty (P&C), reinsurance, capital markets, life settlements, or from the Canadian space and other international bodies? Could this lead to guides or practices that can be used by regulators?
- ▶ What can be learned from the challenges faced by public pension plans and long-term care products? (see section 4.2.4)
- ▶ How should practitioners work more closely with the academic community to learn and test the latest theories and developments?
- ▶ How will governments deal with the discredited fixed retirement age? How will society adapt to an aging workforce? (see section 4.2.1)
- ▶ What are the benefits and limitations of general guidelines and rules of thumb for retirement planning? How can we improve the accuracy and personalization of these generalities?
- ▶ How can the compensation and business structure for financial advisors in the U.S. be modified to better align their clients' best interests with their own?^[B-39]
- ▶ How can the private sector and the government solve the challenges faced by the long-term care system, during a time when confidence in insurers is low and people underestimate eligibility requirements for Medicaid while overestimating its benefits? (see section 4.2.4)
- ▶ Did the mortality improvement pattern change in recent years around the world and in different sectors of the society? How should the mortality improvement be modeled?
- ▶ What impact will the sharing economy have on the successful aging?^[B-39]
- ▶ Could mortality be broken down to regional, state or county data? How would migration affect that breakdown? (see section 4.1.4.3)
- ▶ Can mortality tables be consolidated to serve multiple actuarial purposes? (see section 4.1.4.4)
- ▶ How will the opioid crisis impact mortality of specific cohorts?
- ▶ What causes the gender/locational/wealth disparity in longevity, and will it continue to evolve into the future?^{[A-155] [B-44]}
- ▶ Should reduction of disparity in longevity a public policy goal? What action should the government and society in general take to achieve that goal?^[A-155]

Following on the theme of discussion at the 2017 symposia, with changes in demography, mortality evolution patterns, and social and economic conditions around the world, it is critical for actuaries to shift their focus from numerical technicality to social applicability. As science edges ever closer to a monumental breakthrough in longevity, the world will look to actuaries for solutions on what promises to be a major disruptor to the traditional standard of living and society itself.

4. Summary of Literature Reviewed

It is important to note that the views expressed in this report are those of the authors who presented their work at the symposia and do not necessarily reflect those of EY, the members of the Project Oversight Group or the Society of Actuaries.

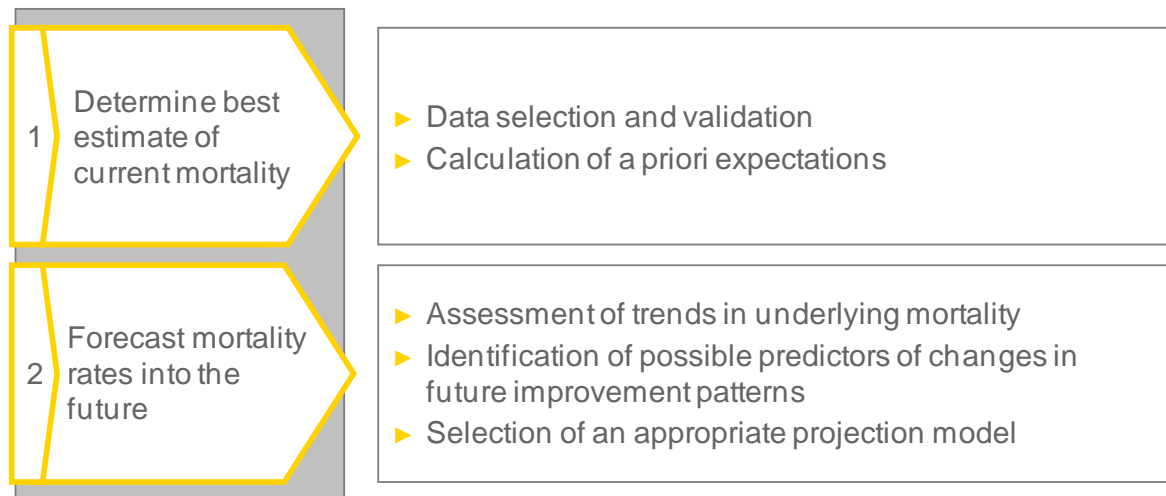
4.1 Part 1: The Analytical Process

The Society of Actuaries and other actuarial societies worldwide are not medical experts, but they may be the only organizations in the private and public sectors that have the technical ability to model these highly complex, multi-decade research projects. The input they could provide to public health authorities is urgently needed—reasoned advice regarding the implications of different research and funding priorities on morbidity, mortality, life expectancy and entitlement costs that will be borne by future generations.

Robert Pokorski, MD

4.1.1 Overview

The analytical process for developing mortality rates and projecting them forward can be broadly categorized into two main processes with five sub-steps.



We have used this approach to organize symposia material into five sections with two final sections with applications:

- ▶ Data selection and validation (section 4.1.2)
- ▶ A priori expectations (section 4.1.3)
- ▶ Assessing trends in underlying mortality and morbidity (section 4.1.4)
- ▶ Identifying possible predictors of changes in future improvement patterns (section 4.1.5)
- ▶ Selecting the appropriate projection model (section 4.1.6)

4.1.2 Data Selection and Validation

Data selection and validation is one of the first steps in the development of mortality rates.

This section is devoted to identifying datasets available to practitioners, challenges that exist when using such data sources, and validation methods to mitigate those challenges. It focuses primarily on data for people of older ages because a number of challenges, such as limited data, hinder practitioner efforts in this area. This section attempts to present solutions to these problems; however, many of the solutions would require significant time and money, making it necessary to weigh their benefits against their required effort.

This section also explores problems that might arise from incorrect usage of data. While many data sources are available, especially from government sources like social insurance programs and population censuses, practitioners must consider whether or not given data can be applied effectively. Health practitioners, for example, may be more concerned with factors associated with morbidity than mortality. This section highlights those problems for which there is limited consensus on methods to address. Applying different methods for validating and presenting data has led to different conclusions on the emerging trends and patterns. This phenomenon is discussed in this section.

The material presented in this paper raises several important questions that may provide opportunities for future research:

- ▶ When data are compared across countries, should we assume that country-specific trends will continue, or will differences diminish (or widen) over time?
- ▶ How can our profession improve data collection for insured, annuitant and pensioner populations? There are obviously significant differences from the general population, and many companies do not participate in the voluntary data submissions to SOA/AAA research, resulting in tables that do not necessarily provide a comprehensive view of the particular industry under study.
- ▶ How can we apply lessons learned from professional organizations like the United Kingdom's Continuous Mortality Investigation or the German Actuarial Society?
- ▶ How can the profession acquire data segmented by cause of death, and what are some viable strategies for resolving privacy and confidentiality concerns?
- ▶ What are some key articles/areas in which practitioners can learn from the academic community? Can the academic community furnish a practical and reasonable starting point for practitioners to use?
- ▶ Where should actuaries add more rigor to data scrubbing/analysis processes, or to predictive modeling, or any other component?
- ▶ What other validation techniques can be utilized to correct inconsistencies and errors related to issues in recording deaths and its causes?
- ▶ Can methodology be developed to adjust mortality estimates to make up for errors with problems like age misreporting?

This section is divided into three subsections. The first lists data sources referenced by the symposia material. It is not meant to be an exhaustive list of all possible data sources for studying old age mortality nor an endorsement by EY, members of the POG or the SOA on the data sources that should be used in studying old age mortality. It is also noteworthy that the data sources referenced by symposia material and shown below may change over time. Thus, comments on accessibility, accuracy and/or quality presented in the papers may no longer apply. The second subsection examines the challenges practitioners face when using data. The third subsection summarizes the methods for validating such data.

4.1.2.1 Key Data Sources

1. Medicare enrollment files^[A-3]

The master records of Medicare enrollment have extensive information on the mortality of very old persons in the U.S. The data are generally of high quality—the ages in the records, for example, are supported by documentation. However, Medicare enrollment files do contain errors related to duplicate information, incorrect ages and unreported deaths. These errors are most prevalent among subjects of older ages.

Medicare data contain approximately 85–90 percent of full census population data because the data are based only on people enrolled in Social Security or Medicaid instead of the entire population, but the data are more reliable for ages 65 and over in the United States. Medicare enrollment files have data lags, with the 2013 death counts having been released in 2016.^[B-35]

2. The Death Master File (DMF) maintained by the Social Security Administration^[A-4]

The DMF, maintained by the Social Security Administration (SSA), is the largest collection of publicly accessible death records in the U.S. As of December 2000, the public release version of the DMF (DMF-PR) contained over 65 million death records for deaths occurring between 1900 and 2000. Furthermore, the DMF includes data for people of older ages: there are 124 records for people who allegedly lived to 125–129 years old, and there exist scattered records for even higher reported ages at death.

Some argue that there is strong evidence that the SSA death data are highly accurate for all but the most extreme ages. This is especially true when additional requirements, such as insured status and Medicare Part B enrollment, are imposed. Therefore, these types of carefully constructed samples from the DMF-PR hold the best prospect for valuable demographic work. In particular, the DMF-PR is an important resource for increasing our understanding of centenarianism and supercentenarianism.

Natalia S. Gavrilova and Leonid A. Gavrilov note how death records are not as reliable for Puerto Rico, Hawaii, and the Southern states¹ of the U.S. The authors confirmed this finding as the non-Southern group demonstrated significantly less mortality understatement, suggesting more accurate age reporting in the group.^[A-139]

3. International Database on Longevity^[A-30]

Since the first symposium, “Living to 100 and Beyond: Survival at Advanced Ages,” held in 2002, there has been a collaborative effort to assemble an international database on longevity that would gather validated longevity records for people 110 years of age or older. More than 15 countries, including the U.S., Canada and Japan, along with European countries, have been participating in this “supercentenarian” project. Collaboration with national statistical offices and/or health departments has allowed investigators to obtain complete lists of alleged supercentenarians in most countries. By March 2004, more than 500 validated records had been gathered. This paper will later evaluate the quality of said data according to several criteria, such as the country of residence and the validation process undertaken, and will then provide an estimation of the mortality trajectory up to age 114.

4. Computerized genealogies^{[A-39] [A-165]}

S. Gavrilova and Leonid A. Gavrilov explored the availability and quality of computerized online genealogies of long-lived individuals by cross-checking them with other internet resources, including the SSA DMF and the early U.S. censuses. Gavrilova and Gavrilov drew centenarian family histories from computerized family trees using the following selection criteria: (1) persons should have birth and death date information and a life-span of 100 years

¹ Arkansas, Alabama, Georgia, Mississippi, Louisiana, Tennessee, Florida, Kentucky, South Carolina, North Carolina, Virginia, West Virginia, Arizona, New Mexico, Texas, and Oklahoma

and over, (2) persons should be born in the U.S. after 1875 and (3) persons should have pedigree information for at least three generations of ancestry (both on paternal and maternal sides), as well as information on the birth date and death dates of parents.

Computerized genealogies contain important information about family and life-course events, which are otherwise difficult to collect. These life-course events include life-span of parents and other relatives, number and gender of siblings, birth order, ages of parents when person was born, age at marriage, number of spouses and life-span of spouses and other non-blood relatives, number and gender of children and timing of their birth, place of birth, and information about residence during the life course.

Another project by Nussbaum et al developed a program to automatically collect data from multiple online data sources to build pedigrees (the recorded ancestry of a person or family) around known centenarians. A database of pedigrees would be used to conduct a variety of analysis, such as development of the “longevity propensity score.”^[A-165]

The researchers suggest that computerized genealogies, although difficult to produce, provide the most complete information on the life-span of long-lived individuals when compared to other sources. Ancestry.com is one example that houses many vital records and pedigrees that individuals have built.^{[A-129] [A-165]}

5. National Health Interview Survey’s Health Promotion and Disease Prevention Supplement^[A-87]

Data from the 1990–1991 National Health Interview Survey’s Health Promotion and Disease Prevention Supplement and the mortality follow-up through 2002 can be used to study socioeconomic and demographic characteristics, health status and health behaviors that are associated with oldest-old mortality, and survivorship among people who have survived to old age.

6. Canadian National Population Health Survey^[A-93]

Longitudinal data from the Canadian National Population Health Survey were used in proportional hazards models to identify factors associated with loss of good (self-rated) health over a 14-year period and among age groups 20 to 44, 45 to 64, and 65 and over. The data show that about 30 percent of persons aged 20 to 44 lost their good health over this period, compared to about 50 and 80 percent of middle- and old-age persons, respectively.

7. Framingham Heart Study (FHS)^[A-103]

Researchers investigated the effects of age trajectories of physiological indices on mortality risk and longevity using longitudinal data on more than 5,000 individuals. The data were collected over a 50-year period with biannual examinations on the Framingham Heart Study (FHS) original age group.^[A-103]

8. Human Mortality Database (HMD)^[A-148]

The HMD, a joint project by the University of California at Berkeley and the Max Planck Institute for Demographic Research, provides data on objective mortality for many countries. The core data contained in the HMD are a set of period life tables for reporting age- and gender-specific death rates in a given year for a given country. The HMD also contains cohort life tables that provide age-specific death rates for a given birth cohort.^[A-148]

The life tables are provided by single calendar years for 38 countries, including many, but not all, European countries, countries from North America, Australia, New Zealand, Chile (although tables stopped in 2005 due to data quality concerns), Japan, Taiwan and Israel. They have detail for single years of age up to 138. Additionally, the HMD provides original data used to build the life tables and the documentation of the process used. The HMD focuses on creating life tables that are comparable between countries, accessible (free), flexible in format and reproducible and that have sound quality controls. The HMD currently has period life tables for all countries and has cohort life tables only for countries with enough years of data. HMD intends to continue to build out cohort life tables as the datasets grow for all countries.^[B-41]

Thomas Edwals claims that this is a gold standard for mortality analysis given the high quality of data. The HMD currently has a limited number of data elements but is expanding the data elements as reliable data become available.^[B-47] Magali Barbieri notes the HMD isn't designed to be the most reliable table at the oldest ages due to estimates that are made around the distribution of deaths above age 100. At those high ages, the death is combined into open age intervals, then reconstructed based on the most plausible distribution of death at the high ages.^[B-41]

9. U.S. census data^[A-165]

A census has taken place in the U.S. every 10 years since 1790 except in 1890. Names connected to the data are available only 72 years after the census is taken, so currently full data from 1790–1940 are available. Census data provide information about family structure, which helps in constructing a pedigree.

10. Vital registrations^{[A-158] [A-165] [A-171]}

Many countries, including the U.S., U.K. and Canada, collect registrations on events such as birth, marriage and death, which can be used to verify names and ages of individuals from other data sources.

11. Canadian censuses^[A-158]

The first Canadian national censuses occurred in 1851, and they have continued every 10 years until 1951. Since 1951, they have occurred every 5 years.

12. Cause-of-death mortality database^[A-155]

The cause-of-death database, which is provided by the Office for National Statistics, includes gender, age, year, socioeconomic circumstances and cause of death for each registered death in England between 1981 and 2007.

13. Japanese Mortality Database^[A-168]

These data are Japanese age-specific mortality rates from 1975 to 2013. The data include ages 60–99 in single year of age and 100+ as final group. Data can be disaggregated by sex, region (of which there are eight), or prefecture (of which there are 47) and combination of region X sex (16) and prefecture X sex (94). The data contain a total of 168 series with all of the possible combinations.

14. New England Centenarian Study^[A-165]

The New England Centenarian Study (NECS) began in 1994 and aims to collect information and pedigrees for all individuals in North America who live to 95 and older. NECS has enrolled approximately 2,500 centenarians and nonagenarians, including 637 semi-supercentenarians and 171 supercentenarians.

15. Belgian National Register^[A-161]

This is the centralizing database in Belgium providing official population figures. It is considered very complete and has reliable data on specific ages of individuals including 46,666 observations of individuals who died at 95 or older since 1981.

16. Center for Disease Control Data^[B-35]

The Center for Disease Control (CDC) has a querying facility called WONDER with population data, including age, gender, race, cause of death and geography. Data are aggregated for ages over 100. The CDC doesn't verify ages of underlying data, so it might be less dependable at older ages.

17. Gerontology Research Group Database on Supercentenarians^[A-159]

Steven Kaye, M.D., and Stephen Coles, M.D., Ph.D., cofounded the Gerontology Research Group (GRG) during the spring of 1990. One of the continuing interests of the group is to authenticate cases of the oldest humans in history, the population of so-called supercentenarians. The GRG publishes the most current validated list of living and deceased supercentenarians on a regular basis in the journal *Rejuvenation Research* (Young, Muir and Adams 2015). The GRG also maintains a database on supercentenarians on the group's website at <http://www.grg.org/Adams/TableE.html>.

18. National Center for Health Statistics^[A-156]

Annual life tables for ages 80 and over and for the period from 1959 to 2011 have been computed for each U.S. state, based on individual death certificate records disseminated by the National Center for Health Statistics (NCHS) in the form of Mortality Detail Files available since 1959.

4.1.2.2 Challenges Related to Using Publicly Available Data Sources

1. Inconsistencies in underlying data

Publicly available data are not always ready to use for analysis due to known errors related to duplicate information, incorrect ages and unreported deaths.^[A-4]

Furthermore, levels of accuracy in data collection over the years can vary. For example, the data in the DMF are less reliable for older birth-year cohorts. While approximately 90 percent of the total deaths of U.S. residents were reported in the DMF for the 1979 to 1999 period, records for older death-year cohorts—especially those before 1962, when death records were first automated—are far less complete. This bias affects any mortality study on extinct birth-year cohorts constructed from the DMF.^[A-4]

Natalia S. Gavrilova and Leonid A. Gavrilov also noted how the quality of data within the DMF is acceptable until age 106, which they note is supported by other studies. At more advanced ages, there appears to be deterioration in the quality of data as evidenced by an observed excess of men relative to women, which is inconsistent with expectations given that female mortality is consistently lower than male mortality across all ages.^[A-139]

Censuses can have issues with automated systems misreporting information. For example, handwritten 6s are sometimes picked up as 0s, and 7s as 1s and vice versa. This causes discrepancies in underlying data.^[A-171]

One of the biggest problems with finding and analyzing information of centenarians is the risk that naming conventions change for a variety of reasons between data sources. It can be a challenge either manually or with an automated process to validate that the same individual is being tracked through time. This is very difficult for marriages because women will often change their name. It becomes challenging to determine whether a woman has died or gotten married when tracing records through time. It is necessary to cross-check with multiple sources to confirm information is consistent, but risk remains that a person won't be able to be tracked in available databases through time.^[A-165]

2. Availability of good quality data at older ages

The low number of reported deaths at older ages poses serious challenges to researchers measuring mortality of the elderly. For example, for ages above 110, as observed in Japan, the inaccuracy of death reporting can be as high as 50 percent for ages 110 and 111 due to their deaths not being tracked as accurately as deaths at more exceptional ages beyond age 111.^[B-5]

The growing number of people who live beyond age 100 is increasing the need for accurate measurement and modeling of mortality at advanced ages. Current limitations in the data have the following implications for the study of mortality at older ages. This list is drawn from multiple sources within the symposia materials:

- ▶ Cause of death may not be available, accurate or complete.
- ▶ The low reported number of deaths creates large fluctuations in estimated mortality rates.
- ▶ The small number of people at advanced ages may require researchers to pool data for people belonging to different birth cohorts, which results in data heterogeneity.
- ▶ A standard approach based on annual mortality estimates may not be applicable to extremely high and rapidly changing risk of death at advanced ages.
- ▶ It may be difficult to verify that the population satisfies certain mortality features such as the Gompertz law.
- ▶ The actual age at death may be lower than reported due to seniors overstating their age.
- ▶ For non-publicly available data sources, the process to retrieve death data can be elongated due to privacy, ethical and legal considerations.^[B-5]
- ▶ Finally, it may be difficult to determine the appropriate age at which to terminate life tables.

There are several explanations for the poor quality of data for older people. These include illiteracy rates and cognitive disability that prevent some centenarians from reporting their ages accurately, cultural factors that can impact an individual's knowledge of his or her true age, and an age-related sense of pride that may cause the extremely elderly to overstate their ages. Studies using highly reliable subpopulation data explore the impacts of such inaccuracies.^[A-138]

In the study "Liars, Cheaters and Procrastinators: How They Upset Mortality Studies," Bob Howard quantifies the impact data contamination could have on old-age mortality analyses. In particular, he explores the impact of seniors overstating their age, the failure to report deaths and late reporting of deaths.^[A-130]

- ▶ Overstatement of age: Individuals overstated their age due to a sense of pride. In addition, those applying for an annuity contract have a financial incentive to be thought older than they really are.
- ▶ This study offers two observations on this issue. First, those born earlier and those living longer, within the same year of birth, are more likely to overstate their age than their counterparts. Second, the impact on mortality rate increases with the length of the overstatement. For example, an overstatement of 6 percent of deaths by five years each has much less impact than 3 percent overstatement by 10 years, even though the number of life years overstated is the same.
- ▶ Unreported deaths: The study notes that if practitioners construct a mortality table where the initial number of lives is known and rely heavily on death being accurately and promptly reported (e.g., pension administration), a deceleration in the mortality curve can be caused by only a few unreported deaths.
- ▶ Late reporting of death: Howard notes there are very few instances where deaths are reported late with the intent to defraud. Most cases are from people who are not aware they need to report a death or how to do it. For ages under 85, late death reporting is relatively immaterial, as long as it is not ignored. At higher ages, it becomes increasingly important to make an appropriate adjustment for late reporting. Depending on the method used for handling late reported death claims, the author notes that late reported deaths can cause a deceleration in the mortality curve at extreme old ages.

Age misreporting is a common data challenge in many symposium papers. In addition, during the period 1959–1969 studied by Andreev et al, there was a tendency toward "age heaping" where deaths were reported too often at 80,

90 and 100 instead of adjacent ages. It is typical for birth date and thus age to be misreported in census data, often by a multiple of 10 years.^{[A-156] [A-171]}

However, the study by Andreev et al further indicates that data quality in the U.S. is improving by comparing mortality rates in 1959–1969 to the recent mortality rates. Rates were significantly lower than benchmark European countries, likely due to age misreporting and unreliability of underlying data. The narrowing of the gap in mortality rates between high-longevity countries is a positive sign that the problem of age misreporting is diminishing.^[A-156]

Another common issue is the pooling of deaths at older ages. Canadian census data typically had a category for age 95 and over until 1971, making it impossible to quantify centenarians. Additionally, since 1971, Statistics Canada rounds the 100+ age group up to multiples of 5 to protect confidentiality. Data over the age of 100 are less reliable.^[A-158]

The issue of a lack of available quality data for the elderly is even worse for countries or regions with small populations. Bias in age-related parameters in common models like the Lee-Carter model becomes pronounced when populations are 200,000 or less. In an example with a model of Taiwan’s population, Yue et al demonstrate the alpha and beta variables for the age pattern of log mortality and the first principal component reflecting relative change in log mortality rate at each age each show bias, which is amplified for smaller populations.^[A-169]

Jean-Marie Robine indicates that one of the problems with the lack of consensus of mortality trends at the oldest ages is that data are not freely available to re-create calculations done in previous studies. Data collection has improved, and ensuring that the data are publicly available for researchers to use is crucial to progress.^[B-48]

Additionally, Kirill Andreev comments that U.S. data quality at advanced ages is not sufficient and adjustments have to be made, but there is no standard for how to make such adjustments.^[B-24]

3. Lack of consistency in the approach to develop life tables impedes ability to consolidate data sources

The different methodologies adopted for graduating mortality rates at the oldest ages limit the ability of practitioners to make comparisons between life tables at advanced ages. Many of the different methodologies are explained in later sections of this report.^[A-36]

4. Nonstandard nomenclature

In the U.S., different agencies collect demographic data, such as the National Center for Health Statistics, the Census Bureau, and the Social Security Administration. Since each entity has its own set of definitions and reporting approaches, this provides a challenge in reconciling the retrieved data.^[B-5]

Adrian Gallop also notes how it is possible for classifications of deaths and interpretation of death certificates to be changed over time. This can make it difficult to determine mortality rates by cause of death, as it may introduce abrupt jumps due to the inconsistent taxonomy in recording deaths.^[B-8]

Communication in the field of biogerontology is difficult, as commonly used terms have no universally accepted definitions. Not only does the problem result in communication failures, it also produces erroneous interpretation of research results, illogical allocation of research funds and misdirected scientific, economic, social and political policy decisions.^[A-76]

Magali Barbieri noted there have also been issues when country borders change because this suddenly changes the makeup of the population.^[B-41]

5. Lack of reliable data by state or region

States were admitted to the U.S. birth registration system in different years, generally starting with Northeastern states and ending with Southern states. This challenges data credibility in some states, typically from the South.^[A-156]

It is a common strategy to enhance local data by expanding the region of interest or referencing mortality data from populations with similar mortality improvements, but that can become challenging to judge which populations have similar mortality profiles.^[A-169]

6. Data timing

Countries don't always release data after they have collected it. At the time of the 2017 symposium, Statistics Canada had released complete mortality data only up to 2011.^[B-41]

Additionally, when looking at data on an annual basis a decision must be made about when to extract the data. It can be done on a registration basis where deaths are taken based on when they are registered or on an occurrence basis based on date of death. The occurrence dataset tends to be more accurate while the registration dataset is more complete due to late registration deaths. Statistics published by England have gone back and forth on this issue with registration based before 1993 and from 2006 onward but occurrence based from 1993–2005. This could cause issues when using the published data as a time series.^[A-171]

4.1.2.3 Validation Techniques

1. Verifying records

Actuaries can use several data validation techniques to correct errors recording deaths. Using validation techniques such as the ones described below, practitioners can identify consistent bias in death reports and account for them in their studies.

For instance, Bert Kestenbaum and B. Renee Ferguson use three techniques to deal with inconsistencies in the Medicare enrollment files:^[A-3]

- ▶ Eliminate duplicate records: Pairs of records were identified as those with common identification numbers or the same uncommon name, date of birth and state of last residence.
- ▶ Evaluate and react to data anomalies: Various files were compared to the Master Beneficiary Record to correct missing or invalid birth/death dates and to identify further duplicate records for alleged supercentenarians. Birth dates were verified by checking recorded data against early U.S. census records collected when the alleged supercentenarians were children or young adults.
- ▶ Person-level records of utilization of Medicare services were linked to the Master Beneficiary Record to infer death at extreme ages from protracted non-utilization.

These are the three most common validation techniques, but there are other, less known methods as well. They include:

- ▶ Draft registration cards: To validate records in the SSA DMF of men exhibiting exceptional longevity, one study compared a random representative sample of 240 men who were born in 1887 and who survived to age 100 to U.S. World War I draft registration cards collected in 1917, when these men were 30 years old. Natalia S. Gavrilova and Leonid A. Gavrilov were thus able to validate 171 cases of exceptional longevity and to obtain information on vital characteristics of male centenarians when they were young adults. Randomly selected, shorter-lived men with the same birth year, race and/or country of draft as the centenarians served as controls.^[A-61]
- ▶ Historical data from parish registers: In Quebec, the available data on deaths of centenarians according to ethnic origin allow for the differentiation of mortality based on this characteristic. Data on French Canadians, for example, can be found using parish registers as demonstrated by Mélissa Beaudry-Godin, Robert Bourbeau and Bertrand Desjardins.^{[A-55] [A-138]}

Nussbaum et al indicate that the most helpful sources for verifying death records are death certificates, Find a Grave (owned by Ancestry.com linking directly to cemetery records) and obituaries. These give details about an individual's life and family that can be helpful when researching specific individuals.^[A-165]

The approach by England and Wales is to retain information on deaths in an online registration system that includes automated checks such as valid ranges and logical consistencies. Additionally, manual and automated checks are completed to identify any discrepancy and confirm completeness and accuracy. Checks on frequency of collected data are carried out to provide plausible data.^[A-171]

Additionally, in England and Wales, information for semi-supercentenarians and supercentenarians are validated by directly checking the age of birth based on the birth certificate to compare to the death date. That validation rate was over 96 percent for males and females. Many of the reported ages that weren't validated simply had an incorrect day or month, but the age was still correct. However, it is too costly to do the same validation for everyone age 90 and older.^[A-171]

Adrian Gallop comments that census data need validation because a few errors at older ages can skew the data significantly. He suggests it can be useful to compile estimates from administrative data to try to essentially recreate census data more often than censuses occur to try to facilitate more accuracy.^[B-27]

Census data can be given a confidence interval. Coverage adjustments can be made based on surveys where error is dependent on size of the population, census response rates, survey sample size and homogeneity of sampled population.^[A-171]

Census data can also be compared against other years of census data to verify birth year of individuals. The data can be compared against other available datasets like MIDAS as well. When this was done in England and Wales, 94.7 percent of the data for individuals over the age of 80 matched exactly in birth year, and 99.7 percent of people had a modal birth year reported in the last census. When compared to MIDAS records, 94 percent of cases had only one birth year reported, and 99.7 percent of cases had matched the MIDAS birth year to the census modal birth year. The year recorded in the 2011 census was not the modal year of birth across all available records in only 1.1 percent of cases, and reliability of 2011 data decreased as age increased over 80.^[A-171]

To resolve issues in data timing, England and Wales have considered extracting death occurrences from a live dataset daily after the initial extract of data to improve data completeness.^[A-171]

2. More advanced data validation techniques

The validation method used by Beaudry et al is to compare census data to tables for the Human Mortality Database. The HMD is largely considered to hold accurate data, so this comparison can give clues as to how far off census data might be for a given country.^[A-158]

Another way to validate the best data are being used is to go back and recompute prior life tables if new data become available after the fact. As noted by Magali Barbieri, the HMD does this when countries come out with new data or new best estimates, so that prior tables are as accurate as possible.^[B-41]

As mentioned by Thomas Edwalds, there is little consensus on whether there are enough data for the data to be reliable when segmented by region, state or county.^[B-47] However, Dr. Andreev indicates there is potential that segmenting data would allow for more accurate mortality predictions. His study segmented mortality by state, and it relatively matched a study conducted at the University of Washington that predicted life expectancy at birth broken down by county. Both studies showed highest mortality in the Deep South region and lowest mortality on the coasts, which gives credibility to the possibility of this approach being viable for future development.^[B-23]

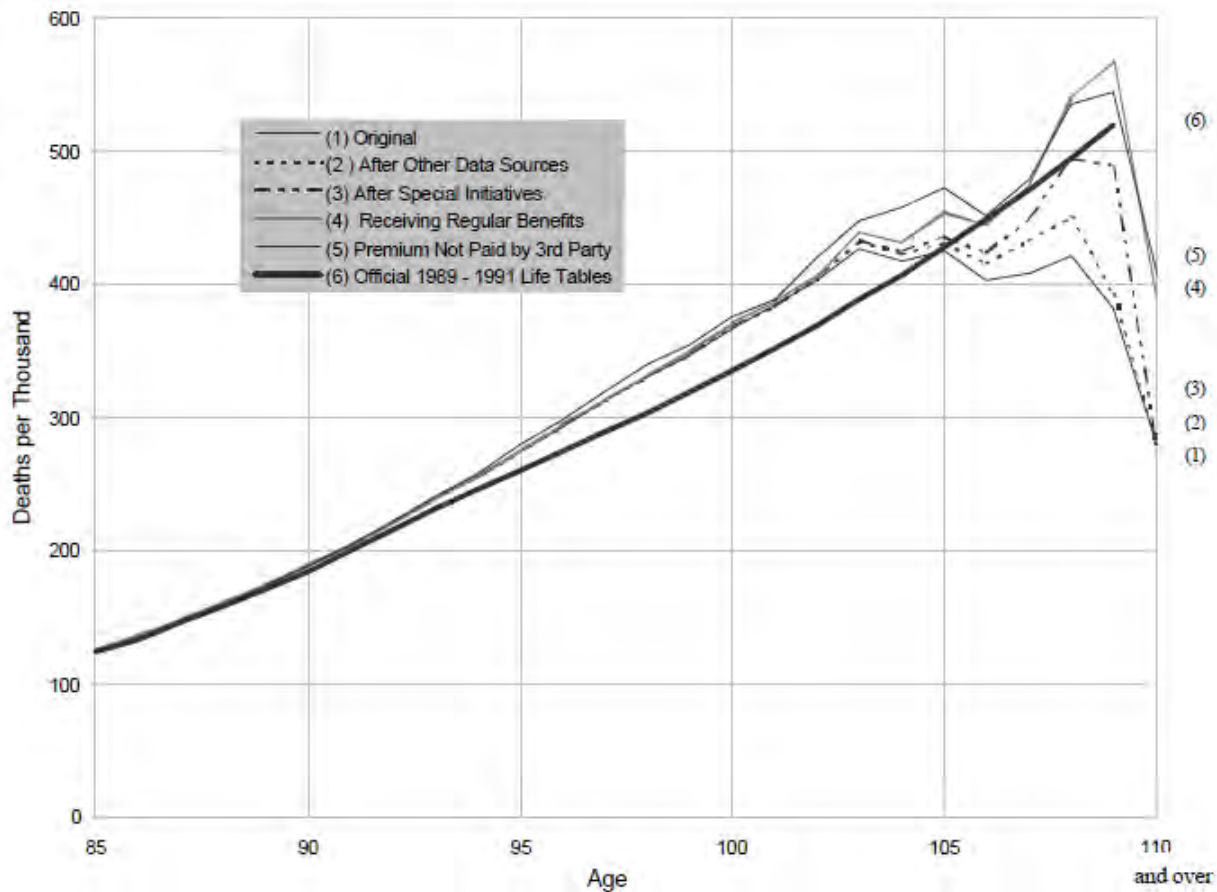
A relatively new validation and automation technique that is being developed by Nussbaum et al uses Java and Hibernate to search digitized databases to gather information to fill pedigrees for centenarians. The process is iterative and continues to build out bigger pedigrees to give a more complete look at whether old age truly does run

in families. As more data become digitized and accessible, this technique has robust capability to efficiently gather data to verify other sources and pull additional useful information.^[A-165]

A comparison of mortality at older ages between U.S. states and 13 other high-longevity countries showed marked improvement in alignment between the periods 1959–1969 and 2000–2011. This shows that data quality has been improving over time.^[A-156]

Validation techniques like those from above have played an important role in correcting missing or invalid data for the elderly. One set of data corrected by such methods was the 1989–1991 Life Tables in which death dates for the elderly were originally exaggerated. Figure 4.1.2-01 shows a comparison between raw mortality rates for elderly male deaths, which have been refined using techniques like those described above, and the 1989–1991 Life Tables. Note that the effects of the validation techniques were most prominent between the ages of 105 and 110.^[A-3]

Figure 4.1.2-01: Male Deaths per Thousand at the Oldest Ages^[A-3]



4.1.2.4 Related Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

Appendix Reference	Paper
A-3	Mortality of the Extreme Aged in the United States in the 1990s, Based on Improved Medicare Data https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-ferguson.pdf

<i>Appendix Reference</i>	Paper
A-4	Reported Deaths of Centenarians and Near-Centenarians in the Social Security Administration's Death Master File https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-faig.pdf
A-30	IDL, the International Database on Longevity https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxiii.pdf
A-36	Mortality at Advanced Ages in the United Kingdom https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxi.pdf
A-39	Search for Predictors of Exceptional Human Longevity: Using Computerized Genealogies and Internet Resources for Human Longevity Studies https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-v.pdf
A-55	Data Validation and Measurement of Cohort Mortality among Centenarians in Quebec (Canada) According to Ethnic Origin https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5b-bourbeau.pdf
A-61	Physical and Socioeconomic Characteristics at Young Age as Predictors of Survival to 100: A Study of a New Historical Data Resource (U.S. WWI Draft Cards) https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5b-gavrilov.pdf
A-76	The Biology of Human Longevity, Aging and Age-Associated Diseases https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-03-hayflick.pdf
A-87	The Role of Social and Health-Related Characteristics in Determining Survivorship Among the U.S. Oldest Old https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-alshire.pdf
A-93	Age-Related Changes in Factors Associated with Loss of Good Health https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g3-brown.pdf
A-103	Patterns of Aging-Related Changes on the Way to 100: An Approach to Studying Aging, Mortality and Longevity From Longitudinal Data https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g5-yashin.pdf
A-129	Predictors of Exceptional Longevity: Effects of Early-Life Childhood Conditions, Midlife Environment and Parental Characteristics https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-gavrilov.pdf
A-130	Liars, Cheaters and Procrastinators: How They Upset Mortality Studies https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-howard.pdf
A-138	Measurement of Mortality among Centenarians in Canada https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-oulette.pdf
A-139	Mortality Trajectories at Extreme Old Ages: A Comparative Study of Different Data Sources on U.S. Old-Age Mortality https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-gavrilova.pdf
A-148	Subjective Survival Probabilities and Life Tables: Evidence from Europe https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-peracchi.pdf

<i>Appendix Reference</i>	Paper
A-155	Causal Mortality by Socioeconomic Circumstances: A Model to Assess the Impact of Policy Options on Inequalities in Life Expectancy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-alai-arnold-bajekal-villegas-paper.pdf
A-156	Regional Mortality in the United States at Ages 80 and Older: An Analysis of Direct Estimates over Period 1959-2011 https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-andreev-gu-dupre-paper.pdf
A-158	Improvement in Late-Life Mortality and Its Impact on the Increase in the Number of Centenarians in Quebec (Canada) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-beaudry-godin-bourbeau-desjardins-paper.pdf
A-159	Mortality Trajectories at Exceptionally High Ages: A Study of Supercentenarians https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gavrilova-gavrilov-krutko-paper.pdf
A-161	Extreme Value Analysis of Mortality at the Oldest Ages: A Case Study Based on Individual Ages at Death https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gbari-poulain-dal-denuit-paper.pdf
A-165	Compiling a Very Large Sample of Centenarian Pedigrees to Ascertain Patterns of Inheritance and a Familial Propensity for Longevity Score https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-nussbaum-nebbia-helmkamp-andersen-perls-sebastiani-paper.pdf
A-168	Grouped Multivariate and Functional Time Series Forecasting: An Application to Annuity Pricing https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-shang-haberman-paper.pdf
A-169	Using Life Table Techniques to Model Mortality Rates for Small Populations https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-yue-wang-paper.pdf
A-171	Accuracy of Official High-Age Population Estimates, In England and Wales: An Evaluation https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/methodologies/accuracyofofficialhighagepopulationestimatesinenglandandwalesanevaluation
B-5	Summary of Panel Discussion on Data Sources and Projection Methods for Successfully Supporting the Needs of the Senior Market https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3c-discussion.pdf
B-8	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
B-23	Session 1A Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1a-

<i>Appendix Reference</i>	Paper
	transcript.pdf
B-24	Session 1B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1b-transcript.pdf
B-27	Session 2B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2b-transcript.pdf
B-35	SOA Mortality and Longevity Research https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-5a-transcript.pdf
B-41	The Nitty Gritty of Human Mortality Database https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsv-transcript.pdf
B-45	Discussant Comments for Session on Older-Age Mortality Trends https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-2b-discussant-comments.pdf
B-47	Discussant Comments for Session on Data Sources and Analysis https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-edwalds-discussant-comments.pdf
B-48	Discussant Comments for Session on Late-Life Mortality Curves https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-robine-discussant-comments.pdf

4.1.3 A Priori Expectations

This section summarizes the content from symposium articles that deals with fitting a curve to historical experience, the challenges associated with that task and the techniques for validating the result.

Since life expectancy had been relatively stagnant until the mid-19th century, as well as the poor quality of available data, researchers and actuaries alike have focused their studies using data from the 20th century onward.^[B-1]

In the past, actuaries have focused on developing “mortality laws” that explain data, a process that involves fitting a curve, using some intuition, to a dataset. It is apparent from the symposia material that actuaries tend to fit data for the elderly with theoretical and empirical evidence studies.

The symposia papers presented several parametric models that fit a mortality curve/law to old-age data. The models were useful in several ways:

- ▶ They reveal any underlying mathematical structure.
- ▶ They show underlying trends by smoothing/removing noise from data.
- ▶ They extrapolate to older ages where the data are sparse.
- ▶ They project mortality by using underlying parameters.

A number of symposia papers focused on fitting parametric curves to population data from different countries. In the process, authors segmented data in various ways to understand correlations and establish appropriate subgroupings. Most based their subgroupings on gender and sometimes region. Non-parametric models, such as the two-factor analysis model,^[A-160] extreme value theory,^[A-161] heterogeneity population model^[A-175] and multivariate functional time series forecasting methods, were discussed in the 2017 symposium.^[A-168] Non-parametric models are less rigid and provide more flexibility to respond to possible changes in mortality trends and fluctuations.^[A-160] The models, both parametric and non-parametric, are summarized in Appendix D.

There was less uniformity among authors when it came to data for the elderly. For old-age data, the authors developed a variety of tables and extrapolation methodologies without any consensus on a single, standard approach. In general, there are three schools of thought about what ultimate value mortality rates by age take on, according to Roger Thatcher:^[B-16]

- ▶ Value of one as age tends to infinity, which corresponds to no deceleration in the force of mortality.
- ▶ Value slightly less than one as age tends to infinity, which corresponds to a deceleration in the force of mortality.
- ▶ Value of one at a finite age: the traditional assumption used for closing the life table at a limiting age 'omega.'

Furthermore, there's an ongoing debate on the existence and implications of mortality deceleration, compression and shift. There also exists a need for validation techniques, which are presently limited.

The lack of consensus has led to discussions over the following key questions:

- ▶ Are there limits to mortality rates? Does the mortality plateau exist for supercentenarians (age 110+)?
- ▶ Is there a limit to life expectancy?
- ▶ Does mortality deceleration exist or is it a repercussion of poor quality of data at extreme ages?
- ▶ Where has mortality compression and shift been observed, and how can their effects be accounted for in fitting curves?

Disagreement over these questions has significant economic implications for longevity risk takers—individuals, corporations and governments. Balancing the vested interests of all stakeholders may require coordinated effort between policymakers, regulators and North American actuarial organizations.

4.1.3.1 Selecting the Methodology to Fit a Curve to Current and Past Experience

1. Exponential class (e.g., Gompertz's law)

For some time, experts graduated base tables if they were able to fit mortality to the Gompertz-Makeham function.^[A-36] In these models, the force of mortality increases at an exponential rate with age. Recent research has shown evidence that after mortality data have been thoroughly cleansed, mortality rates tend to resemble Gompertz curves.^[B-12]

In one study by Gavrilova et al, death records of supercentenarians (age 110+) were taken from the International Database on Longevity (IDL). The study split IDL data into two groups: cohorts born before 1885 and cohorts born in 1885 and later. Hazard rate estimates were conducted using the standard procedure available in Stata software. The study found that mortality in both groups grows with age, although in older cohorts, growth was slower compared with more recent cohorts and not statistically significant. Mortality analysis of more numerous 1884–1894 birth cohort with the Akaike goodness-of-fit criterion showed better fit for the Gompertz model than for the exponential model (flat mortality).^[A-159]

Jean-Marie Robine notes that the Gompertz assumption application in Gavrilova et al should be viewed with skepticism when applied to cohort trajectories. The mortality curve is essentially flat between ages 15 and 50 for females in France from the cohort born in 1840 to the cohort born in 1904, as the yearly improvement has offset the expected increase in mortality due to increasing age. The Gompertz law is meant to be applied to mortality trends in a period approach and not to show mortality changes over time. When Gompertz developed his model in 1825, the distinction between cohorts and periods did not exist.^[B-48]

Kai Kaufhold argues that applying the Gompertz model based on a period effect even if it doesn't follow the cohort effect can be done on a situational basis depending on the model's purpose.^[B-24]

Another study utilizing this family of models was performed by Roland Rau. When analyzing the mortality plateau for supercentenarians, Rau selected the Gamma-Gompertz model based on the minimum AIC value. The AIC is defined as $AIC = (-2) \log(\text{maximum likelihood}) + 2(\text{number of independently adjusted parameters within the model})$.^[A-167]

When analyzing the mortality plateau, Rau noticed worrisome large variation in the estimates (of the plateau) for 16 countries for the years 1960–2010.^[A-167]

The goal of the analysis was to test whether there is support for a plateau of the population hazard at a level of 0.7 as estimated by Gampe with a nonparametric approach. The gamma-Gompertz models are used for the analysis. These models are calibrated with data from the Human Mortality Database. The analysis shows that there is, indeed, support for a mortality plateau for women. At 0.8, it is slightly higher than suggested by Gampe. If a mortality plateau exists for males, it is higher than for females, but the estimates were not convincing. For males, more data for centenarians and semi-supercentenarians are necessary to have more robust estimates.^[A-167]

Robine indicates that actuaries need a better understanding of how the initial frailty is distributed among populations to better apply the gamma-Gompertz model. Using frailty in models of mortality helps merge actuarial models with observed trends in geriatrics. However, accurately modeling frailty is very challenging because it is difficult to determine how frail people will be at birth and how quickly they will lose robustness.^[B-48]

2. Logistic function

Some research has indicated that mortality deviates from the Gompertz law at old ages, showing a decrease, not an exponential increase, in mortality for the elderly. Actuaries, including Gompertz himself, noted this phenomenon. To account for the fall-off of mortality rates at advanced ages, a logistic formula was proposed. Later, in 1939, Greenwood and Irwin created a detailed description of human mortality for the elderly and deduced that old-age mortality follows the law of radioactive decay with half-time approximately equal to one year.^[A-39]

In the study “Logistic Regression for Insured Mortality Experience Studies” performed by Zhiwei Zhu and Zhi Li, the authors listed the strengths and potential uses of logistic regression models for insured mortality experience studies, including:^[A-128]

- ▶ Testing for statistical strength of mortality drivers in explaining mortality variations with effect analysis
- ▶ Generating normalized mortality metrics such as slopes and differentials with odds ratio analysis
- ▶ Extrapolating for advanced age or ultimate mortality with modeled estimation
- ▶ Bridging or smoothing between select and ultimate mortality with model link function
- ▶ Quantifying study reliability with model fit statistics
- ▶ Helping construct multidimensional experience tables by using the model as a predictive model
- ▶ Being implementable with widely available software systems

Zhu and Li studied the use of the logistic q model to analyze the U.S. insured mortality experience. They analyzed life insurance experience data from policies with relatively high face amounts since 1950. The authors found that properly designed logistic modeling processes can utilize available data to deliver solutions such as:^[A-128]

- ▶ Testing the statistical significance of mortality drivers in explaining mortality variations
- ▶ Estimating normalized mortality slopes and mortality differentials, such as mortality increases, by duration or variances between underwriting classes (while product and attained-age distributions are controlled)
- ▶ Addressing analytical challenges such as extrapolating for ultimate mortality, smoothing between select and ultimate estimations, and constructing multidimensional basic experience tables

Tom Edwals noted that the above model does not produce ultimate rates and, consequently, will work better for select mortality rates (as used in life insurance).^[B-12]

Alai et al built a multinomial logistic model that generates probabilities of dying from a specific cause of death (they categorized six different causes of death). They then applied a logistic transformation to link mortality and survival rates to covariates. The regression is performed from the product between the design matrix and the vector of regression parameters. Those parameters are used to calculate the probabilities of interest being the probability of death for each cause of death and the probability of survival.^[A-155]

The Alai et al study applied the model by implementing shocks to the probabilities of cause of death. The shock ranges from zero (meaning that the cause is eliminated) to greater than one (meaning that the cause is increasing in causing mortality). Those shocks allow the authors to determine which causes of death will minimize the gap in life expectancy between economic classes as defined in the study.^[A-155]

The model captures the trends of the data very well while smoothing out the noise substantially. The model is broken out by socioeconomic status, which shows that there is a significant gap in life expectancy and mortality rates. A thorough analysis of the findings separating socioeconomic classes and the policy recommendations from the study are explained in sections 4.1.5.1 and 4.1.7 of this report.^[A-155]

An important assumption of this model is the independence assumption for cause of death. This assumption is used to address the way in which changing the prominence of a cause of death would impact the others. Extrinsic dependence in causes of death would make those impacts unpredictable, and an independence assumption reduces that unpredictability.^[A-155]

S. Jay Olshansky notes this model can be a very valuable tool to guide policymakers in deciding where to invest resources to address issues in mortality. However, he also notes the model has a few weaknesses, including the independence assumption between causes of death. Some methods to reduce risk in mortality from one disease are likely to have a positive or negative effect on the probability of dying from another disease. Additionally, it is very likely that the policies implemented will not reduce mortality equally across the socioeconomic gradient. Solutions implemented are almost always more successful at extending life expectancy for the most affluent and educated groups. The authors of the Alai et al model also fail to include aging as a cause of death in the model.^[B-44]

3. Dynamic reliability in estimating mortality at advanced ages

In this approach, aging is defined as the symptom of cumulative damage to the human system. The author of the article that describes this approach, Fanny Lin, applies a general law for hazard rates to analyze the mortality structure of Taiwan during 1926 to 1991. This is a completely different approach to the traditional parametric models as the model does not use age-dependent relations for hazard rates. This method is not widely used.^[A-13]

Actuaries have developed methods whose sole purpose is to extrapolate estimates of old-age mortality. Because these methods are focused entirely on the elderly, practitioners using them do not need to account for factors like infant sicknesses, which only apply to younger people.

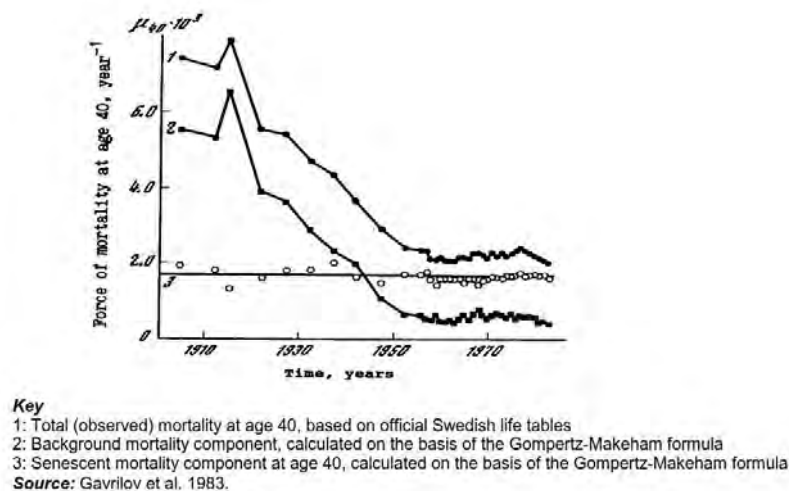
4. Non-parametric model

Gavrilov et al point out that despite the usefulness of the parametric approach for mortality projections, it has serious limitations. The main limitation is a dependence on the particular formula, which makes this approach too rigid for responding to possible changes in mortality trends and fluctuations. They suggest considering non-parametric approaches.^[A-160]

Gavrilov et al proposed a non-parametric two-factor analysis model—age-dependent component and age-independent component—to study mortality trends. The Gompertz-Makeham law was used to introduce mortality forecasting with a separated age-dependent component and age-independent component. The Gompertz-Makeham law, $A + R_0 \exp(x)$, describes the mortality in two components: the age-independent component A (background component / Makeham component) and the second term of this equation, the age-dependent component of mortality (senescent component / Gompertz component).^[A-160]

One would use parametric formulas for population projections by analyzing historical trends of the parameters. For example, in 1979, during an analysis of the historical changes in the mortality of the Swedish male population, it was found that the background component (Makeham parameter) has significantly changed over the studied period (1900–1970) and the senescent mortality (Gompertz parameters) turns out to be practically unchanged. The substantial decline in mortality rates in Sweden at the beginning of the 20th century can be explained by a decrease in the Makeham parameter, while the Gompertz parameters remained virtually constant during the same period. In the 1960s, as the Makeham parameter had almost reached zero, it became foreseeable that the rapid decline in mortality rates would come to an end. And this is what happened, in fact, in the 1960s.^[A-160]

Figure 4.1.3-01: Historical Changes of Age-Independent (Background) and Age-Dependent (Senescent) Mortality, per 1,000, for 40-Year-Old Swedish Males^[A-160]



One limitation of the Lee-Carter model is related to the assumption that historical evolution of mortality at all age groups is driven by one factor only. To overcome this limitation of the one-factor model of mortality and to determine the true number of factors underlying mortality changes over time, Gavrilov conducted a factor analysis of mortality over the period 1900–2014. Data on men and women were analyzed separately. He identified two factors capable of explaining almost 98 percent of the variance in the temporal changes of hazard rates. Thus, for a more accurate description of mortality evolution, Gavrilov recommends the following model:

$$a_0(x) + a_1(x)F_1(t) + a_2(x)F_2(t)$$

Where x is age; t is time; $\alpha(x)$, $\alpha_1(x)$ and $\alpha_2(x)$ are three sets of parameters depending on age only; and $F_1(t)$ and $F_2(t)$ are two sets of parameters depending on time only.^[A-160]

By studying the variation of these factors over time for Swedish population, Gavrilov noted that the first factor—comparable to the Makeham component and observed in the “young” population—declined from the beginning of the century. The second factor—comparable to the senescent mortality and chiefly concerning the “old ages” population—remained remarkably stable over the period 1900–1950. Without more recent data, one might predict continued historical stability of this factor. However, a radical change occurred after the 1950s, and mortality has begun to decline among older people while the mortality of the younger age groups has already reached very low levels close to zero. Thus, factor analysis of the time series of mortality confirms the preferential reduction in the mortality of old people in recent years. Also note that for males, the senescent factor started its rapid decline significantly later than for females.^[A-160]

Figure 4.1.3-02: Time Dependence of Factor Scores for “Young-Age” and “Old-Age” Factors for Swedish Males^[A-160]

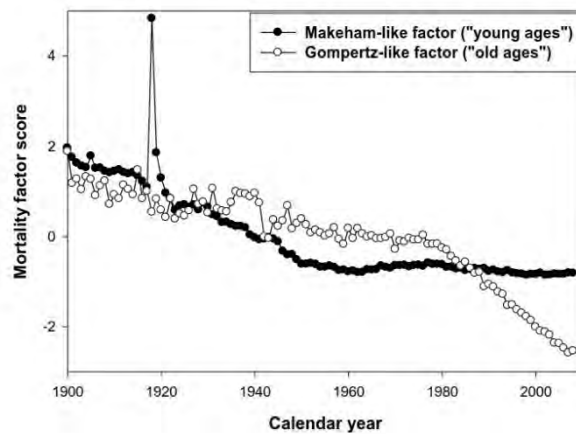
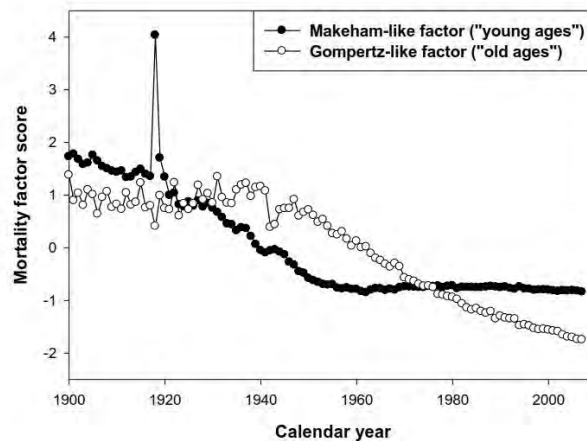


Figure 4.1.3-03: Time Dependence of Factor Scores for “Young-Age” and “Old-Age” Factors for Swedish Females^[A-160]



Gavrilov applied the factor analysis methodology to age-specific death rates for ages 65 through 100 in U.S. men and women separately. Two factors would explain 96 to 97 percent of the variance. The first factor is similar to the senescent mortality and explains 84 to 86 percent of mortality variation. The senescent factor has the highest factor loadings for ages between 65 and 93 for men and between 65 and 96 for women. The second factor, explaining 11 to 12 percent of mortality variation, has the highest loadings at ages 95 to 100 and hence can be called the extreme old factor of mortality. Gavrilov found that mortality of centenarians in the U.S. does not demonstrate an obvious tendency to decline over time, in contrast to mortality at younger ages. This stability of mortality of centenarians over time was first observed for Swedish centenarians and recently was reported for centenarians in the United Kingdom. In this study, Gavrilov observed the same phenomenon for centenarians in the U.S.^[A-160]

Gavrilov points out that the approach based on the factor analysis has several advantages. First, it is able to determine the number of factors affecting mortality changes over time. Second, this approach allows researchers to determine the time interval in which underlying factors remain stable or undergo rapid changes.^[A-160]

On the other hand, Robine warns about the adult longevity revolution (the strong increase in the modal age at death after World War II). He doesn't believe this can be applied consistently across all ages and all countries. There is an impactful difference in the mortality trends after the age of 85 in different countries.^[B-48]

Robine agrees it is beneficial not to use all of the potentially available data because new recent trends have emerged. However, it is important to have enough years of data to create long-term forecasts. There are questions about the period of reference needing to be consistent across different countries.^[B-48]

5. Extreme value theory

Extreme value theory (EVT) deals with the far tail of probability distributions and is a good candidate for extending mortality rates beyond the last age of death in the data to model oldest ages.^[A-161]

Gbari et al develops an EVT model that uses data on hand and probabilistic arguments of the behavior of extreme sample values. Analysis of residual lifetimes at high ages is in line with the peaks-over-threshold method, which assumes the distribution of exceedances over a threshold converge to a generalized Pareto distribution when the threshold increases.^[A-161]

The Gbari et al model takes a sequence of independent lifetimes with a common distribution function. For example, when modeling at extreme old ages, this can be done by examining lifetimes above age 95. The EVT examines the asymptotic behavior of the maximum age at death of observed homogeneous groups subject to the same life table. If there is a normalized sequence that converges to a distribution, for all points of continuity, then the distribution is a generalized extreme value. The variable controlling the tail index can be greater than zero, less than zero or equal to zero. Those produce the Fréchet distribution, the Weibull distribution and the Gumbel distribution, respectively. If the variable controlling the tail index is less than zero, it supports that there is a finite ultimate age.^[A-161]

After normalizing the remaining lifetime distribution, it is possible to establish that a limited class of distribution functions are eligible, namely, the generalized Pareto distribution. Here when the variable controlling the tail index is positive, negative and zero, the resulting distributions are the Pareto, type II Pareto and negative exponential, respectively.^[A-161]

One of the assumptions that has to be calculated under the EVT is the threshold age beyond which to apply the model for the EVT. There are multiple methods to achieve this as indicated and tested in the Gbari et al paper:^[A-161]

- ▶ Empirical mean excess function
Graphic displays of life expectancy above 95 indicate a downward trend as age increases. This indicates a short-tailed distribution and means the variable controlling the tail index should be negative.
- ▶ Pickands method
This method uses a specific subset of the largest observations to give tail information. The threshold is selected as the $n - 4M + 1$ order statistic where M is calculated as the minimum of the difference between the empirical upper tail and the estimate of the survival function of the generalized Pareto.
- ▶ Reiss-Thomas method
This model is an automatic selection procedure based on a shape parameter based on the upper order statistics. The threshold is selected where k minimizes the following equation:

$$\frac{1}{k-1} \sum_{i \leq k} i^{\delta} \left(\hat{\xi}_i - \hat{\xi}_k \right)^2.$$

- ▶ Flexible extreme value mixture model

This is a more sophisticated threshold selection procedure where the goal is to approximate the upper tail of the lifetime distribution with the generalized Pareto without specifying a parametric form for the bulk of the distribution. Maximum likelihood estimation is used and requires initial values for the parameters. This was done using a reasonable grid of values and selecting the ones that minimized the negative log likelihood.

Authors of the Gbari et al study selected the maximum threshold age from the above methods for each gender to be in line with the property of threshold stability of the generalized Pareto distribution. In addition, they use a method of maximum likelihood estimation to estimate the other generalized Pareto parameters. The authors also examine other parameter estimation methods to check the maximum likelihood estimation method, and all methods determine the variable controlling the tail index is negative, implying the existence of a finite ultimate age.^[A-161]

Jean-Marc Fix comments that it might be more logical to select one method with the best threshold estimates for both genders rather than selecting one for males and one for females.^[B-45]

Cohort-specific maximums can be calculated within an EVT framework with a generalized Pareto approximation of the exceedances. The number of survivors at the threshold age is approximately Poisson.^[A-161]

6. Heterogeneity of population, homogenization and natural selection

Severine Arnold et al showed the advantages of the model of heterogeneous population in terms of fitting the mortality data. The paper also provided a biological justification supporting heterogeneous population model.^[A-175]

Arnold et al compared heterogeneous population model with parametric models, which were used to fit actual mortality data. It was found that the model of heterogeneous population is advantageous compared to the other models because it has the flexibility to be adapted to any dataset and therefore provides the best fit to mortality data for the data over the entire life-span as well as for old (over 80) ages.^[A-175]

Arnold et al also demonstrated that contrary to other considered models, the model of heterogeneous population can reproduce and explain controversial observations in late-life mortality (deceleration, plateau and decline).^[A-175]

Assuming that population heterogeneity reflects the genetic variation between subpopulations, Arnold et al showed that the natural selection model based on differential mortality can explain and quantitatively reproduce the homogenization of the Swedish population within a one-century period.^[A-175]

Based on these results, Arnold et al concluded that heterogeneity, beyond its convenient use in reproducing characteristics of age-structured populations, has a fundamentally inherent role in understanding the mortality dynamics across the life-span and the evolution of these dynamics over time.^[A-175]

4.1.3.2 Challenges Inherent in Fitting the Curve

Larry Pinzur notes that, when constructing a mortality curve, it is important to balance the fit, stability and smoothness considering the model's purpose. A good model will have a tight fit to current and past experience, but a model should also be stable and not shift significantly when a new data point is included. There is also a trade-off in the fit of the curve and its smoothness depending on how closely the curve attempts to hit each data point.^[B-37]

1. The debate around mortality deceleration, compression and shift

The increasing number and proportion of centenarians in developed countries have prompted researchers to study the trajectory of mortality at the highest ages and the biological limits of human life. These studies have produced two opposing camps: the first camp maintains that industrialized countries will reach a life expectancy of 100 by 2060; the second camp maintains that the U.S. life expectancy will not exceed 85 by 2060.^[A-40]

Even though both groups arrive at very different conclusions, they assume the same cultural, technical and biological conditions (those of today) in their studies. Their large difference in opinion has serious social and economic consequences, especially for managing health services and social security.^[A-40]

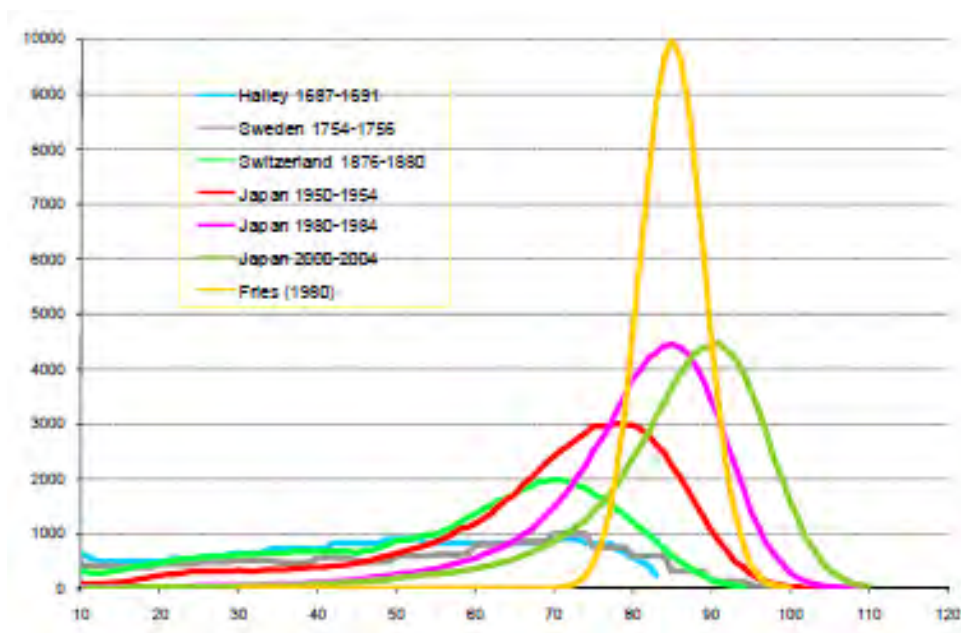
Several forces may cause change in human expectancy. These forces are broadly characterized as mortality compression and shift.

The evidence for compression and shift

With the fall of mortality, the frequency distribution of ages at death shifts to the right, but it does not retain the same shape over time. The distribution of ages at death has become more compressed around the mode.

Figure 4.1.3-04 overleaf shows that by comparing Swiss data in 1876 to 1880 to Japanese data from 1980 to 1984, one can see strong evidence of mortality compression in the age distribution of deaths as the modal length of life moved from 70 to 85 over the course of a century.^[A-57]

Figure 4.1.3-04: Evidence of Mortality Deceleration



The compression of mortality, which has occurred in almost all low-mortality countries during the whole period since World War II, seems to have ceased in Japan for the last 10 to 20 years. Japan, which leads international trends in human longevity, is moving to a new trend pattern called “the shifting mortality scenario,” where the modal length of life keeps increasing but the shape of death distribution curve remains unchanged. France, Switzerland and Italy seem to follow the Japanese pattern with a lag and present an intermediate situation between mortality compression and mortality shift, where a steady increase in the modal length of life is accompanied by a modest decrease in the standard deviation of the ages at death above the mode.^[A-57]

Eric Stallard observed mortality compression in the U.S. SSA historical data, noting that it had run its course by the latter half of the 20th century. Future mortality improvement in the U.S. also follows the aforementioned trends of right-shifting survival.^[A-145]

Many authors and speakers have made the argument that there is a rectangularization of the survival curve as survival likelihood is increasing toward what many consider to be a limit to human life.^{[B-26] [A-157] [A-172] [A-174]}

The evidence against compression

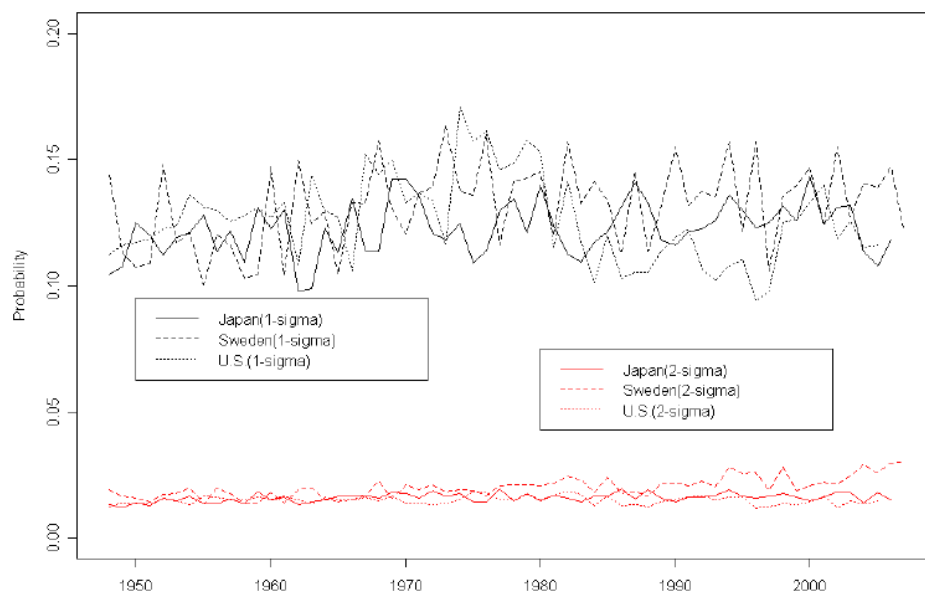
Social Security DMF data allowed the reconstruction of cohort life tables describing survival patterns after age 80 for birth cohorts that are almost extinct now (born in 1891 and earlier). Detailed information about birth and death dates of decedents allowed the estimation of hazard rates of the oldest-old persons with resolution of single month of their age. Study of three birth cohorts (1885, 1889 and 1891) showed that mortality grows steadily with age from 85–89 to 102–105 with almost no obvious signs of expected mortality deceleration. After age 105, the mortality estimates become less reliable because of significant statistical noise. [A-39]

In addition, data for extremely long-lived individuals are scarce and subjected to age exaggeration. Therefore, in order to obtain good-quality estimates of mortality at advanced ages, researchers are forced to pool data for the several calendar periods. Therefore, one explanation for observed cases of mortality deceleration in other studies might be a result of data heterogeneity, as noted in section 4.1.2.2. [A-39]

Instead of fitting stochastic models for mortality rates, increasing life expectancy might be explored by examining the basic properties of survival curves. Unlike prior results using the graduated mortality rates, the authors found no obvious signs that mortality improvements are slowing down when using this second approach. [A-82] Figure 4.1.3-05 overleaf shows the results of one such analysis.

Figure 4.1.3-05: Evidence Against Mortality Deceleration:

The Probability of Survival Beyond a High Age (Male) [A-82]



Furthermore, Jack C. Yue has studied alternatives to non-parametric methods for evaluating mortality compression based off data from 1950 to 2009 for 37 countries found within the Human Mortality Database. Yue concludes there is not enough evidence to conclude there is mortality compression. [A-143]

2. Mortality deceleration

Mortality deceleration is a widely debated phenomenon, characterized as the deceleration of mortality rates at extreme ages. [A-107]

There exists the common view on the exponential growth of mortality with age (Gompertz law) being followed by a period of deceleration with slower increases in mortality rates.

Using parish registers data from Quebec, Nadine Ouellette and Robert Bourbeau showed mortality deceleration to be occurring above age 110 for verified Catholic French-Canadian female centenarians.^[A-138]

In contrast, Natalia Gavrilova and Leonid Gavrilov, using independent datasets and alternative statistical approaches, found mortality after age 80 to follow the Gompertz model not only for the U.S. but also for countries with smaller populations. Ouellette, Bourbeau, Gavrilova and Gavrilov agreed their discrepancy could have been attributed to Ouellette and Bourbeau working off a dataset of ages above 110, while Gavrilova and Gavrilov used mortality data starting at age 80.^{[A-139] [B-16]}

In the study “Liars, Cheaters and Procrastinators: How They Upset Mortality Studies,” Bob Howard shows how mortality deceleration at extreme ages can be caused by overstatement of age, unreported deaths and late reporting of deaths. In particular, he shows how more recent cohorts have shown less pronounced mortality deceleration at extreme ages than older cohorts. This can be explained as more recent cohorts will be required to present valid documents to prove their date of birth, making it more difficult to overstate one’s age.^[A-130]

Furthermore, Gavrilova and Gavrilov identified the following reasons previous studies might have concluded mortality deceleration at advanced ages:^[A-139]

- ▶ Studies conducted prior to 1998 used data for older birth cohorts when age reporting was not particularly accurate.
- ▶ Most developed countries have much smaller populations compared to the U.S. and thus need to aggregate their data by combining many single-year birth cohorts, thereby increasing the heterogeneity of the sample.
- ▶ Many studies analyze age-specific probability of death, which has a theoretical upper limit equal to one. Thus, when mortality is high at advanced ages, it is expected to have a tendency to decelerate.
- ▶ Mortality rates calculated for wide age intervals can produce biased estimates of hazard rates.
- ▶ Loss of individuals to follow up in longitudinal studies may also be a factor.

Furthermore, Gavrilova and Gavrilov identified the DMF as containing an excess of men relative to women, contrary to expectations (see section 4.1.2.2 for details). This excess suggests elderly men have overstated their ages, which, in light of Howard’s study where overstatement of age can cause mortality deceleration, raises the possibility of observed mortality deceleration being simply the artifact of poor data quality at extreme ages.^{[A-130] [A-139]}

The newest study by Gavrilova et al concluding that deceleration didn’t exist compared results based on IDL data with a more contemporary database maintained by the Gerontology Research Group (GRG). Mortality analyses with GRG data produced similar results.^[A-159]

An older study by Gampe (2010) analyzed the hazard rate of supercentenarians, using the same IDL database as in this study, and came to a different conclusion that mortality after age 110 is flat. Gavrilova et al believe that the main reason for differences between the conclusion made by Gampe and their results lies in the manner of data analyses. Gampe based her conclusion on visual inspection of graphs presenting age trajectories of hazard (in plain scale) and the logarithm of survival function, rather than quantitative analyses. Also, Gampe wrote her own program for hazard rate calculation, rather than using estimates provided by standard statistical packages.^[A-159]

Using the gamma-Gompertz models, Rau found support for a mortality plateau for women. The gamma-Gompertz models are calibrated with data from the Human Mortality Database. At hazard rate of 0.8, it is slightly higher than the hazard rate of 0.7 suggested by Gampe (2010). The support was not convincing for men.^[A-167]

To reconcile the difference in conclusions, Jean-Marie Robine calls for comparison of the studies and for the two research groups to collaborate to eliminate these disturbing discrepancies.^[B-48]

3. The debate over when to end the life table

The decision as to when to end the life table is an area subject to debate. Within the symposia material, multiple studies support a range of possible solutions; the spectrum of solutions is presented below.

Certain studies have shown that it is not possible to reach life expectancies of 100 or more unless two events happen: (1) people modify their lifestyles in such a way that all causes of death currently listed on death certificates disappear and (2) people discover an intervention that slows the current process of aging.^[A-19]

Despite the findings of such studies, life expectancies appear to be increasing, causing a debate over the limits of human life.

The debate is especially interesting for developing countries because rates of improvement accelerate as these countries develop. For example, by the middle of the 20th century, life expectancy at birth was 51.4 years in Latin America and 69.0 in North America. By the end of the century these figures turned into 69.2 and 76.9, respectively. According to current demographic tendencies and based on assumptions about the social and economic developments that affect mortality, forecasts for the mid-21st century suggest figures of 77.6 and 81.9.^[A-33]

One reason the debate over ending the life tables exists is because unreliable data for the elderly makes it difficult to determine the level and age trajectory of mortality at advanced ages. Without uncontroversial evidence, the debate can thrive. The symposia material presents three approaches to address this problem:

- ▶ Validate a sufficient number of unbiased high-age deaths and use them to produce a level and age trajectory with the extinct or almost extinct generation method.^[A-12]
- ▶ Establish a survival pattern for the elderly with convincing evidence. Actuaries could then use this information to mathematically generate mortality rates for people older than 100.^[A-12]
- ▶ Identify the age at which probability of survival is so low that the life table can end there. (It is important to consider manufactured time—the result of economic, social and medical developments that prolong life—when using this method.)^[A-33]

Estimated ultimate age is an important consideration for models to deal with extreme old age. The authors of the Gbari study find that depending on the estimation method used, for their dataset from Belgium, ultimate age is in the range 111.64–114.82 for males and 120.3–122.73 for females. These ranges show that there is sensitivity to the estimation method selected.^[A-161]

Jean-Marc Fix comments that increases in the ability to collect data at the oldest ages combined with the increase in numbers of centenarians should help future symposiums to understand the trends and drivers near the oldest ages to better develop patterns of what is occurring.^[B-27]

4. Technology constraints

The process for fitting a curve to base mortality involves pooling millions of records into one data system, with millions more flooding in every quarter. This presents a significant challenge to IT departments and their analysts. Transforming this amount of data into useful business information requires both data processing and data analysis. For an organization to be successful in both these tasks, it must have dedicated administrative support, strong IT operation and knowledgeable business guidance.^[A-6]

5. Outlier cohorts

Adrian Gallop, from the U.K. Government Actuary's Department, noted there have been instances in the U.K. population mortality data where a particular cohort was identified to be the main cause of observed stagnation in historical life expectancy. Such instances might be considered anomalies in historical data, which should be noted when trying to fit a model.^[B-8]

Dr. James Vaupel noted that life expectancy in U.S. females at age 50, as well as Danish and Dutch females, was identified by the U.S. National Academy of Science to be stagnating in the latter half of the 20th century. Smoking was found to be a primary cause as it was fairly consistent across the majority of females and is supported by how prolonged smoking effects on mortality are not observed until elderly ages. This stagnation in life expectancy was not observed in males as females generally started smoking later than males and, consequently, started quitting smoking later than males.^[B-1]

6. Mortality trends have different trajectories by insured group

Mortality for life settlement, life insurance and general populations is quite different at the outset because of several factors, including selection, impairments and the wealth effect. But as these populations age, their mortality rates converge, suggesting that original factors become increasingly negligible as time goes on. The convergence of different populations' mortality rates occurs much sooner than the typical 25-year select period used in life insurance populations and tables. Current studies are underway to better define the select period for these populations. Much of the primary research regarding Medicare data was performed by the Chronic Disease Research Group and will be published at a later date.^[A-117]

7. Varying levels of mortality improvement by cohort

Adrian Gallop noted how the U.K. longevity outlook is more optimistic than that of Canada. One of the reasons was the different methodology used in projecting mortality improvements for the U.K.'s golden cohort and how Canada only has a male golden cohort in its projections. While Canada assumes its golden cohort's higher mortality improvement rates will eventually converge to a long-term improvement factor used by other cohorts, the U.K. assumes its golden cohort's higher mortality improvement rates will be sustained through time. As a result, the U.K. model also transmits higher mortality improvement rates to later cohorts.^[B-8]

S. Jay Olshansky's view on the way previous improvements should be used to model future improvements is that it is much more impactful to look at the health of individual cohorts rather than assuming that trends of their grandparents will continue. He also notes that due to biological aging, there will be a pattern of diminished improvements.^[B-44]

As indicated by Larry Pinzur, the U.S. has a golden cohort born around 1935, which is about five years after the U.K. golden cohort. The U.S. also has what he calls a death valley, which is the baby boomer generation.^[B-37]

Canada has a cohort effect for males born in the 1930s and 1940s, which experience higher mortality improvement rates than cohorts before and after.^[A-172]

4.1.3.3 Related Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

<i>Appendix Reference</i>	Paper
A-6	Estimating Mortality of Insured Advanced-Age Population with Cox Regression Model https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-zhu.pdf
A-12	Dealing with Problems in Data Quality for the Measurement of Mortality at Advanced Ages in Canada https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-bourbeau.pdf

<i>Appendix Reference</i>	Paper
A-13	Using Dynamic Reliability in Estimating Mortality at Advanced Ages https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-lin.pdf
A-19	Longevity Determination and Aging https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-hayflick.pdf
A-33	Shapes and Limits of Longevity in Mexico https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-ii.pdf
A-39	Search for Predictors of Exceptional Human Longevity: Using Computerized Genealogies and Internet Resources for Human Longevity Studies https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-v.pdf
A-40	The Great Debate on the Outlook for Human Longevity: Exposition and Evaluation of Two Divergent Views https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xv.pdf
A-57	Is There a Limit to the Compression of Mortality? https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-03-cheung.pdf
A-82	Mortality Compression and Longevity Risk https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1b-yue.pdf
A-128	Logistic Regression for Insured Mortality Experience Studies https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-zhu.pdf
A-143	A Study of Measuring the Mortality Compression https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-yue.pdf
A-145	Compression of Morbidity and Mortality: New Perspectives https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-stallard.pdf
A-155	Causal Mortality by Socioeconomic Circumstances: A Model to Assess the Impact of Policy Options on Inequalities in Life Expectancy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-alai-arnold-bajekal-villegas-paper.pdf
A-157	Health Technology, Health Care Cost, Longevity and Retirement Security: A Dynamic Upward Spiral and Challenge to Future Policy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-bailey-paper.pdf
A-159	Mortality Trajectories at Exceptionally High Ages: A Study of Supercentenarians https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gavrilova-gavrilov-krutko-paper.pdf
A-160	Historical Evolution of Old-Age Mortality and New Approaches to Mortality Forecasting https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gavrilov-gavrilova-krutko-paper.pdf
A-161	Extreme Value Analysis of Mortality at the Oldest Ages: A Case Study Based on Individual Ages at Death https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gbari-poulain-dal-denuit-paper.pdf

<i>Appendix Reference</i>	Paper
A-167	Where is the Level of the Mortality Plateau? https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-rau-ebeling-peters-bohnk-ewald-missov-paper.pdf
A-172	Mortality Projections from a Social Security Panel https://www.youtube.com/watch?v=CmnO5kPber8&t=2s
A-174	Suppressing Aging and Extending Longevity: Will the Twain Meet? https://www.youtube.com/watch?v=Beax-wE4gsA&feature=youtu.be
B-1	Summary of Panel Discussion on the Advancing Frontier of Human Survival https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1-soa-informal-discussant.pdf
B-8	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
B-12	Discussant Comments for Session on From Population to Insured Lives, Finding Longevity Drivers https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-edwalds-discussant-comments.pdf
B-16	Discussant Comments for Session on Mortality Age Patterns: Trends and Projections https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-lid-discussant-comments.pdf
B-24	Session 1B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1b-transcript.pdf
B-26	Session 2A: Panel: Drivers of Future Mortality https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2a-transcript.pdf
B-27	Session 2B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2b-transcript.pdf
B-37	Session 6A: Mortality Improvement Approaches https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6a-transcript.pdf
B-44	Discussant Comments for Session on Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-olshansky-discussant-comments.pdf
B-45	Discussant Comments for Session on Older-Age Mortality Trends https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-2b-discussant-comments.pdf
B-48	Discussant Comments for Session on Late-Life Mortality Curves https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-robine-discussant-comments.pdf

4.1.4 Assessing Trends in Underlying Mortality and Morbidity

This section is devoted to papers that support the trend of mortality improvement around the globe. These papers focus on longevity patterns of developed and developing countries in North America, Europe, Asia and Africa.

This section is divided into seven subsections. The first subsection summarizes papers that show support for increasing longevity in specified geographic regions. The second subsection analyzes methods for adjusting trends for smaller populations. The third subsection discusses methods for comparing estimates of different populations. The fourth subsection identifies challenges in determining life tables and mortality improvements. The fifth subsection presents techniques currently in use by different countries and actuarial groups when creating life tables and improvement scales. The sixth subsection presents techniques for validation of the base tables at advanced ages, while the seventh subsection focuses on morbidity compression.

4.1.4.1 Overview of Trends in Longevity

1. Global overview

A study that used data from the International Database on Longevity (IDL) has shown that mortality rates for people between the ages of 110 and 114 have not increased over the study period (or increased very slightly). The study includes 660 death records collected from 1892 to 2003 for 16 participating countries. The people who performed these studies believe that their findings reject the exponential trajectories of Gompertz and Makeham. However, the findings cannot distinguish between logistic and quadratic trajectories, as the latter only diverges from observations for subjects with more than 115 years of age (Robine and Vaupel, 2002). Regardless, the results of the IDL studies do not appear to demonstrate an obvious age limit for human longevity, meaning that no biologically controlled limits, such as clock genes or other mechanisms linked to natural selection have yet been discovered.^[A-30]

Although the exponential increase in the number of centenarians is well documented in Europe and Japan today, this is still not the case for older persons of 105 years (semi-supercentenarians) and 110 years (supercentenarians) of age. However, it is still clear that the number of semi/supercentenarians has been increasing, just like that of the regular centenarians. The number of supercentenarians in low mortality IDL countries, for example, is now 10 times greater than during the mid-1970s. And as the number of regular, semi-super- and supercentenarians has increased, so too has the maximum life-span for humans, which has gone from 112 to 122.^[A-10]

The number of centenarians and percentage of the overall population across multiple countries studied are continuing to grow. Beaudry-Godin et al indicate this trend should be expected to continue with new records being set in terms of survival into extreme old age in the 21st century.^[A-158]

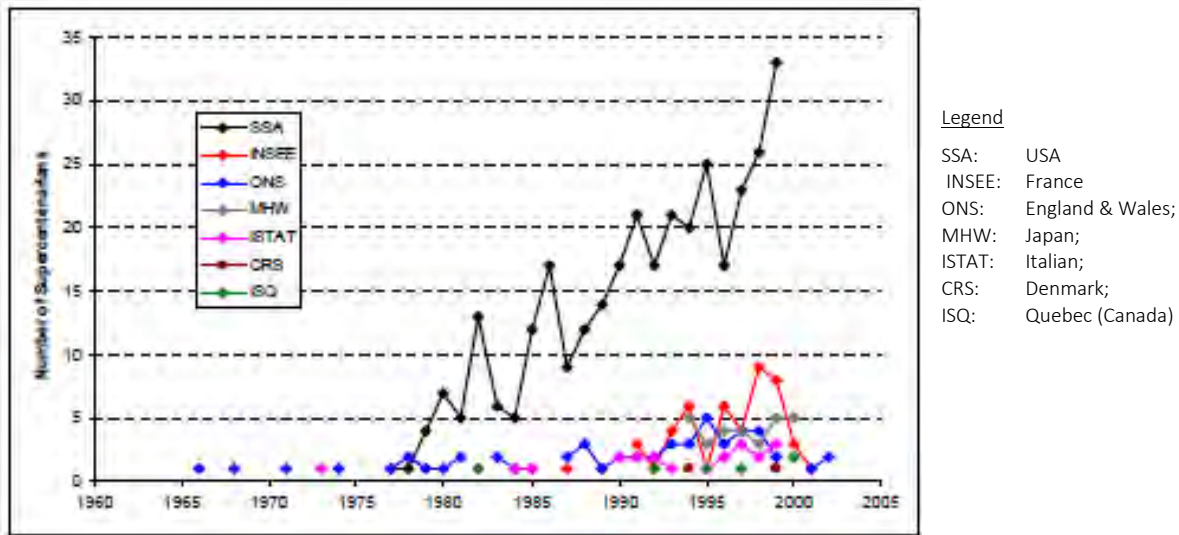
The ratio of centenarians per 10,000 persons aged 60 has been growing substantially in many of the low-mortality countries. Three probable causes are driving that increase:^[A-158]

- ▶ Increased cohort size
- ▶ Increased probability of surviving to age 80
For example, in Quebec, for generations born in 1871 to 1901, probability of surviving to age 80 increased from 0.09 to 0.14 for males and from 0.11 to 0.23 for females.
- ▶ Increased probability of surviving from age 80 to 100
For example, in Quebec for the same generations born in 1871 to 1901 the probability of survival from 80 to 100 doubled for men and tripled for women. This is the most significant driver of the increase in centenarians.

Figure 4.1.4-01 shows the number of persons who have attained 110 years of age for countries that have submitted data to the IDL as of March 2004. Note that there should be a significant increase of supercentenarians as of today.

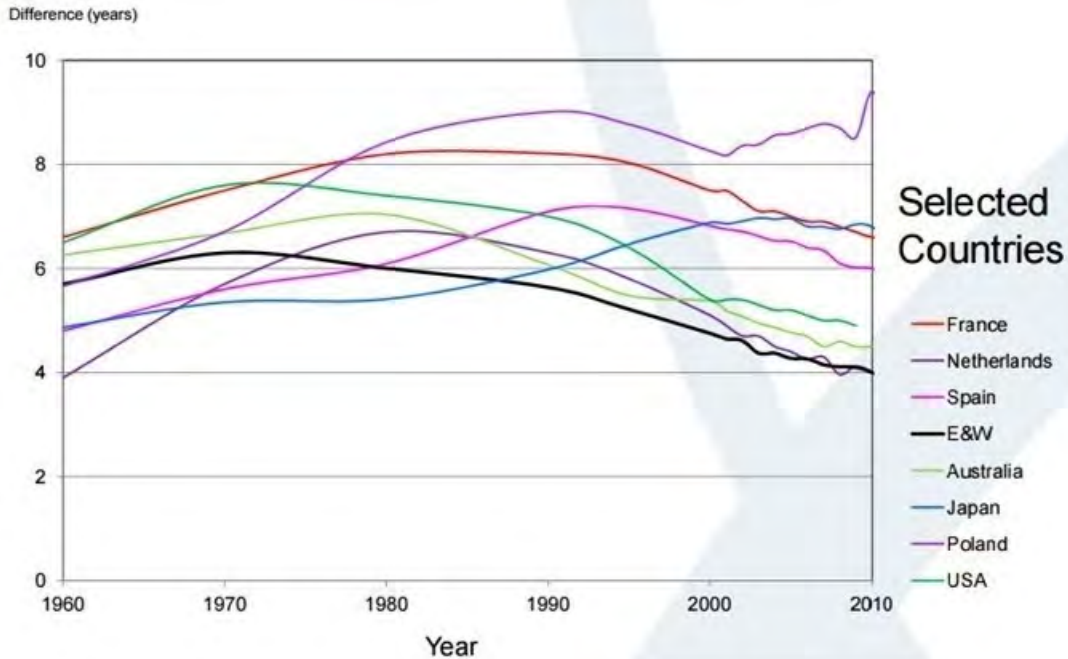
Figure 4.1.4-01: Number of Persons Having Reached 110 Years of Age by Year^[A-30]

(International Database on Longevity, March 2004, Persons Deceased at Age 110 and Over)



Another emerging global trend is the narrowing gap between female and male life expectancies. Figure 4.1.4-02 below shows how the gap has changed during the last 50 years. There are countries, such as Japan, where female life expectancy has been increasing much more rapidly than male life expectancy in recent years and starting to plateau in recent years.^[B-8]

Figure 4.1.4-02: Gap in Period Life Expectancy at Birth (Female—Male)



Sam Guterman found that rate of mortality improvement, which in the last several decades has been greater for males, could converge to those of females after next several decades as the effect on mortality of the earlier

dramatic decreases in male smoking prevalence are followed by the effects of the smaller, but still significant, reduction in female smoking prevalence.^[A-133]

2. United States

The state of New York examined data from 1921 onward, paying special attention to data collected after 1986. Researchers used the data to forecast future mortality rates and to calculate the effects of liabilities and the funding of the New York State and Local Retirement System. Assuming that past trends would continue into the future, the study showed that, 30 years from now, mortality rates for pensioners over age 80 would develop at approximately 67 percent of our present-day assumptions. This would translate into a four-year increase in life expectancy, from 22 to 26, for 62-year-old pensioners.^[A-1]

Authors reviewed longevity over a similar period (1980 to 1998), when there were substantial improvements in the health and mortality of the elderly (age 65+), the old-old (age 75-85) and the oldest-age (age 85+). Interestingly, the authors found that the improvements in life expectancy at age 75 (which increased by 8.7 percent) differed by gender. Among males, the increase was 13.6 percent, while among females, it was 6.1 percent. The improvements also differed based on cause of death and time period.^[A-17]

Stephen Goss, Chief Actuary for the U.S. Social Security Administration, noted how the difference in mortality improvements by gender was attributed to how females started smoking later than males and, consequently, quit later than males. Thus, while males have surpassed the smoking-related drag on mortality improvements, females, in particular the cohort born in the early 20th century, are still experiencing its effects.^[B-8]

Goss also mentioned the following factors as major contributors to historical mortality improvements in the U.S.:^[B-8]

- ▶ 1930–1950: Introduction of penicillin, antibiotics, large increase in the standard of living, as well as improved access to primary health care.
- ▶ 1960s: Introduction of Medicare and Medicaid, creating availability of primary health care for aged, disabled and poor people who had been responsible for the majority of deaths in the population, especially at younger ages.
- ▶ U.S. government health expenditure increasing from 3 percent of GDP to 18 percent of GDP since 1970.

However, Goss notes that mortality improvements over the last century have been shifting from occurring at younger ages to occurring at older ages. When it comes to increasing life expectancy, a minor mortality improvement at a young age is the equivalent of a major mortality improvement at an old age. Thus, Goss concludes, the implied mortality improvements required to occur at elderly ages, in order to maintain the historical increasing linear rate of life expectancy, is unattainable.^[B-8]

On the other hand, Dr. James Vaupel argues that the current Social Security Administration estimates are not reasonable; they project U.S. life expectancy at birth in 2050 to be less than the 2014 values of French life expectancy (85 for females and 78 for males). While France has projected its life expectancy to be 95 for females and 88 for males in 2050, it is hard to believe U.S. life expectancy in 2050 will be 10 years below that of France.^[B-1]

Dr. Vaupel also notes how if future trends in life expectancy were to be extrapolated from its historical increase since 1950 (of 2.5 years per decade), the projected life expectancy increase on a period basis would be three months per year. However, on a cohort basis, it would yield an increase of four months per year. This four-month increase in life expectancy per year shows that most Americans born since 2000 would celebrate their 100th birthday.^[B-1]

In a study by Andreev et al, U.S. life expectancy at older ages used to be dramatically higher than the average of 13 peer countries in the period 1959–1969, but recent life expectancies are significantly closer. This is likely due to

poorer data quality in the U.S., so trends that look at longer-term data should consider the reliability of those changes.^[A-156]

When analyzing state-specific data, mortality in Hawaii, especially for males, is exceptionally low. Other states with the lowest mortality include California, Florida and Connecticut. States with the highest mortality levels are West Virginia, Alabama and Mississippi.^[A-156]

Life expectancy at the age of 80 is significantly longer for females than males in the U.S. states. The only overlap in the distributions are Hawaiian males, who have life expectancy at age 80 equal to and slightly above the lowest end of the distribution for females by state.^[A-156]

While mortality improvement continues, some researchers observed a decrease in the rate of the improvement. Deaths from heart disease have decreased dramatically; however, Stephen Goss indicates that there is likely not much improvement left to be made in deaths from heart disease into the future, which could decrease improvement rates at older ages. Most recent U.S. experience indicated that decreases in mortality in recent years have decelerated significantly faster than projected, and it is unclear if this is a blip or a shift in the trend.^[A-172]

3. Canada

In 2014, the Office of the Chief Actuary noted that life expectancy in Canada at age 65 has increased by two years over the previous decade, representing a growth rate of about twice of what has been observed over each of the previous decades since 1929. Life expectancy at birth in Canada has increased by approximately 33 years, with most of the change occurring before 1950. In particular, however, increases in life expectancy for the population over the last 30 years have been largely due to reduction of mortality rates after age 65, as a result of fewer deaths caused by heart disease. Life expectancies at age 65 are projected to increase from 21 to 24 years for men and from 23 to 26 years for women by 2075. This means that Canadians are expected to live beyond age 90 on average in the future. Moreover, if the same mortality improvement rates as the ones experienced during the last 15 years by cause of death were to be sustained over the projection period, males would be expected to outlive females from 2026 onward. Increases in life expectancy have been largely due to the decrease of deaths caused by heart disease. Canada is expected to continue to have one of the highest life expectancies of the world, along with Japan, France, Switzerland, Italy and Australia.^[A-154]

Mortality improvement rates at the older ages are being driven by decreases in deaths for some of the leading causes of death. For ages 65–74 there was a 22 percent reduction in mortality from 1931 to 1971 and a 52 percent reduction from 1971 to 2011. The predicted reduction for 2011–2051 is 40 percent.^[A-172]

In Canada, three-quarters of males and 82 percent of women aged 20 are expected to live to age 80. Almost half of males and 58 percent of women aged 20 are expected to survive to age 90. Eight percent of males and 14 percent of women aged 20 are expected to live to age 100.^[A-172]

Jean-Claude Ménard, from the Office of the Chief Actuary, noted that a life expectancy of 100 years is achievable if the maximum life-span increases to 140 for males and 132 for females. Office of the Chief Actuary (Canada) also comments on how the cohort effect of those born in the 1930s (who experienced higher mortality rate improvements than other cohorts) exists for Canadian males but not for Canadian females.^[B-8]

Robert Bourbeau and Bertrand Desjardins used parish registers in the province of Quebec to establish a computerized database with the basic demographic parameters of the French-Canadian population. The authors used these data to derive a comprehensive longitudinal observation of the adult mortality of the entire population—specifically the reliable measure of the mortality of 3,697 men and 4,386 women born between 1680 and 1704, who married.^[A-12]

Contrary to expectations, the data seem to show that the progression of mortality remains approximately exponential until the oldest ages, where the data become erratic due to limited observations. The authors

concluded that the nature of the selections, which would slow down the rate of increase in mortality for the elderly today, were not present a few centuries ago.^[A-12]

In a subsequent research on centenarian mortality using the same parish register data, Nadine Ouellette and Robert Bourbeau noted that, while the aggregation of several birth cohorts is not responsible for the late-life mortality deceleration observed in the studied data, the studied data support the existence of such deceleration.^[A-138]

In Quebec in 1921, under two-thirds of centenarians were female, whereas in 2012, 90 percent were females. The number of total centenarians during that time grew from 15 to 1,359, with the largest growth between 1971 and 1991.^[A-158]

Maximum age at death has also trended upward in Quebec. The “adjusted” maximum age at death rose from 101 to 107 for men and from 103 to 109 for women.^[A-158]

Life expectancy in Canada has been increasing steadily since the beginning of the 20th century, but the increases are starting to flatten out. Continued increases are shifting to being driven by improvements in mortality from birth to 65 and are now being driven by improvements in life expectancy after the age of 65.^[A-172]

4. United Kingdom

In line with observations from other developed countries, U.K. mortality rates have fallen dramatically over the 20th century. Overall, mortality rates in the United Kingdom for people of age 90 fell by 22 percent from the period of 1964–1968 to the period of 1999–2003. Breaking those results down by gender, those mortality rates fell for females at all ages up to 100 and for males up to 96. Death rates at higher ages are erratic as a result of the limited number of observations at higher ages.^[A-36]

Other research noted that the modal age at death increased by 14.59 years for males and 11.37 years for females between 1841 and 2010.^[A-144]

Adrian Gallop, from the U.K. Government Actuary’s Department, noted how in 2014 life expectancy at birth was 79.0 years for males and 82.7 years for females, while life expectancy at age 65 was 18.3 years for males and 20.7 years for females. Projections to the year 2087 shows expectation of life at birth to be 90.4 years for males and 93.2 years for females, while life expectancy at age 65 will be 27.5 years for males and 29.7 years for females.^[B-8]

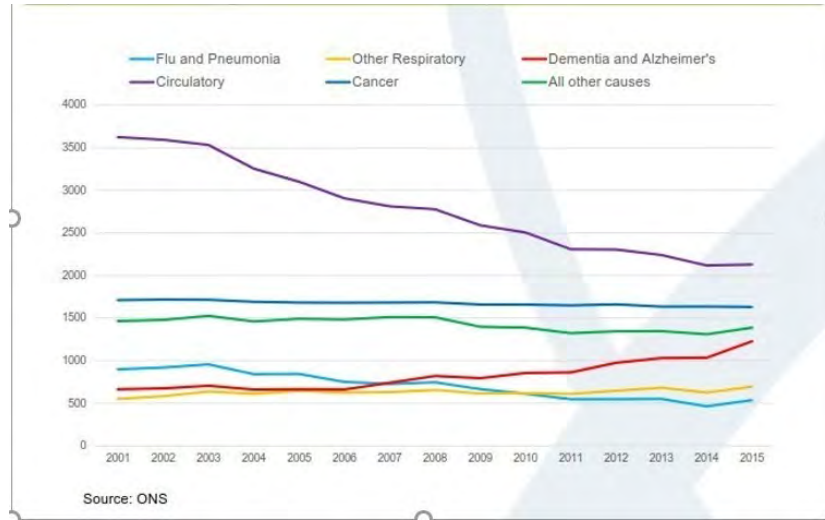
After examining data for cohorts born before 1947, the authors of a separate study proved that different generations exhibit different rates of mortality improvement. For example, the mortality rates of generations born around 1931 are improving faster than those of earlier *and* later generations: the U.K.’s “golden cohort.”^[A-36]

Although the exact reasons for the existence of the golden cohort have not yet been determined, various hypotheses remain: the introduction of National Health Services in 1948 or calorie restriction during the Second World War (which has been proven to increase longevity in mice).^[B-8]

Recently, dementia and Alzheimer’s have been causing more deaths over the age of 75. This is becoming a main driver of mortality for the older cohorts.^[A-172]

Figure 4.1.4-03: Age Standardized Mortality Rate by Cause, England and Wales

Age standardized mortality rate by cause, persons aged 75 and over



In England and Wales there were estimated to be 504,030 people 90 and older in 2015 compared to 222,820 in 1991, which was a 0.5 percent increase in percentage of total population.^[A-171]

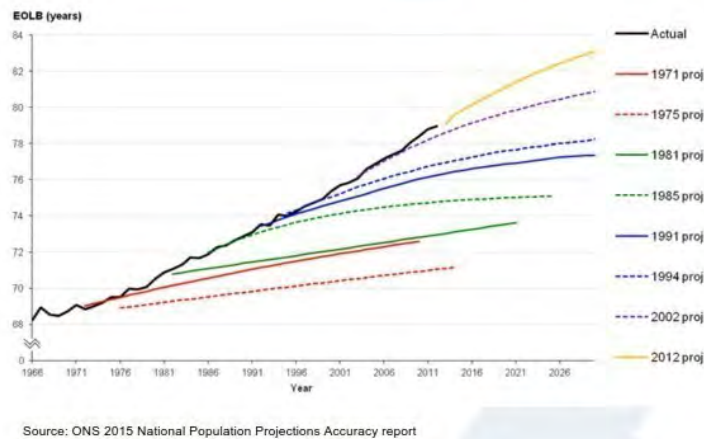
The U.K. has seen an increase in life expectancy at birth from 1841 to 2011, but that has leveled off in the recent years. There have been improvements in mortality rates for ages 40–59; however, the 80–89 age group is not seeing improvements.^[A-172]

Gallop indicates that recent decreases in improvement deviate from previous projections, but it is unclear if that is a blip in the data or an inflection point with future implications on the mortality curve. One possible explanation for this shift is an outbreak of influenza that was specifically deadly for older people in the U.K. during 2014.^[A-172]

The actual expectation of life at birth increased more than all previous projections.

Figure 4.1.4-04: Actual and Projected Expectation of Life at Birth

Actual and projected period expectation of life at birth, Males, United Kingdom, 1966 to 2030, selected projections



5. Spain

Authors collected data on those who passed away between the years of 1975 and 1995 and analyzed the number of people over the age of 100 with a focus on gender, cause of death, month of death, location of death, marital status and profession. The authors compared their data with that of the 10-year census (1981 and 1991) and its 5-year updates (1986 and 1996). Based on the analysis, the authors showed that the number of inhabitants over the age of 100 increased by 43.29 percent from 1981 to 1999, which correlates to a 2.41 percent increase each year. In the same period, the total Spanish population increased by 6.68 percent, demonstrating that the percentage of people over the age of 100 from the total population was approximately 34.32 percent more in 1999 than it was 19 years previously.^[A-11]

6. Denmark

In Denmark, life expectancy increased by 40 years from 1835 to 2006. The initial improvement is attributed to reduced infant and child mortality; the improvements from 1950 are attributed to improved old-age mortality.^[A-122]

7. Sweden

Sweden's modal age of death has steadily increased from 1950 until recently. Its mean deviation above the mode only started decreasing from 1970 onward, indicating a period of strong compression of mortality.^[B-18]

8. Japan

Japan's modal age of death has steadily increased from 1950 until recently. However, unlike Sweden, while its mean deviation above the mode has decreased from 1950 to 1980, it has remained stagnant since 1980, suggesting Japan has transitioned from a period of strong compression of mortality to a shifting mortality scenario.^[B-18]

9. France

France's modal age at death has been increasing steadily from 1950 until recently, although its mean deviation above the mode decreased only from 1970 to 1990. This indicates France experienced a short period of mortality compression from 1970 to 1990 but a shifting of mortality in other years.^[B-18]

10. Italy

Italy's modal age at death has been increasing steadily from 1950 until recently, although its mean deviation above the mode has increased slightly since 1950. A clear shift of mortality has occurred.^[B-18]

11. India

Authors analyzed census reports, which indicated that the Indian population has approximately tripled in the last 50 years, with the elderly population having increased more than fourfold. The United Nations predicts that the Indian population will grow by another 50 percent in the next 50 years, with another fourfold increase for the elderly.^[A-34]

12. Sub-Saharan Africa

The deaths associated with the HIV epidemic in sub-Saharan Africa have a significant impact on longevity. Within each nation, longevity has been bimodal, demonstrating those with and without HIV. That epidemic has at least temporarily reversed the trend of increasing longevity for the region.^[A-157]

4.1.4.2 Methods for Adjusting Estimates of Smaller Populations

It can be beneficial to break down trends and future estimates into smaller populations to get a more accurate prediction for a specific group of people. However, as mentioned earlier, that causes issues with credibility of the

data and biases that small numbers can create. Graduation methods based on a reference population to smooth irregularities can be used.^[A-169]

- ▶ The partial standard mortality ratio (partial SMR)^[A-169]
The idea behind this method is to calculate the sum of observed deaths at each age divided by the sum of expected deaths at that age. This can be calculated with reference to another population by determining expected deaths as the sum of the population size of one age for the small population times the central mortality rate at that age for the reference population. Adjusting that idea to the method of partial SMR means the graduated mortality rates satisfy the weighted average between raw mortality rates and the SMR. This idea is similar to a credibility-weighted estimate, as it is a linear combination of observed information and reference information. The larger population should be weighted more heavily when the number of deaths in the smaller population is smaller.
- ▶ Whittaker graduation method^[A-169]
This method calculates the ratio of the age-specific mortality rates of the small population to those of the larger reference population. The Whittaker method minimizes that ratio by weighting the squared differences in graduated mortality ratios and adding a smoothing parameter.
- ▶ Evaluating methods^[A-169]
In the study by Yue and Wang, when using a sample population of 2 million to adjust estimates for populations of 100,000 or 200,000, using graduation methods improved the mean absolute percentage error. Specifically, the partial SMR method is very successful for when mortality rates of the small and reference populations have the same mortality proportions for all ages. For scenarios where the mortality ratio of the small and reference populations has differing proportions across ages, the Whittaker ratio is generally better (except for the scenario of the reverse V shape of mortality rates).

The mortality adjustments developed in the Yue and Wang paper are further applied using the Lee-Carter model. There are many options of how to apply the adjustments to the Lee-Carter model, including the order of mortality graduation, which graduation method to apply and which version of the Lee-Carter model to use. When the alpha of the populations is different but the betas are the same, the partial SMR method applied to the original Lee-Carter model yields the smallest mean absolute percentage error for consistent mortality proportions across ages. When mortality ratios between the smaller and larger populations vary across ages, the coherent Lee-Carter model (also called the Li-Lee model) combined with the Whittaker graduation method produces the smallest MAPE (mean absolute percentage error).^[A-169]

When applying the same scenarios where the alphas of the two populations are the same and the betas differ, using the partial SMR method to graduate mortality rates and then applying the Lee-Carter model has the smallest mean absolute percentage errors for all scenarios of mortality rate proportions.^[A-169]

Applying graduation methods can improve mortality estimations, but the proper graduation methods need to be selected based on characteristics of mortality rates. Data analysis is key to selecting the appropriate combination of methods and models.^[A-169]

The time-related parameter of the Lee-Carter model can create problems when the reference populations are included. Differing time-related parameters between the populations should be considered because this can distort the effect of graduation.^[A-169]

Kaufhold comments that the simple approach to this method is appealing. He likes the approach of using life table techniques and smoothing that actuaries are familiar with.^[B-42]

Kaufhold also notes that it would be interesting to compare the Lee-Carter model with other more modern methods of graduating mortality tables to find a potential more optimal approach.^[B-42]

Yue indicates that the use of life table construction as a graduation method accomplishes the goal of model simplicity, which is desired in any study, and that future analysis of other graduation methods would be a good validation.^[B-30]

4.1.4.3 Methods of Comparing Longevity Between Regions and Countries

It can be valuable for actuaries working with countries of similar demographics to compare trends in longevity to gain more understanding of global trends.

1. Methods suggested by Beaudry-Godin

Beaudry-Godin et al discuss multiple methods to do so and the drawbacks of each:^[A-158]

- ▶ Life expectancy
This method uses life expectancy at a given age (for studies on centenarians the age is 100). Drawbacks to this method include the inexact nature of those expectancies due to low numbers of people who attain age 100. The method also assumed that mortality rates at different ages will be the same over time regardless of conditions or cohort effects.
- ▶ Prevalence of centenarians
This method relates centenarians to total population. This method faces challenges of migration and differing events that influence longevity and age structure within a location. Those problems make it difficult to apply to international comparisons.
- ▶ Ratio of centenarians per 10,000 births
This method divides the number of 100-year-olds at a given date by the number of births that took place in a year time frame one century earlier. This biggest challenge with this method is migration. The numerator and denominator measure different populations, leaving room for underestimation or overestimation.
- ▶ Extreme longevity index
This method might be the most successful because it considers all survivors to age 100 in a given generation to the number of births in that generation. This is better than other methods because it prevents issues of migration from altering the results. However, application of this method is difficult because a region must have data on number of births in a given time (currently late 19th and early 20th century data are needed). Additionally, tracking of immigrants who reach 100 years is not readily available. This method will also compare cohorts who weren't subject to the same mortality regimes (wars, epidemics etc.), so it is difficult to apply in international comparisons.
- ▶ Ratio of centenarians per 10,000 persons aged 60 forty years before
This method is the same as the ratio of centenarians per 10,000 births except it uses data from people who were 60 years old 40 years earlier. This helps in studying extreme old age because it removes noise from infant mortality and exposure to some mortality-driving events. Additionally, migration after the age of 60 is less common than earlier in life. This is the method selected by Beaudry-Godin et al in a study comparing Quebec to other countries.

2. Methods suggested by Martin Genz

The paper by Martin Genz uses four statistics for comparisons between countries: modal age at death, the upper bound of the deaths curve's support, degree of inequality (DoI) and number of deaths at the modal age at death. The first two measure changes in position of the deaths curve, while the second two measure change of the shape of the curve:^[A-162]

- ▶ Modal age at death is the position of the deaths curve's peak. Increases are called right shifts, and decreases are left shifts.

- ▶ The upper bound of the deaths curve's support is the age where the survival curve equals zero. An increase in the upper bound is called extension, and a decrease is called contraction.
- ▶ The degree of inequality measures compression and decompression. Compression is a process where the deaths curve becomes more unequal over time. Compression means the curve is getting further from a uniform distribution on the age interval (0, upper bound), and the opposite is true and is called decompression.
- ▶ Number of deaths at the modal age of death describes the relative importance of the modal age at death compared to other ages. Increases in this statistic are called concentration, and decreases are called diffusion.

Regional and country comparison results

To find trends and trend changes, the Genz paper uses a three-step approach: (1) identify and eliminate outliers, (2) identify periods where the time series has a constant linear trend, and (3) test each trend from the second step to see if it is significantly different from zero.^[A-162]

Comparisons can be helpful when they are regionally clustered. For analysis in Genz's paper, the author used the following clusters:^[A-162]

- ▶ Northwestern Europe: Sweden, Norway, Iceland, Finland, Denmark, Scotland, England and Wales
- ▶ Central Europe: the Netherlands, Belgium, Luxemburg, West Germany, Austria and Switzerland
- ▶ Southwestern Europe: France, Spain, Portugal and Italy
- ▶ Eastern Europe: East Germany, Poland, Czech Republic, Slovakia, Estonia, Latvia, Hungary, Bulgaria, Belarus, Ukraine and Russia
- ▶ North America: U.S. and Canada
- ▶ Asia-Pacific area: Japan, Australia and New Zealand (non-Maori and Maori)

A few main trends have been noticed over the most recent decades. First, most countries are seeing growth in statistics measuring the position of the deaths curve, meaning the curve has shifted to the right and extended. The general trend of increasing statistics is also true for statistics measuring shape of the curve with a few more exceptions. This means the overarching global trends are right shift, extension, compression and concentration. A second main observation is that around 1970 many countries saw trend changes around the same time. A final observation is that around 1990, trends in most statistics change for Eastern European countries, where they often change from being different from other populations to the same.^[A-162]

When considering overall relative similarity of the sexes, only four countries exceed 80 percent, and the majority are smaller than 70 percent. This is a very good defense for the use of single-sex mortality evaluations. Unisex models should be carefully applied.^[A-162]

Kaufhold notes that the relative similarity metric developed by Genz could be very beneficial in many studies that need a reference population to enhance the estimate.^[B-42]

Three main observations come from the Genz paper analyzing the differences in sex across all the countries in the study. The left shift of the modal age at death is consistent in recent decades, but there is an important difference in how long that has been occurring. Generally observed trends in compression or decompression are not significantly different between the sexes. For the upper bound and number of deaths at the modal age in death statistics, there are relatively few sex-related differences, but they can't be considered immaterial.^[A-162]

The age impact of where to start the deaths curve (age zero or 60) has a larger impact on males than females. This seems to be true because mortality changes for women are dominated by shifts in older age, which create the same

patterns between curves at either starting age. However, for males, shifts in the curve are more driven by changes below the age of 60, which cause starker differences.^[A-162]

Genz notes that one of the challenges with the approach of steady time series and fitting with a continuous line is some of the jumps get lost in the linear trends. Further research will be conducted to better combine a method of detecting jumps and changes in trends.^[B-30]

According to Beaudry et al, until 2001 Quebec had a notably higher centenarian ratio than European countries, but in 2011 France surpassed Quebec in centenarian ratio per 10,000 individuals aged 60 forty years earlier. This is an overall trend where the gap is being reduced between Quebec and European countries.^[A-158]

4.1.4.4 Creation of Life Tables and Mortality Improvement Scale

Many approaches are taken by many different actuarial groups to develop accurate life tables and improvement scale to reflect global trends and projection models for older age mortality for specific-use case/product lines/actuarial applications, such as life insurance, annuity, private pension and social programs. Recognizing and reconciling differences can be important for a variety of actuarial applications and for actuarial groups to be able to collaborate.

1. Life tables and mortality improvement of the general population

HMD uses the Lexis triangle method to create its life tables. This is done by finding the ratio of deaths to exposures within each Lexis triangle. A Lexis triangle is defined as a single calendar year, age and cohort.^[B-40]

The HMD uses the intercensal survival method for cohorts that are not extinct or near extinction. HMD then uses the survivor ratio method for all almost extinct cohorts. For extinct cohorts, it uses the extinct cohort method. The HMD used the Kannisto methodology to estimate mortality rates at the oldest ages where data are less credible. These methods are further discussed in the next subsection. To move between census years, deaths are taken out of cohort population, and those populations are rolled forward annually until they meet the population data from the next available census.^[B-40]

U.S. life tables produced by the Social Security Administration, the National Center for Health Statistics and the Human Mortality database differ, due to both underlying data used over the age of 65 and the methods selected to create estimates for mortality at older ages.^[B-40]

One large distinction in recent updates is the use of two-dimensional projection scale. Two-dimensional projection scales are gender-specific scales that are functions of age and calendar year.^[B-37]

Two-dimensional tables show a cohort effect along the diagonals of the table as age and year increase by one going down and right along a diagonal. Static one-dimensional tables can be used to approximate generational annuities by pushing out the static calculation to around the duration of the underlying annuity.^[B-37]

2. Improvement scales for insured groups

Here are examples of tables that actuaries currently use for different products:^[B-37]

- ▶ AG38 mortality improvement is the one-dimensional scale currently used for life insurance products. This scale is designed for short-term projections and has a high age gradient from age zero onward.
- ▶ Scale G2 is the one-dimensional scale used for individual annuities, where it is much more important to project future mortality improvement much farther out compared to the life insurance table.
- ▶ Scale AA is the one-dimensional scale used for statutory basis group annuity reserves. This scale is also used for many government calculations. It is based on historical mortality improvement from 1977 to 1993, so it is a good candidate for a scale to be updated. It essentially takes cohort effects that existed around

1985 and projected the same effects will continue perpetually, and Pinzur comments that this seems very unreliable.

- ▶ Scale BB was used a transitional scale for pension actuaries to replace scale AA. It was created starting with a two-dimensional table with deferred-to-age-62 annuity values based on base mortality rates. It then used the annuity values and assumed a 6 percent interest rate to back into the age-only rates. This was done to allow time for software updates to be made to accommodate two-dimensional tables.
- ▶ MP-2014 was the first two-dimensional scale created under the Retirement Plans Expense Committee (RPEC) and published by the Society of Actuaries. Updated twice to create MP-2015 and MP-2016 with the same methodology, it is based on framework for the Continuous Mortality Investigation's (CMI) current model, which has three key concepts:
 - ▶ Near-term mortality improvement rates should reflect recent experience.
 - ▶ Long-term mortality improvement rates should be created based on expert opinion.
 - ▶ Near-term rates should blend smoothly into long-term rates.
- ▶ The SSA model is a two-dimensional model that is one assumption used by the Social Security Administration to determine the viability of the system. The starting point is calculated by averaging the prior 10 years of mortality improvement for each age, and there's a steep convergence to long-term rates. This two-dimensional table also doesn't have the diagonal cohort effects that the RPEC 2014 table has.
- ▶ CMI, the model created by the Continuous Mortality Investigation, which was the baseline for the first U.S. two-dimensional table, is the U.K. version with similar characteristics to MP-2016, but it uses specific age, period and cohort effects.
- ▶ CPM is the Canadian pensioners mortality improvement scale. It uses long-term rates from 2030 and beyond of a flat 0.8 percent until age 82 and grading down to 0 by 115. It doesn't have a cohort effect explicitly recognized.

4.1.4.5 Validation of Current Base Tables at Advanced Ages

Because of the challenges involved in producing reliable data for older age mortality, the symposia material presents several methods for identifying the level and age trajectory of mortality at advanced ages. These methods are especially important when it comes to establishing end points for life tables.

As noted by Magali Barbieri, the HMD validates its life tables with country-specific experts and discusses any idiosyncrasies to produce the highest quality tables.^[B-40]

1. The extinct generation method

It is difficult to produce accurate level and age trajectories in Canada because of problems with the reliability of data on deaths and on population counts beyond a certain point in the official statistics. Still, there are ways to determine appropriate termination of life tables. One such way is to validate a sufficient number of unbiased high ages at death, which can then be used to produce an accurate termination age with the extinct or almost extinct generation method.^[A-12]

This is done by summing deaths starting with zero with remaining count of survivors to find exposures and comparing to cumulated deaths. These estimates rely heavily on death data and use only estimations of remaining survivors for the last few years.^[A-156]

The almost extinct cohort method is believed to be more reliable for estimates of mortality at older ages. It uses only death registration data, which are more reliable than estimated population counts. It also allows more detailed

rates by individual age.^[A-156] This method produces correct results if migration is negligible, age reporting is accurate, population counts are accurate, and death and population registrations are complete and consistent in coverage.^[A-156] Age misreporting has caused implausible rates using this method in the past. If mortality rates are declining as they have been in contemporary trends, age misreporting will dampen rates of mortality improvement.^[A-156] In a study by Andreev et al using this method, the U.S. had significantly lower mortality from 1959 to 1969 than 13 other countries with similar modern longevity. That indicates this method was failing due to the age misreporting that occurred.^[A-156]

2. Survivor ratio method

Actuaries could establish convincing evidence in support of a survival pattern for people of old ages. With this tool, actuaries could employ mathematical techniques to generate mortality rates as extensions of those mortality rates for ages 70 to 90 or 100.^[A-12] This method assumes deaths by year of age of a generation are distributed in the same proportions as those the 5 or 10 preceding generations.^[A-158]

The Kannisto-Thatcher (KT) model is a version of the survivor ratio method that produces age-specific estimates of population at older ages using death data. For cohorts that are almost extinct, the ratio of number of survivors to deaths in a given previous number of years can be estimated from experience from previous cohorts. An iterative process can be done to determine ratios for the highest age of an expected survivor downward to obtain survivor ratios by recreating past populations. Those ratios can be averaged over a certain number of earlier cohorts to dampen fluctuations. The KT takes this structure and constrains estimates to sum to official population estimates of a given age group to adjust for reduced mortality at higher ages.^[A-171]

Kannisto-Thatcher assumptions:^[A-171]

- ▶ Migration at oldest ages is minimal.
- ▶ Information on age at death is accurate and complete.
- ▶ Birthdays and deaths are evenly distributed throughout the calendar year:
 - ▶ Since data are needed at the midyear and obtained on January 1, an adjustment is made to assume half of the deaths at a certain age in a year were one year younger at January 1 and the other half were the age at death on January 1.

Based on a study of Finland and Sweden, the KT produces a similar result to population register estimates, but estimates are further apart at the oldest ages and for younger ages in recent years. This is due to having fewer deaths data for younger ages in recent years, making population counts harder to estimate. Additionally, the adjustment that is set for ages of death back to January 1st impacts the estimate by creating more variability and closeness of fit and slightly larger differences.^[A-171]

The KT approach produces very similar results to other population models when the mortality is assumed to stay constant. When mortality is increasing or decreasing, the KT approach will over- or underestimate the 90 and older population.^[A-171]

When comparing to census data and Statistical Population Datasets (SPDs) in England and Wales, the KT estimate of the number of people 90 and older is lower than the other estimates. The breakdown in percentage of that population of each age is very consistent among the different methods of estimating the population. The census had a different breakdown of the sex ratio, but the KT method and SPD had similar results.^[A-171]

The HMD is developing a new strategy to deal with years where births are not universally distributed in a given year. Adjustments will be made to the measure of exposure using births-by-month data. This process will use the mean of when the births occurred during the year and the variance of the distribution to adjust the exposures.^[B-40]

3. Narrow the age intervals to monthly time steps

In particular, the authors Natalia Gavrilova and Leonid Gavrilov use data from the DMF-PR to conduct mortality estimates for more homogeneous single-year birth cohorts with hazard rates estimated for narrow (monthly) age intervals. It was shown that mortality deceleration in humans observed at advanced ages may be caused by age exaggeration, data heterogeneity or use of improper estimates of hazard rate, which can be overcome by using datasets of higher data quality.^[A-107]

4.1.4.6 Morbidity Compression

Morbidity compression is the reduction in the total amount of time spent in a disabled state and depends not only on incidence rates, but also on the mortality rates of the back-end such that the relationship between disabled life expectancy and disability prevalence rates dictates the direction of morbidity compression.^[A-145]

The rate of mortality improvement and, consequently, the temporal improvement in life expectancy has an observable effect on morbidity compression that appears to have run its course by the mid-20th century. In contrast, the life expectancy of those aged 65 displayed an increase in variability. This fact is used to bridge the relationship of morbidity compression and mortality improvement to morbidity compression and morbidity improvement.^[A-145]

Eric Stallard noted that for morbidity compression to occur, any decrease in disability prevalence must be larger than the increase in survival probabilities. And just as importantly, a decrease in prevalence does not necessarily result in morbidity compression.^[A-145]

Observations from the National Long Term Care Survey (NLTC) in the U.S. indicate that morbidity compression is apparent over the period of 1984–2004, which follows the reduction in prevalence rates that exceeded the survival increment. The historical observation is that there was a substantial amount of morbidity compression during a period where there was little mortality compression—so it is evident that morbidity compression did not require concurrent mortality compression.^[A-145]

According to Nir Barzilai, onset of disease for male and female centenarians is delayed by about 20–30 years. That means that centenarians live longer and healthier lives before experiencing disease and dying. This is an indicator of proof of compression of morbidity.^[A-173]

4.1.4.7 Relevant Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

<i>Appendix Reference</i>	Paper
A-1	Pensioner Mortality in the New York State Public Retirement Systems https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-fox.pdf
A-10	Emergence of Supercentenarians in Low Mortality Countries https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-robine.pdf
A-11	Mortality at Advanced Ages in Spain https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-checa.pdf
A-12	Dealing with Problems in Data Quality for the Measurement of Mortality at Advanced Ages in Canada https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-bourbeau.pdf
A-17	Underlying and Multiple Cause Mortality at Advanced Ages: United States 1980-1998 https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-stallard.pdf

<i>Appendix Reference</i>	Paper
A-21	Some Background from Census 2000 https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxxiv.pdf
A-29	Number of Centenarians in the United States Jan. 1, 1990, Jan. 1, 2000, and Jan. 1, 2010 Based on Improved Medicare Data https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxvi.pdf
A-30	IDL, the International Database on Longevity https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxiii.pdf
A-34	Implications of an Aging Population in India: Challenges and Opportunities https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-iii.pdf
A-36	Mortality at Advanced Ages in the United Kingdom https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxi.pdf
A-58	Mortality Measurement at Advanced Ages: A Study of the Social Security Administration Death Master File https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4b-gavrilov.pdf
A-107	Mortality Measurement and Modeling Beyond Age 100 https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5b-gavrilova.pdf
A-117	Mortality Experience of Three Senior Populations https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4b-granieri.pdf
A-122	Social Insurance: Perspectives and Implications https://www.soa.org/files/pd/2011-orlando-living-100-dengsoe-gs7.pdf
A-133	Mortality of Smoking by Gender https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-gutterman.pdf
A-138	Measurement of Mortality among Centenarians in Canada https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-oulette.pdf
A-139	Mortality Trajectories at Extreme Old Ages: A Comparative Study of Different Data Sources on U.S. Old-Age Mortality https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-gavrilova.pdf
A-144	Modal Age at Death: Mortality Trends in England and Wales 1841–2010 https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-clay.pdf
A-145	Compression of Morbidity and Mortality: New Perspectives https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-stallard.pdf
A-154	Mortality Projections for Social Security Programs in Canada https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs4-chief.pdf
A-156	Regional Mortality in the United States at Ages 80 and Older: An Analysis of Direct Estimates over Period 1959-2011 https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-andreev-gu-dupre-paper.pdf

<i>Appendix Reference</i>	Paper
A-157	Health Technology, Health Care Cost, Longevity and Retirement Security: A Dynamic Upward Spiral and Challenge to Future Policy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-bailey-paper.pdf
A-158	Improvement in Late-Life Mortality and Its Impact on the Increase in the Number of Centenarians in Quebec (Canada) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-beaudry-godin-bourbeau-desjardins-paper.pdf
A-162	A Comprehensive Analysis of the Patterns of Worldwide Mortality Evolution https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-genz-paper.pdf
A-169	Using Life Table Techniques to Model Mortality Rates for Small Populations https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-yue-wang-paper.pdf
A-171	Accuracy of Official High-Age Population Estimates, in England and Wales: an Evaluation https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/methodologies/accuracyofofficialhighagepopulationestimatesinenglandandwalesanevaluation
A-172	Mortality Projections from a Social Security Panel https://www.youtube.com/watch?v=CmnO5kPber8&t=2s
A-173	How to Die Young at a Very Old Age https://youtu.be/p0JqXXFWCzQ
B-1	Summary of Panel Discussion on the Advancing Frontier of Human Survival https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1-soa-informal-discussant.pdf
B-8	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
B-16	Discussant Comments for Session on Mortality Age Patterns: Trends and Projections https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-lid-discussant-comments.pdf
B-18	Discussant Comments for Session on the Changing Age Distribution of Deaths https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-robine-discussant-comments.pdf
B-30	Session 3B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3b-transcript.pdf
B-37	Session 6A: Mortality Improvement Approaches https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6a-transcript.pdf

<i>Appendix Reference</i>	Paper
B-40	Senior Citizen in 2050 https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsvi-transcript.pdf
B-42	Discussant Comments for Session on Comparing Mortality of Different Groups https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-kaufhold-discussant-comments.pdf
B-44	Discussant Comments for Session on Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-olshansky-discussant-comments.pdf

4.1.5 Identifying Possible Predictors of Changes in Future Improvement Patterns

More and more, we are able to use our growing understanding of our genetic and non-genetic makeup to help identify the predictors of longevity. However, death can rarely be attributed to a single cause and the complexity and interrelatedness of the elements of our biological systems makes this a very intricate and very difficult exercise.

Eric Stallard, ASA, FCA, MAAA, Research Professor, Duke University

This section discusses the different approaches for identifying predictors of changes in future mortality improvement.

To understand what drives trends in population mortality, researchers separate data into a number of subgroupings. The most common are gender and smoker status, but several other subgroupings—socioeconomic status, occupation, marital status, physical traits (especially obesity) and birth characteristics—are also used.

Actuaries usually begin their analyses with the same validated sources. However, the way they proceed with data from those sources differs depending on the purpose of the analysis.

Actuaries from different disciplines need to work together on longevity issues. There is a core of longevity research—both empirical and theoretical—that would be very useful as a starting point for a number of different actuarial applications. Each SOA section would then be able to build upon that common framework to focus more explicitly on the mortality/longevity issues that are most relevant to its membership.

Larry Pinzur, FSA, Ph.D.

As the reader reviews the material, several open questions and gaps in current knowledge can be identified. In particular:

- ▶ How is the usefulness of subgroupings best assessed? A number of factors could be important to consider: the logical basis for the subgrouping; the supporting data available; the intended use (for example, pricing versus valuation); the complexity of incorporating the subgrouping into projection models; and finally, the appropriateness of the subgrouping given the societal, legal, political, industry and regulatory environment.
- ▶ Do more specialized factors, such as seasonal effects (identified in A-28) or birth characteristics (identified in A-39; A-45, and A-95), provide actuaries with useful information?
- ▶ How will the current obesity and opioid epidemics in the U.S. affect future mortality rates?

- ▶ Should life, health and pension actuaries standardize their summary metrics to facilitate communication with consumers and policymakers? Which metrics would be standardized?
- ▶ As we enter the “new pharmaceutical phase of aging research,” how do we incorporate the advancements in pharmaceuticals and their effect on aging into our projections of future mortality?^[A-77]
- ▶ How can dependency between causes of death be accounted for when evaluating the influence on mortality of a single cause of death?
- ▶ How will research on the role of genes in longevity and future breakthroughs affect mortality?
- ▶ What other methods can be used to validate research results and hypotheses?

What is the No. 1 goal of medical research? I suggest it’s not to cure or prevent cancer, heart disease or dementia; these are tactical steps that support a broader strategy. Rather, the No. 1 goal is to increase healthy life expectancy. We can accomplish this goal by finding new and better ways to treat and prevent common medical problems, attacking them one by one, disease by disease. And we can try to delay aging. This is not an either/or decision; rather, it’s a matter of balancing research priorities to increase the likelihood of success.

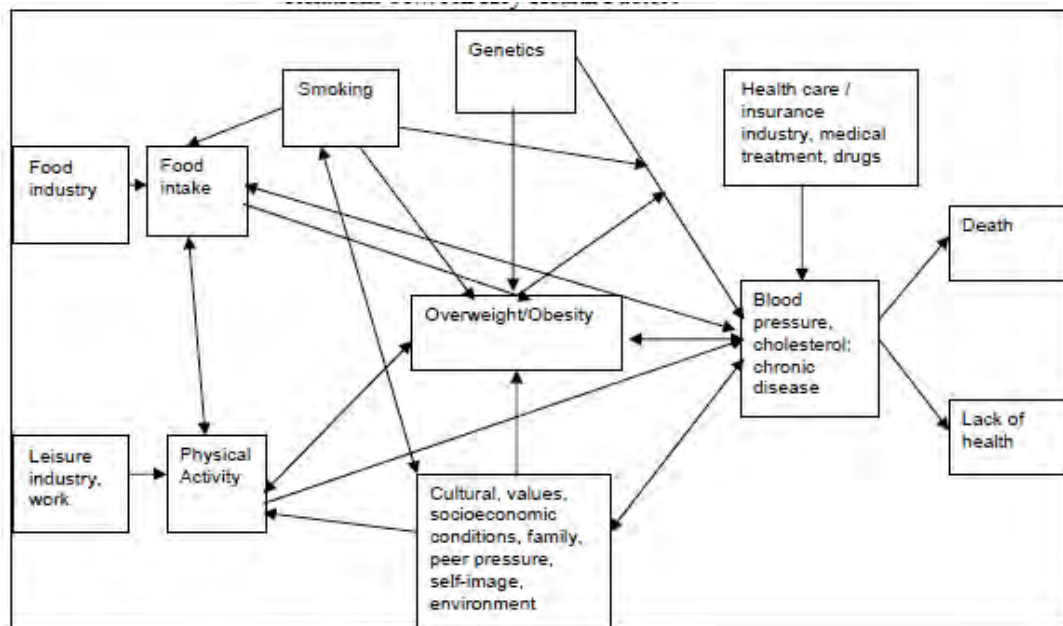
Robert Pokorski, MD

The information in the sections below summarizes the symposia information that addresses these topics.

4.1.5.1 Determining the Predictors of Mortality and Morbidity

Figure 4.1.5-01 below illustrates factors that contribute to the health of an individual. These factors fit into five broad categories: (1) an individual’s starting point, which is dictated by genetics; (2) the external environment, including the home, environment (e.g., medical practice and pollution) and the communities in which a person lives; (3) the cumulative effect of individual behaviors and corresponding mitigating factors, including nutrition, physical activity, smoking and medications; and (4) the current individual risk profile, including weight, blood pressure, cholesterol level and socioeconomic factors (the latter is not included in Figure 4.1.5-01 for simplicity’s sake only).^[A-48]

Figure 4.1.5-01: Relations between Key Health Factors^[A-48]



Human behavior has always had a significant effect on mortality and life expectancy. Many symposia papers attempt to analyze this behavior to identify statistically significant predictors of longevity. The following section summarizes that research. More detail on the assumptions and methodology associated with each result can be found in the underlying source material.^[A-48]

The authors of symposia papers used three main approaches to judge the significance of predictor variables:

- ▶ Cox proportional hazards model:^{[A-8] [A-79]} This is the most common approach among symposia authors performing survival analysis. This model makes no assumption on the baseline hazard, which can take any form. The shape of the hazard function over time is defined by the baseline hazard for all cases. The covariates help to determine the overall magnitude of the function.
- ▶ The proportional hazards model was augmented in one case using a kernel estimator to obtain a semi-parametric model of mortality that describes how mortality varies by age and gender.^{[A-8] [A-79]}
- ▶ Relative mortality ratio analysis:^[A-79] The authors calculated actual-to-expected mortality ratios for each subgroup under study and then standardized the ratios to enable cross-group comparisons.
- ▶ Joint frequency distributions:^[A-17] This approach models the complexity of diseases that led subjects to death. The authors used the technique to model changes in four types of mortality measures: underlying cause death rates; multiple cause death rates; associated (i.e., non-underlying) cause death rates; and death rates based on the joint occurrences of multiple cause conditions.

The complexity of this approach means that a practitioner would likely use it sparingly. One symposia author commented that if the goal is to forecast non-underwritten total death rates, it is unnecessary to consider cause of death data and related risk factors and lifestyle behaviors. On the other hand, if the goal is to model the health status of the population, which is relevant to forecasts of health care costs, then the multiple cause mortality data are relevant as end points of the health status process.

Some of the symposia papers focused on comparing the health effects caused by socioeconomic factors to those caused by behavior. In the article “Age-Related Changes in Factors Associated with Loss of Good Health,” for

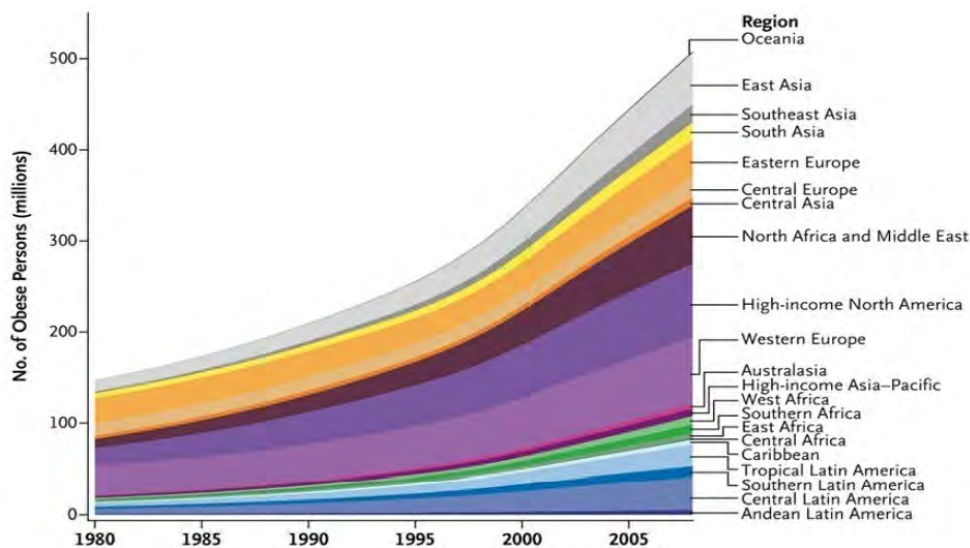
example, the authors studied longitudinal data from the Canadian National Population Health Survey and concluded that socioeconomic factors played a much greater role than behavior in the deteriorating health among young and middle-aged people, while the opposite was true for the elderly.^[A-93]

Other symposia papers focused on more specific predictor variables. The symposia studies revealed the following information on predictor variables:

1. Physical characteristics

- ▶ Stout body build: The “stout” body build (being in the heaviest 15 percent of the population) is negatively associated with survival to age 100.^[A-61]
- ▶ Obesity: With obesity levels having dramatically increased from 1970 to the early 21st century in the U.S., it has become one of the most significant factors to influence current and future mortality. Adults who suffer from obesity prior to turning 30 years old are three times less likely to reach age 100 than adults who are of the same age, but who are not obese.^[A-61]

Figure 4.1.5-02: Historical Trend of Global Obesity Levels^[A-131]



A key issue discussed in a second paper is the adverse long-term health effects of adolescent obesity. The analysis shows that the effects of obesity have to date been more than offset by significant risk mitigation and other developments, particularly treatments for high blood pressure and cholesterol levels and reductions in smoking. The author notes that uncertainty associated with mortality projections includes the extent that these sets of factors and future technological developments will offset each other in the future.^[A-48]

Another paper discussed the effect of obesity on disability and mortality at different ages. It reports that obesity at one’s current age is associated with significant increases in diabetes and disability and significant decreases in mortality among the elderly, with the latter exemplifying the obesity paradox for mortality. The paper found that obesity at age 50 has slightly different effects: significant increases in diabetes and disability but insignificant increases in mortality among the elderly.^[A-86]

A paper by Sam Gutterman studied the “obesity-mortality paradox,” where mortality experience is lower for overweight individuals, and in some cases those who are obese, than for those in the normal weight category. The study discussed 16 factors contributing to the paradox, which can be categorized into four general topics: (1) study participants have not been obese long enough for mortality deterioration to surface, (2) heterogeneity of the obese

population, (3) measurement issues and (4) study design limitations. The study also pointed out that the commonly used body mass index (BMI) is not a good measure of obesity.^[A-131]

The author also mentions how fundamental changes in the microbiota of the human gut may have made weight loss more difficult to incur in recent years and, consequently, contributed to the rise of the obesity epidemic. This finding is supported by other emerging evidence that identifies the presence of particular microbes in the gut prior to the introduction of certain antibiotics in the 1970s. Ultimately, current linkages between obesity and mortality are calculated using data on people who acquired their obesity in adulthood, which is not a fair representation of future cohorts exhibiting obesity-related mortality, disability and frailty who acquired their obesity during their childhood.^{[A-131] [B-13]}

An additional paper by Sam Gutterman indicates that the rise in morbid obesity and obesity earlier in life is creating an impact that is starting to drive drops in life expectancy as a result of obesity.^[A-163]

Overall, the study indicates that the resulting estimated reduction in cohort life expectancy due to the increase in obesity for a 35-year-old in 2015 is between 0.95 and 1.41 years for females and between 1.34 and 1.84 years for males, depending on the scenario; for a 65-year-old in 2015, it is between 0.53 and 0.78 years for females and between 0.67 and 0.90 for males. This reduction is based on a model with four projections of future obesity: National Health and Nutrition Examination Survey (NHANES) 1988–1994 and low, mid- and high projections as deemed reasonable by the author based on NHANES 2013–2014. The lower bound is consistent with current 2013–2014 levels of obesity, and the mid- and high projections are based on 10 and 20 percent increases in prevalence, respectively. A comparison is made between current mortality experience and the expected future mortality experience, which corresponds with the current and expected future obesity prevalence level. The ultimate excess ratio of mortality for each scenario was estimated to be the excess of the prevalent rate and corresponding mortality hazard ratio on a weighted basis for each of the three 2013–2014 NHANES scenarios compared with the 1988–2004 NHANES ratio.^[A-163]

While obesity is becoming more prevalent, overweight and obese mortality hazard ratios are smaller for measurements after 1990 than those prior to 1990. A significant reason for this improvement in the relative mortality of the obese is the decrease over the last several decades in the percentage of total deaths caused by cardiovascular diseases, for which obesity is one of the drivers.^[A-163]

Furthermore, it appears that gender has an interaction, as high BMI levels were observed to be a significant risk factor for men, but not women.^[A-151]

Mortality-related effects from obesity might be similar to those from smoking; it only affects mortality if the individual has been obese for a long enough period of time. Thus, excess mortality for recent cohorts will not be observed in the short term.^[B-8]

The trend over the last few decades is that onset of obesity has emerged at earlier ages. The longer a person's organs are exposed to excess adipose tissues, the more harmful the health effects.^[A-163]

Olshansky comments that obesity should be carefully applied across all ages because many people lose significant weight near the end of their lives, so being underweight can lead to incorrect predictions when applied equally to all ages.^[B-44]

2. Lifestyle characteristics

- ▶ Psychological: Recent pioneering biomedical research on the hypothalamus indicates that the brain may exert fundamental control over aging. As individuals progress beyond “young old” age (65–74), factors such as foreign languages learned, hobbies involving mental and physical exercise, club memberships, voluntary work, sense of well-being, extended family, and social networks become increasingly important to understand the observed differentials in mortality.^[A-152] Personal stress is also an indicator of health decline with it being a more significant indicator of health decline in men than in women.^[A-151]

- ▶ Mental, physical and social activities: Staying active in a variety of ways is key to living a longer life. Engaging in mental activities like crossword puzzles may help prevent Alzheimer's. Simply remaining physically active is helpful to stay healthy. Having friends and social groups reduces loneliness, which can enhance outlook on life, and outlook on life can be very influential on longevity.^[B-26]
- ▶ Cognitive impairment: Using the Cox proportional hazards model and relative mortality ratio analysis, the symposia papers show that cognitively impaired individuals have a significantly higher mortality than those who are cognitively intact. In fact, holding age and gender constant, a cognitively impaired individual has a death hazard between 1.52 and 1.69 times greater than someone who is cognitively intact.^[A-79]
- ▶ Rural lifestyle: A longitudinal study of adult Canadians revealed that living in rural areas had a positive effect on health maintenance in men but had no notable effect on women. It seems likely to speak to the exercise received from manual outdoor labor.^[A-151]
- ▶ Fitness: This factor is shown to correlate with age; therefore, while it is demonstrated that cardiorespiratory fitness is correlated with mortality, the strength of the effect is masked by other age-related factors.^[A-8] Symposia papers demonstrate that activity limitation and exercise play an important role in survival into old age (between 65 and 85) but have a smaller effect on survival past age 85.^[A-87] A longitudinal study on adult Canadians showed that risk of deterioration was significantly higher among women who exercised infrequently compared to women who exercised and compared to their male counterparts.^[A-151]
- ▶ Drugs: Certain drugs and substances have been associated with an extended life-span.^{[B-7] [A-173]}
 - ▶ Metformin: Treatment for diabetes has recently shown extended life-span in certain animals.
 - ▶ Resveratrol: This wine extract has increased life-span in a variety of animals.
 - ▶ Rapamycin: Traditionally an immunomodulator given to patients after a transplant has been shown to elongate the life-span significantly within animals.
- ▶ Nutrition: Studies have shown caloric restrictions in rodents and animals have elongated their life-spans by around 40 percent.^[B-7]

Lifestyle characteristic—smoking

The decline in cigarette smoking has had a favorable impact on survival rates. Significant effort has been made in developing countries to continue this trend through public policy interventions, increased taxation and other efforts. In contrast, smoking prevalence rates continue to grow in developing countries such as China and India.^[A-48]

The overall effect of reductions in smoking is an increase in life-span of about 0.96 years for a 35-year-old female and about 0.99 years for a 35-year-old male. For 65-year-olds, the effect is an increase of about 0.61 years for a female and about 0.79 years for a male. This increase is based on a model for decreases in causes of death from smoking proportional to decreases in smoking when compared to intermediate projections from the Trustees of the Social Security Administration, who use only recent trends for projections.^[A-163]

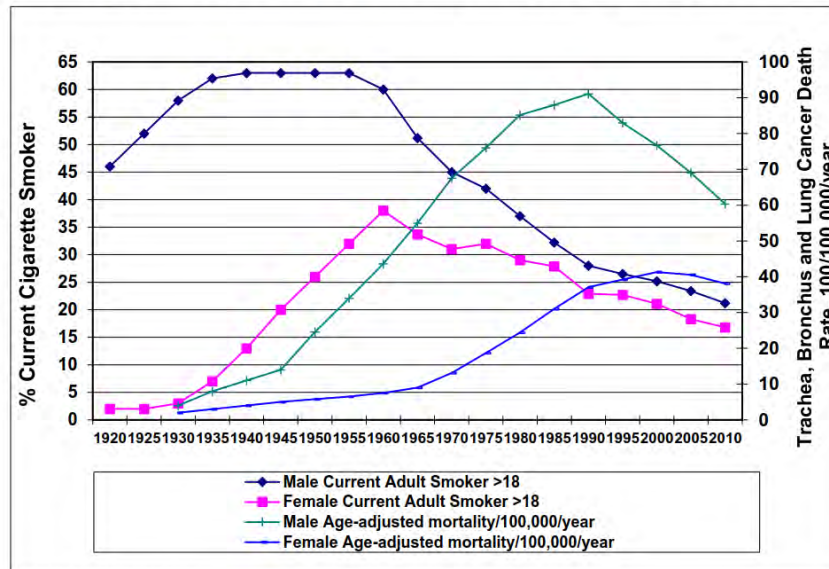
According to Ng et al (2014), the global prevalence of smokers decreased from about 41.2 percent in 1980 to 31.1 percent in 2012 for males, while it decreased from 10.6 percent to 6.2 percent for females. Prevalence rates decreased at a faster pace from 1996 to 2006 (1.7 percent annually) than for the period 2006–2012 (0.9 percent annually). Nevertheless, due to the increase in the total population and its age structure, there was an increase of 41 percent in the number of male smokers and a 7 percent increase in female smokers, or an increase in the number of daily smokers from 721 million in 1980 to about 967 million in 2012.^[A-133]

Sam Gutterman studied the impact of smoking on mortality, which had the following findings:^[A-133] [A-163]

- ▶ It appears that females are more sensitive to the effects of smoking, as their mortality rates are greater than if they had been proportional to the rates of smoking prevalence for males. (An alternative cause is that other contributors to lung cancer may be more significant for females than for males.) However, males have smoked more, so the impact on their mortality is greater.
- ▶ The combined effect of greater historical smoking prevalence rates by males and their corresponding earlier and larger reduction has in part been responsible for the recent improvement in mortality rates for males compared to those of females across the globe.
- ▶ Exposure to cigarette smoke has been shown to increase mortality on a lagged basis. This lag can range from two to five decades.
- ▶ Aggregate mortality for current smokers between ages 25 and 75 was three times the corresponding mortality of those who never smoked, which translates into a 10-year life expectancy gap between both groups.
- ▶ The effect of smoking cessation is more rapid. Adults who quit smoking between ages 25 and 34 live 10 years longer than those who continue to smoke, 9 years longer if they quit between ages 35 and 44, and 6 years longer if they quit between the ages of 45 and 54. In addition, it is estimated that between 10 and 19 years after cessation, lung cancer mortality rates are 42 percent and 21 percent of that of current smokers for males and females, respectively; for the period between 20 and 29 years, the corresponding percentages are 28 percent and 5 percent of current smokers. Some studies indicate that those who stopped smoking for more than 30 years have not experienced any appreciable extra mortality.
- ▶ The rate of smoking in the U.S. increased quickly during the first half of the 20th century for males, peaking in the 1940s and 1950s. The percentage of women smoking peaked at a lower percentage in the 1970s and 1980s. Since the peaks there has been a significant gradual reduction in percentage of smokers. As can be seen in Figure 4.1.5-03, the deaths caused by trachea, bronchus and lung cancer, which are usually causes of death because of smoking, peaked at a lagged time and have tapered off. The mortality for females is still relatively close to its peak when compared to that of males, which is why mortality improvement for men has been better in recent years.

Figure 4.1.5-03: Historical Trend of Global Obesity Levels ^[A-131]

Fig. 1. Smoking Prevalence and Death Rate for Trachea, Bronchus and Lung Cancer, by Gender



Source: Gutterman (2015).

- ▶ Today’s smokers have a much higher risk for lung cancer and COPD than did smokers in 1964, despite smoking fewer cigarettes. Gutterman found this is in part to current smokers being likely to have been smoking for a longer period of time, as well as changes in the design and composition of cigarettes.
- ▶ In studying the combined effect of smoking and obesity, the mortality effect of smoking dominates that of obesity at ages older than 60, while the opposite holds at younger ages.
- ▶ An initial model combining the effects of smoking and obesity and analyzing historical data indicates the net effect of reduction in smoking and increase in obesity on life-span is approximately a decrease of 0.23 years for a 35-year-old female and about 0.62 years for a 35-year-old male. The deterioration predicted for 65-year-olds is 0.02 for females and 0.18 years for males.^[A-163]

S. Jay Olshansky comments that primary risk factors for smoking and obesity aren’t independent, and risk of death can’t be determined just by adding independent risk factors.^[B-44]

3. Family characteristics

- ▶ Marital status: Central death rates for unmarried men at some ages are as much as three times those for their married counterparts, the resulting longevity advantage being more pronounced than that for women, perhaps by four or more years for a man age 65.^[A-47]

Research on Taiwan’s general population has revealed significantly lower mortality rates in married individuals relative to their single counterparts, with a higher mortality gap compared to the gap between smokers and nonsmokers for particular age groups. In particular, divorced/widowed individuals appear to have the largest gains in life expectancy, followed by marrieds and then singles.^[A-127]

A longitudinal study of adult Canadians also revealed that never-married men had an elevated risk of health deterioration than married men. It also revealed how divorced/separated/widowed women were more likely than their married counterparts to report deterioration in health.^[A-151]

Jean-Claude Menard noted how Canadian male widows’ and Canadian female widows’ mortality rates ultimately converge to the general population mortality at advanced ages.^[B-8]

Natalia S. Gavrilova and Leonid A. Gavrilov found marital status to be less important as a predictor of future longevity relative to physical characteristics such as body build.^[A-61]

In a separate study, Natalia S. Gavrilova and Leonid A. Gavrilov examined the impact of parental characteristics in longevity:^[A-129]

- ▶ Chances of living to age 100 were enhanced if a parent lived to age 80 or more, with further enhancements if both parents lived beyond age 80. However, loss of parents early in life had no effect on the chances of becoming a centenarian.
- ▶ Husbands of centenarians live 2.3 fewer years on average than married brothers of centenarians. Although fathers of centenarians are born about 30 years earlier than brothers-in-law of centenarians, they still have higher life-spans conditional on survival to age 50 than later-born nonbiological relatives such as siblings-in-law and husbands of centenarians. On the other hand, mothers of centenarians survived to age 50 have the lowest life-span among all relatives: 77.2 years on average.
- ▶ Males are more likely to experience improved longevity if their brother was a centenarian, while the improvement would not be as much if their sister was a centenarian. In either case, being male and having a centenarian sibling still improved the male's longevity prospect more than if their wife is a centenarian.
- ▶ Overall, siblings-in-law of centenarians have the lowest life-span compared to biological relatives and spouses of centenarians born in a similar time. At the same time, life-span of siblings-in-law is still higher than mean life-span of the general population. This difference is particularly high for men (1.7 years).

The following have also been identified at the symposia as influential family characteristics:

- ▶ Number of children (4+): Having a large number of children (4+) at age 30 more than doubles the chances of exceptional longevity.^[A-61]
- ▶ Agricultural lifestyle: Growing up in a farming community increase the chances of exceptional longevity by 100 to 200 percent.^[A-61] The authors refined the study by linking both childhood and midlife characteristics and concluding the actual predictor for longevity was being a farmer rather than growing up in a farming community, where the longevity effect was more prevalent for males.^[A-129]
- ▶ Maternal age: Symposia papers show that young maternal age increases offspring's chance of reaching age 100 (data show maternal ages between 20 and 24 have the largest effect). This is especially true for small families.^[A-95]
- ▶ Age at first marriage: Natalia S. Gavrilova and Leonid A. Gavrilov identified females who had their first marriage at a late age were more likely to experience exceptional longevity.^[A-129]

Nussbaum et al indicate the potential of quantifying a familial effect on longevity by creating a Familial Propensity for Longevity Score to show how an understanding of familial longevity can predict longevity. They have done extensive research to compile familial data, but more work needs to be done to create a metric to use those data as a predictor of longevity.^[A-165]

4. Economic characteristics

- ▶ Income equality: Symposia papers studying wealthy nations report a negative association between income inequality and life expectancy at birth. This negative association becomes insignificant after controlling for average total income. Overall, the data for wealthy nations do not support the hypothesis that higher levels of income inequality are directly related to lower levels of population health.^{[A-50] [A-117]}

There is a significant gap in life expectancies when comparing the lowest to the highest quintile of regions based on socioeconomic status in England. People in the poorest residential areas can, on average, expect to die eight years earlier than people living in the most affluent areas. In 2001 a national target was set for narrowing health inequalities in infant mortality and life expectancy. The life expectancy target stipulated a reduction of at least 10 percent in the gap between the bottom quintile, based on health and deprivation, and the population as a whole. A study by Alai et al indicates that targeting specific causes of death could decrease the socioeconomic gap in life expectancy while increasing life expectancy for the entire population. Outcomes of the study point to a focus on decreasing mortality from circulatory and respiratory diseases for both men and women of all ages as the optimal starting point to increase life expectancy and close the socioeconomic gap.^[A-155]

Another way to see the socioeconomic inequality in mortality rates is to compare the average pension by industry to the mortality rates compared to expected rates. For employees in the financial industry in the U.K., they have the largest pension and the lowest mortality when compared to expected mortality. The trend is fairly consistent, with the higher pension industries having lower mortality compared to the lower pension industries.^[A-172]

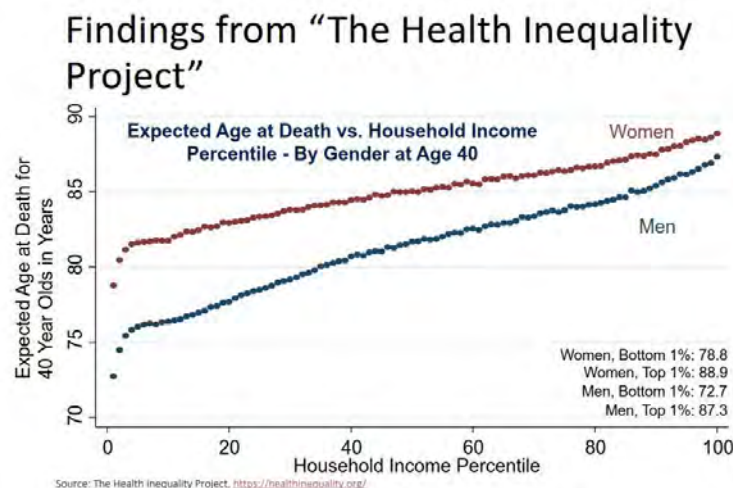
Socioeconomic factors such as level of incomes and marital status in Canada are analyzed to show that married people without the need for government-subsidized incomes live longest. For males, marital status plays a more important role than income. However, for females, marital status and income have a similar effect on life expectancy.^[A-172]

Larson, Yaffe, and Langa noted evidence supporting the theory of better education and greater economic well-being reducing the risk of late-life dementias in people who survive to old age.^[B-22]

Jean-Claude Menard noted how Canadian social security beneficiaries with higher levels of income have higher life expectancies than the overall population. This may be explained by a possible relationship between a higher level of income and improved health and quality of life.^[B-8]

The findings from the Health Inequity Project in Figure 4.1.1-04 show a relationship between the expected age at death and household income percentile.

Figure 4.1.4-04: Expected Age at Death vs. Household Income Percentile



5. Societal changes

Outside of the individual factors, such as physical, lifestyle-related and family-related factors that are described above impacting the ability to project mortality, in addition to the economic factors, there are other societal factors with the potential to impact large groups of people simultaneously. These factors are also important to consider in future projections of mortality. Allen Klein introduced the following factors at the symposium:^[B-26]

- ▶ Catastrophes: Catastrophic events can obviously play a role in mortality, but most are assumed by including past catastrophes in long-term assumptions. One catastrophe that isn't often included in those trends is electromagnetic pulses (EMPs). Electromagnetic pulses come from the sun about once every 150 years, and the last occurred in 1859. That EMP caused a fire in every telegraph office around the world. If another comes, it could wipe out technology worldwide and create a massive impact. NASA predicted in 2015 that there is a 12 percent chance of the next EMP within 10 years.^[B-26]
- ▶ Diseases: Antibiotic drug-resistant infections are increasing much quicker than the rate of development of new antibiotics to treat them. Additionally, new diseases could emerge and old diseases could re-emerge and impact future mortality.^[A-172]
- ▶ Environmental: We are increasingly exposed to more chemicals in daily life that cause cancer. Additionally, pollution causes respiratory problems, cancer and birth defects, leading to 7 million deaths in 2012.^[B-26]
- ▶ Health care and medical care: In a study by the Commonwealth Fund, the U.S. is ranked third worst in 12 developed countries in the study. The U.S. system was the most expensive and had the lowest rating in terms of both efficiency and outcomes. The third leading cause of death in the U.S. is classified as medical error, so improvements in this sector could have large implications.^[B-26]
- ▶ Medical advances: Breakthroughs like 3D organ printing, CRISPR (which allows for replacement or deletion of specific genes), understanding of genetics and immunotherapy could improve longevity.^[B-26]

A process called parabiosis is being developed, which could have huge implications on slowing the aging process. The process was tested initially on mice where the bloodstreams of a younger and older mouse were linked, and the older mouse became younger in every aspect and vice versa. A new company is trying to extend this theory by performing blood transfusions for individuals older than 35 from someone who is 25 years or younger. If successful, this type of medical breakthrough could alter the current trends in mortality.^[B-26]

Another example, according to Nir Barzilai, is metformin, which has been shown to have a large potential to delay aging and diseases for a significant time in animals. A research study referred to as TAME (Targeting Aging with Metformin) has been developing this drug for humans to try to delay the aging process. In clinical studies on humans, it has been proven to enhance healthy life-spans by delaying many diseases across the board for a notable period.^[A-173]

- ▶ Political: Longevity could depend largely on funding for research on many of the other drivers. U.S. spending on health as percentage of GDP since 2009 has stopped increasing the way it had over the prior 50 years. That corresponds with the latest deceleration in mortality improvement rates.^[A-172]
- ▶ Technological advances: Some notable technology advances that could impact longevity include ingestible sensors, the Internet of Things to transfer information, robotics and self-driving cars.^[B-26]

6. Other characteristics

- ▶ Geography of birthplace: Geography of a birthplace (or factors associated with it) within the U.S. is shown to be an important determinant of human longevity. The preliminary findings presented in this paper

suggest that there may be a threefold difference in chances of survival to 100, depending on location of childhood residence.^[A-39]

- ▶ Infectious burden: One study showed that lower burden of infectious diseases during childhood will increase the chances of survival to 100. Geography of birthplace is one factor that influences infectious burden.^[A-129]
- ▶ Seasonality: This study shows that the ages at death are more concentrated in winter where the mortality conditions are worse than in summer.^[A-28]
- ▶ Birth order: Symposia papers found that first-born daughters are three times more likely to survive to age 100 than daughters of higher birth orders (7+). Similarly, first-born sons are two times more likely to become centenarians than sons of birth orders four through six. Interestingly, last-born sons (9+) also had higher chances of living to age 100, something untrue for females.^[A-39]
- ▶ Season of birth: Symposia papers indicate that season of birth has a significant effect on survival to age 100, with individuals born in September to November having the highest chance of becoming centenarians.^{[A-95] [A-129]}
- ▶ Individual's own survival assessment: Survival probabilities are highly heterogeneous within a population, depending on various observable and unobservable characteristics:
 - ▶ Research in Europe has shown that subjective survival probabilities are relatively close to objective survival probabilities based on demographic studies for males, while female subjective probabilities of survival appear to be consistently lower than their objective probabilities.^[A-148]
 - ▶ On the other hand, Anna Rappaport found both men and women underestimate their survival probability. This discrepancy may be due to Rappaport's research being based in the U.S. and not Europe.^[A-147]
- ▶ Access and engagement with technology and communications: One study showed that having a radio in the household in 1930 has a positive effect on longevity for women, but not for men. The researchers explained this finding by the fact that women in 1930 spent most of their time at home and were much more exposed to radio (as an educational and entertainment source) compared to men. Listening to radio improved people's feelings of happiness and energy, and an electro-encephalographic study found that listening to radio creates high levels of positivity engagement in the brain.^[A-129]

The symposia papers also discussed variables that do not have predictive power, such as body height.^[A-61]

Finally, the symposia papers briefly address the principal factors that contribute to frailty, which is important to the study of morbidity. A frail person is at high risk for disability (disability insurance), failure of instrumental activities of daily living (IADLs) and activities of daily living (ADLs) (long-term care insurance), and death (life insurance and substandard annuities). The principal factors include age, gender, functional and cognitive impairment, nutritional status, comorbid impairments, self-reported function, and difficulties with mobility, balance and aerobic capacity. Frail insurance applicants could often be identified via historical data and simple tests of cognitive and physical performance. The article referenced reviews the geriatric literature to identify risk factors that could be used by insurers to identify existing or incipient frailty.^[A-7]

Kingkade mentions that one of the difficulties in modeling frailty is the lack of ability to explicitly measure presence or absence. It can be used in many situations as an explanation for an unexpected trend, but it is difficult to prove that frailty is the underlying cause.^[B-43]

4.1.5.2 Genetic Predictors of Mortality and Morbidity

There is little consensus on how genes affect longevity.

One belief, as explained by Leonard Hayflick, is the determination of longevity being incidental to the main goal of the genome: to govern events in order to reach reproductive maturity. Thus, the genome only determines longevity indirectly in a non-random process through governing the levels of physiological capacity reached at the time of sexual maturation, which then starts degrading afterwards due to the second law of thermodynamics.^[B-14]

An opposing belief of author Tom Bakos is that the main goal of the genome is not necessarily to govern events in order to reach reproductive maturity, as this is only an outcome of natural selection. The fact that organisms die at younger ages prior to sexual maturity or live long life after sexual maturity is indicative of the second law of thermodynamics being deteriorated or ameliorated by an outside influence, namely, the genetic and epigenetic control of the regenerative or self-repair processes within living cells: genetics.^[B-15]

However, both Hayflick and Bakos agreed on how the loss of molecular structure within cells caused by the second law of thermodynamics can be circumvented for varying time periods by the enormous capacity for biological systems to replace or repair themselves.^{[B-14] [B-15]}

The following have been identified as genetic-related factors affecting mortality and morbidity:

- ▶ Genetic information, and its interpretation, is rapidly becoming available to individuals given it is useful in diagnosing, treating and mitigating health and life risks. This inexpensive, readily available genetic information will inevitably inform and influence decision-making processes affecting life, health and longevity, both from an individual and societal perspective.^[A-134]
- ▶ As genetic information is becoming more readily available and understood by doctors, medical treatments can be better designed and tailored to fit the individualized needs of patients. Understanding genetic risk factors will allow doctors to better predict negative drug side effects and administer more effective drugs in the right dosage.^[B-26]
- ▶ Genetic understanding of the cells that are creating diseases like cancer could also cut down on mortality due to the enhanced ability of doctors to understand and treat those diseases.^[B-26]
- ▶ There is growing research around the potential to alter genes that would be able to replace an abnormal gene with a normal gene to cure diseases with large impacts.^[B-26]
- ▶ Preliminary research on twins postulated that longevity may be hereditary; however, the oldest subjects in these studies were in their mid- to late-80s, and thus the results say little about the relative importance of genes and environment or behaviors in the ability to live to much more exceptional ages.^[A-121]
- ▶ A possible increasing level of homogeneity in functional history and medical histories among centenarians beyond the age of 105 may lead to increased power to reveal genetic associations with the phenotype of exceptional longevity and sub-phenotypes such as the delay or escape of specific age-related diseases and syndromes such as dementia.^[A-121]
- ▶ The increasing relative risks of survival to very old age that are associated with older and older ages of studied siblings are consistent with the conjecture that the heritability of longevity is substantial only when looking at the oldest fifth and smaller percentiles of survival. The authors note that the lack of information concerning the impact of familial longevity is a glaring deficiency in the current study of mortality risk.^[A-136]
- ▶ A study done on 600 seniors, all above age 95 and living independently, found that everyone had a strong family history of longevity; the effect was tenfold if compared to the control group. This group of centenarians also had similar prevalence levels of hypertension, myocardial infarction and stroke to a group 30 years younger than these centenarians but without familial history.^[B-7]

Regarding longevity genotypes:^[B-7]

- ▶ Certain genotypes have been linked with longevity due to their higher prevalence in centenarians as opposed to the general population. CETP and APOC3, whose genotype homozygosity is normally between 18 and 20 percent, have been identified at double the rate at age 100.
- ▶ Centenarians do not have the perfect genome; they have just as many bad snips in their genomes as the general population. It is currently hypothesized that although they have bad snips, they have certain genes ensuring their longevity. These “protector” genes are thought to guard from the effect of bad genes found in people with certain critical illnesses.
- ▶ Studies of centenarians are looking at rare and extreme phenotypes to see if there is a consistent coding for a protective mechanism that gives understanding of centenarians’ ability to live to 100. Using those genetics, pharmacists are attempting to develop drugs to enhance genomes of individuals without the ideal genome observed in centenarians.^[A-172]
- ▶ Nir Barzilai discusses a tie that exists between the IGF-1 receptor hormone and longevity. Centenarians often have a functional mutation in this growth hormone specifically for females, which could be a clue about what in the genome allows centenarians to live as long as they do.^[A-172]

In many animals that have been studied for aging, genetic modifications and drugs have successfully delayed aging. Two examples of drugs that have had success are rapamycin and metformin.^[A-172]

At the population level, Severine Arnold et al use a heterogeneity population model and natural selection model to explain the variability of mortality rates across the life-span and late-life mortality dynamics. The paper, which assumed that population heterogeneity reflects the genetic variation between subpopulations, showed that the natural selection model based on differential mortality can explain and quantitatively reproduce the homogenization of the Swedish population within a one-century period.^[A-175]

4.1.5.3 Public Policy and Mortality

There are many potential ways to view policies surrounding mortality. Some aims will focus on increasing overall longevity for society through various medical advancements and breakthroughs. Other policy aims might focus more on rebalancing life expectancies to reduce the gaps between socioeconomic groups.

Based on the cause of death elimination model developed by Alai et al, if policies were able to completely eliminate one cause of death, the elimination of circulatory diseases and neoplasms produces the largest gains in life expectancy for those over 65. Eliminating deaths from digestive diseases and respiratory diseases decreases the gap in life expectancy between socioeconomic groups for men and women.^[A-155]

One public policy aim established by the World Health Organization (WHO) is to reduce premature mortality from cardiovascular diseases, chronic respiratory diseases, cancers and diabetes by 25 percent relative to 2010 levels by the year 2025. When analysis on these shocks to mortality is performed using the Alai et al model, the target set by the WHO would cause an increase in 0.12 years in the difference in life expectancy between the least and most deprived quintiles in England. According to the same Alai et al model, for women, targeting mortality from circulatory diseases, neoplasms and respiratory diseases will simultaneously increase life expectancy and decrease the socioeconomic gap. This coincides well with the target for the WHO policy. For men, the optimal targeted mortality is from circulatory, digestive and respiratory diseases. Focusing policy on reducing mortality from digestive diseases, especially for men, might do more to reduce socioeconomic inequalities.^[A-155]

Mortality improvements were very low in the 1960s. However, an example of a successful policy to improve mortality was Medicare, which was introduced in 1965. By 1975 mortality improvements were significantly higher across ages for both genders. This is known as the “Medicare Ridge.”^[B-37]

Roland Rau comments that the same ridge could coincide with treating and preventing circulatory diseases because the trend was also seen in countries other than the U.S.^[B-23]

According to Stephen Goss, the U.S. has had clear period effects with large improvements coming in the periods of 1936 to 1954 and 1968 to 1982, coinciding with the introduction of antibiotics and Medicare/Medicaid expansion, respectively.^[A-172]

Currently, the Food and Drug Administration (FDA) doesn't recognize aging as a target for drugs, which is discouraging investment in research on aging. Dr. Nir Barzilai suggests finding a way to target aging indirectly by trying to find drugs that reduce the risk of multiple diseases that are often a function of aging. This could be a crucial next policy step for medical and pharmaceutical research to enhance the aging process, allowing for longer, healthier lives.^[A-173]

Modern medicine has gotten very good at treating individual diseases, but it currently does not treat aging. Treating aging will be key to expanding longevity.^[A-174]

4.1.5.4 Challenges Associated with Determining the Predictors of Mortality and Morbidity

1. Long-term lags between the underlying behaviors and their mortality consequences

While researchers have investigated the relationship between obesity and mortality with thoroughness in recent years, they have not provided sufficient long-term follow-up information that is also important to life expectancy studies. As a result, there is significant uncertainty in the estimation of future mortality patterns and their relationship to obesity.^[A-48]

Sam Gutterman also noted how research on the relationship between smoking and mortality should be studied with caution given the changing dynamics of data quality, reference population issues, confounding factors, secular changes in smoking pattern, and the long lag time between exposure to smoking and death.^{[A-133] [A-163]}

2. Interpretation of the patterns in the underlying data

It is not always clear what drives patterns in the underlying data. For example, when evaluating whether morbidity compression exists at older ages, recent reviews of national health trends show conflicting results. In addition, if an expansion of morbidity is shown to accompany a compression of disability, it is difficult to interpret the cause of a decline in disability. The pattern could be a result of a healthier elderly population or of individuals having access to better technical devices in a more favorable environment.^[A-49]

3. The interaction among multiple pathological and biological processes

When an individual dies from a disease, it is really a series of pathological processes—not one simple disease—that contributes to death. As such, when an individual dies from disease and his/her death is attributed to the disease, the explanation for the death is somewhat oversimplified in a deceiving manner.^{[A-8] [A-17]}

In the articles that reference this issue, it is found first that declines in mortality rates have not been distributed evenly by disease. In particular, the success in treating the top three major killers did not translate into subsequent successes against many of the lower ranked diseases. Second, diseases can play different roles in the mortality process, and it is appropriate to consider models in which certain diseases are viewed as lethal sequel of other underlying conditions. Therefore, an understanding of the dynamics of cause-specific mortality is essential to an understanding of concurrent gains in life expectancy and to our ability to accurately forecast the rates of reduction in mortality in future years.^{[A-8] [A-17]}

A common assumption in cause-of-death mortality studies is that causes of death are independent. However, dependencies do exist among different causes of death. Gaille and Sherris used vector error correction models (VECMs) to analyze the five main causes of death across ten major countries representing a diversity of developed

economies. The five causes of death include diseases of circulatory system, cancer, diseases of the respiratory system, external causes and infectious and parasitic diseases. These are the major causes that accounted for more than 80 percent of deaths in recent years. Their analysis shows that long-run equilibrium relationships exist between the five main causes of deaths for all ten countries. In addition, countries usually had different experience in regard to cause-of-death mortality trends and thus applying results from one country to another may be misleading. The authors noted that the study only analyzed age-standardized death rates, since applying a VECM to age- and cause-specific death rates would result in a model with too many parameters.^[A-132]

Robert Pokorski noted how prevention of Alzheimer's disease would markedly reduce many years of morbidity associated with condition, but the impact on a person's aggregate mortality and life expectancy would be limited. In addition to Alzheimer's being a relatively uncommon cause of death at older ages (accounts for 4.4 percent of deaths at ages 65 or older), people would die instead from competing causes of death. Pokorski also references a report that estimated eliminating Alzheimer's disease as a cause of death would add only 51 days to life expectancy at birth.^[B-22]

Authors Anatoliy Yashin et al note how most researchers search for genes that contribute to increased longevity and do not consider the possibility of the absence of harmful genetic factors being the driver for exceptional longevity. The authors also identify how the conventional analytic methods of data ignore externally available knowledge about the traits of interest and treat their own limited dataset as the only source of information; the practice misses the opportunities presented in the research potential of the externally available data. Furthermore, it is mentioned how most genome-wide association studies do not consider the following.^[A-135]

- ▶ Many genetic and non-genetic factors contribute to longevity-related traits.
- ▶ Contribution of specific genes depends on genetic background (internal milieu created by other activated genes), which, in turn, can be modulated by external conditions.
- ▶ Genetic effects are mediated by many biological variables that change their values and their influence on aging and longevity traits during the life course.

Dr. Nir Barzilai notes that it is difficult to study biological factors that might influence longevity as the resulting process is highly complex. Based on his observations, he raises the following questions for practitioners to consider:^[B-7]

- ▶ How does one know if the decline in the level of one factor is causing aging and not a protective mechanism that is delaying aging? There are also difficulties with approving these kinds of studies where there is a possibility of killing the person as you alter the factor's level.
- ▶ Since centenarians have a high probability of dying in the next few years, studying their factors becomes challenging as well. How do researchers determine if centenarians' current biology reflects that of someone about to live longer or somebody who is about to die? What if their current factor levels are at a high level because they are approaching death, but they were at low levels their entire life?
- ▶ As the body ages, it secretes more cytokines and, consequently, has different peptides circulating as opposed to those in a younger body. These different peptide compositions across different-aged bodies create a difficulty with studying the effect of one factor on the body. How will the factor interact with varying levels of peptides across young and old bodies?

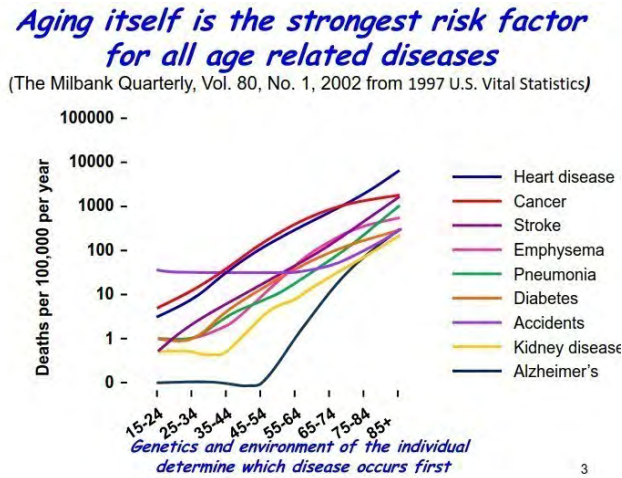
4. Our limited understanding of the aging process

A lack of consensus exists on the nature of the aging process and its implications to longevity studies.

S. Jay Olshansky notes how the observed dependence across diseases exists not because they are biologically dependent on each other, but because they are all together influenced by a common risk factor—the biological aging of the body, which provides a major challenge as our understanding of the aging process is fairly limited.^[B-13]

Dr. Nir Barzilai mentions how since aging is the common and major risk factor of all age-related diseases, improving health from one disease will not improve overall health much since the body will have other competing causes of death; people not dying from one age-related disease will end up dying from another age-related disease. Dr. Barzilai recommends researchers to stop segregating their research by disease and focus on the primary driver of the age-related disease: aging.^[B-7]

Figure 4.1.5-05 Age as the Strongest Risk Factor



Studying the aging process poses many research challenges to overcome. For example, if the researcher gives a drug to a 50-year-old and monitors that person in 30 years, it is not clear what variable the researcher should measure at the end of such period. An alternative in this case would be to use a biological marker, such as the point when people become glucose intolerant.^[B-7]

Leonard Hayflick notes how current knowledge supports aging being a stochastic process rooted in the intrinsic thermodynamic instability of complex biological molecules, indicating aging is a chance-driven catabolic process. Hayflick also states how the belief on genes playing a direct role in the cause of biological aging has not been proven because of the failure to distinguish between aging and longevity determinants.^[B-14]

However, Tom Bakos argues how aging cannot be driven by the common action of an external force as different organisms and species have significant differences in rates of aging and maximum life-spans. In particular, differences within species have been associated with genetic variation, indicating these are attributed at least by genetic drivers associated with the rate of aging and longevity in biological organisms.^[B-15]

In addition, Robert Pokorski references a paper which concludes that continuing the status quo, where heart disease and cancer are addressed as separate research topics, would diminish improvements in both health and longevity over the next 50 years because of competing causes of sickness and death in aging populations. In contrast, preventive measures that slowed the aging process would have a significantly greater impact on disability and longevity.^[B-22]

Judith Campisi points out that certain types of cells might be driving the aging process, leaving humans more susceptible to diseases like cancer as they get older. These senescent cells stop dividing and secrete something causing inflammation over time. That inflammation can damage cells around the senescent cells, including immune cells. This leads to increased issues with diseases like cancer. One potential solution is to try to kill the senescent cells, which would increase median life-span but wouldn't impact maximum life-span.^[A-174]

Advances in our knowledge of age-associated diseases have far outpaced advances in our knowledge of the fundamental aging process that underlies our vulnerability to these pathologies. Longevity determination must be distinguished from aging to take us from the common question Why do we age? to a more revealing question that is rarely posed: Why do we live as long as we do?^[A-18]

5. Inaccuracies in the diagnoses of causes of death

Leonard Hayflick commented on the following challenges in reliable data for cause of death:^[B-14]

- ▶ Our lack of knowledge on causes of mortality in old people can partially be attributed to the decline in performance of autopsies in the U.S., which has fallen from 41 percent of hospital deaths in 1961 to less than 10 percent across the U.S. in the mid-1990s.
- ▶ The quality of the few autopsies performed has not been too reliable either. A 2002 review by the federal Agency for Healthcare Research and Quality found that when patients were autopsied, major errors related to the diagnosis or cause of death were found in one of every four cases. Furthermore, another study showed for autopsies performed on large numbers of old people, 40 to 50 percent of the causes of death appearing on the death certificates have been inaccurate.
- ▶ Researchers who rely on cause of death found within death certificates ignore how multiple pathologies occur in older people, so the true cause of death is rarely known.

6. Migration effects

While migration has not been the focus of past symposia research papers, Ward Kingkade notes how mortality for some ethnicities in a given country may seem lower than it actually is due to migration effects (i.e., the “salmon bias”). In particular, he notes that Hispanic mortality in U.S. could be overestimated due to Hispanics immigrating to the U.S. for work and returning to their home country for retirement. Their deaths are thus not recorded in follow-up censuses within the U.S.^[B-5]

The Office of the Chief Actuary in Canada also noted how immigrants experience lower mortality than those born in Canada for a number of reasons: people in poor health are less likely to migrate to another country; potential immigrants are subject to medical screening; and immigrants are partially selected on the basis of employability, which would imply a certain status of health. In this context, they are expected to be a source of bias given their healthier status relative to the non-immigrant Canadian population.^[A-154]

Migration data for the U.K. can be estimated by extracting patient register (PR) data used to identify them by age and sex saved when people reregister with a new doctor. The National Health Service Center for England and Wales will fill gaps from PR extracts. Lack of registration with a new general practitioner might hinder this strategy, but older populations are more likely to do so quicker.^[A-171]

Net cross-border flows from England and Wales to Scotland or Northern Ireland have ranged from 0.003 to 0.02 percent of the total population age 80 and over and 0.01 to 0.03 percent of the population age 90 and older. International migration is also very low, accounting for 1.0 percent of the total population aged 80 to 89 and 0.2 percent of the total population 90 and over in England in Wales from 2012 to 2014. Due to these low numbers, migration has a minimal impact on measurements like future populations estimates.^[A-171]

4.1.5.5 Validation Techniques

Because of the challenges involved in identifying the predictors for older age mortality, the symposia material presented limited methods to validate research results. One technique used by practitioners to validate their results was to identify proper control groups.^[A-39]

For example, Natalia S. Gavrilova and Leonid A. Gavrilov found in their 2014 study that in general siblings-in-law have the lowest life-span compared to biological relatives and spouses born in a similar time period. At the same time, life-spans of siblings-in-law are still higher than the mean life-span of the general population. Therefore, to assess the survival of siblings of long-lived individuals (or other biological relatives), siblings-in-law are a better control group than the general population. If the general population is chosen as the control group, survival advantage of biological relatives, and hence the genetic effect on life-span, may be overstated.^[A-129]

Finding a control group for an extreme centenarian group is very challenging. One solution would be to consider centenarian offspring instead, under the assumption that they would most likely have the same genes that contribute to becoming a centenarian. From there, it is possible to construct a control group from the centenarians' offspring and compare the genomes between this control group and the offspring.^[B-7]

Studies of exceptional longevity using genealogical data require choice of appropriate control group. Longevity of the population with the trait or characteristic being studied can then be compared against that of the control group to determine its predictive power.

1. Population based

For example, one might use randomly selected, shorter-lived men matched with centenarian men by birth year, race and county of draft registration as controls. This approach can eliminate the confounding effects of birth cohort, race and place of draft registration on survival.^[A-61]

2. Distant blood relatives (e.g., first cousins) or non-blood relatives (e.g., in-laws)

In this case the authors eliminated unobserved shared factors and focused their study on specific effects such as the number of children born and the life-span of parents.^[A-39]

4.1.5.6 Relevant Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

<i>Appendix Reference</i>	Paper
A-7	Detection and Significance of Frailty in Elderly Insurance Applicants https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-pokorski.pdf
A-8	Analysis of Mortality in a Small Sample of Older Adults https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-jones.pdf
A-17	Underlying and Multiple Cause Mortality at Advanced Ages: United States 1980–1998 https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-stallard.pdf
A-18	Plastic Omega https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-held.pdf
A-28	Seasons and Longevity: Mortality Trajectories Among the Oldest Old https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxiv.pdf
A-39	Search for Predictors of Exceptional Human Longevity: Using Computerized Genealogies and Internet Resources for Human Longevity Studies https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-v.pdf
A-45	Ending the Mortality Table https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-ix.pdf

<i>Appendix Reference</i>	Paper
A-47	Health, Wealth and Wisdom—Living Long, Living Well: An Actuary Muses on Longevity https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-cowell.pdf
A-48	Human Behavior: An Impediment to the Future Mortality Improvement: A Focus on Obesity and Related Matters https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-gutterman.pdf
A-49	Is the Compression of Morbidity a Universal Phenomenon? https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-04-cheung.pdf
A-50	New Findings on the International Relationship Between Income Inequality and Population Health https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2a-brown.pdf
A-61	Physical and Socioeconomic Characteristics at Young Age as Predictors of Survival to 100: A Study of a New Historical Data Resource (U.S. WWI Draft Cards) https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5b-gavrilov.pdf
A-77	Putting the Brakes on Aging: Beginning the Pharmaceutical Era https://www.soa.org/files/pd/2011-orlando-living-100-austad-gs1.pdf
A-79	The Relationship Between Cognitive Impairment and Mortality Rates Among Long-Term Care Insurance Applicants https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-cohen.pdf
A-86	The Impact of Obesity and Diabetes on LTC Disability and Mortality: Population Estimates from the National Long Term Care Survey https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-stallard.pdf
A-87	The Role of Social and Health-Related Characteristics in Determining Survivorship Among the U.S. Oldest Old https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-alshire.pdf
A-93	Age-Related Changes in Factors Associated with Loss of Good Health https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g3-brown.pdf
A-95	Early-Life Predictors of Exceptional Longevity in the United States: Why Centenarians are Different from Their Shorter-lived Siblings https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g4-gavrilov.pdf
A-117	Mortality Experience of Three Senior Populations https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4b-granieri.pdf
A-121	Increasing Genetic Contribution to Exceptional Longevity with Increasing Age https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g4-perls.pdf
A-127	Mortality, Health and Marriage: A Study Based on Taiwan’s Population Data https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1b-wang.pdf
A-129	Predictors of Exceptional Longevity: Effects of Early-Life Childhood Conditions, Midlife Environment and Parental Characteristics https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-gavrilov.pdf

<i>Appendix Reference</i>	Paper
A-131	Obesity and Mortality https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-obesity-gutterman.pdf
A-132	Causes-of-Death Mortality: What Do We Know on Their Dependence? https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-arnold.pdf
A-133	Mortality of Smoking by Gender https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-gutterman.pdf
A-134	Genetically Informed Longevity https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-bakos.pdf
A-136	Contribution of Familial Longevity to Living to 100 https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-sebastiani.pdf
A-147	Perspectives on SOA Post-Retirement Risk Research and What It Tells About the Implications of Long Life https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-rappaport.pdf
A-148	Subjective Survival Probabilities and Life Tables: Evidence from Europe https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-peracchi.pdf
A-151	Sex Differences in Predictors of Health Decline https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-prus.pdf
A-152	Cognitive, Psychological and Social Drivers of Longevity https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-woo.pdf
A-154	Mortality Projections for Social Security Programs in Canada https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs4-chief.pdf
A-155	Causal Mortality by Socioeconomic Circumstances: A Model to Assess the Impact of Policy Options on Inequalities in Life Expectancy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-alai-arnold-bajekal-villegas-paper.pdf
A-163	Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gutterman-paper.pdf
A-165	Compiling a Very Large Sample of Centenarian Pedigrees to Ascertain Patterns of Inheritance and a Familial Propensity for Longevity Score https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-nussbaum-nebbia-helmkamp-andersen-perls-sebastiani-paper.pdf
A-171	Accuracy of Official High-Age Population Estimates, in England and Wales: An Evaluation https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/methodologies/accuracyofofficialhighagepopulationestimatesinenglandandwalesanevaluation
A-172	Mortality Projections from a Social Security Panel https://www.youtube.com/watch?v=CmnO5kPber8&t=2s

<i>Appendix Reference</i>	Paper
A-173	How to Die Young at a Very Old Age https://youtu.be/p0JqXFWCzQ
A-174	Suppressing Aging and Extending Longevity: Will the Twain Meet? https://www.youtube.com/watch?v=Beax-wE4gsA&feature=youtu.be
B-5	Summary of Panel Discussion on Data Sources and Projection Methods for Successfully Supporting the Needs of the Senior Market https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3c-discussion.pdf
B-7	Summary of Panel Discussion on Could Moses Live to Be 120? https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4-soa-informal-discussant.pdf
B-8	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
B-13	Discussant Comments for Session on Behavior and Causes of Death: Impact on Mortality and Mortality Modeling https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-olshansky-discussant-comments.pdf
B-14	Discussant Comments for Session on Learning from Genetics https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-hayflick.pdf
B-15	Discussant Comments for Session on Learning from Genetics https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-bakos-reply.pdf
B-22	Discussant Comments for Session on Longevity and Cognitive Impairment https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-pokorski.pdf
B-23	Session 1A Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1a-transcript.pdf
B-26	Session 2A: Panel: Drivers of Future Mortality https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2a-transcript.pdf
B-37	Session 6A: Mortality Improvement Approaches https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6a-transcript.pdf
B-43	Discussant Comments for Session on Mortality Projections https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-kingkade-discussant-comments.pdf
B-44	Discussant Comments for Session on Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-olshansky-discussant-comments.pdf

4.1.6 Selecting the Appropriate Projection Model

Increased life expectancy may have several consequences, including underestimation of certain forms of premiums, pension obligations, health care costs and long-term care obligations. Traditionally, actuaries have used a fixed and deterministic mortality assumption to price and reserve for life-contingent benefits. Now, because of rapid mortality improvements, however, the pure premium of annuity products computed from a period mortality table can be as much as 40 percent lower than that computed from a more accurate cohort life table.^[A-54]

One method used to construct a cohort mortality table that computes pure premiums for annuity products is to use stochastic mortality models or mortality projections. As a result, stochastic mortality models have become an important tool for actuarial professionals in recent years.^[A-54]

It is commonly accepted by the authors of the symposia material referenced in this section that calibrating an extrapolation to different time periods will lead to significantly different results. It is also commonly accepted that the effects of current and recent medical advancements can be incorporated, but major future developments (such as a cure for cancer) are difficult to predict and model.

There is, however, modest consensus with respect to the techniques that are employed. In particular:

- ▶ Some practitioners calibrate experience to a published mortality scale and project future improvements for a set (or unlimited) number of years (for example, they may use 50 percent of the Scale G improvement rates and project continued improvements for 10 years).
- ▶ Some practitioners, particularly in reinsurance and capital markets, use more sophisticated techniques such as stochastic modeling.

There are significant limitations when projecting mortality by causes of death. Disease independence is a widely used assumption for projections, while at the same time is deemed unrealistic since diseases are either dependent or at least related to each other.^{[B-13] [B-44]} But causes of death approach would provide valuable insights to mortality projection among different socioeconomic groups.^[A-155]

Practitioners in different countries use different methods and assumptions for projecting mortality. For further information on the methods adopted by:

- ▶ The U.S., refer to paper A-72, A-156
- ▶ The United Kingdom, refer to paper A-73, A-171
- ▶ Germany, refer to paper A-35
- ▶ Canada, refer to paper A-154, A-158

It is still common practice to use only deterministic models and a shock strategy to develop future mortality improvement. Stochastic modeling has the potential to be enhanced and used increasingly to model best- and worst-case scenarios more accurately than shocking deterministic scenarios.^[B-37]

In addition to a low level of consensus, a number of unanswered questions should be the focus of additional efforts:

- ▶ Will life expectancy continue to increase at the same pace it has since the middle of the 19th century?
- ▶ How can companies mitigate risks associated with major technological advances in medicine? What are some ways to model these risks?
- ▶ What are some mechanisms for assessing the utility and validity of more sophisticated, multivariate projections?

- ▶ Will policyholder behavior vary as longevity patterns continue to shift, and how should that be incorporated in modeling and planning?
- ▶ What can life actuaries learn about predictive modeling from P&C, reinsurance, capital markets and life settlements? Can life actuaries learn from other industries? From other countries? Can this lead to guides or practices for principle-based reserving?
- ▶ When is it appropriate to use age cohorts for projections, and what should be the size of the age groups?
- ▶ What will be key drivers of future mortality, and how will these vary by age group or cohorts over time?

This section provides an overview of papers that discuss models and modeling techniques. In addition, this section illustrates the results of using those models to project U.S. male mortality based on data in the Human Mortality Database as of 2011.

4.1.6.1 Selecting an Appropriate Model

1. Classes of extrapolation models

Several classes of extrapolation models were presented at the conference. A practitioner must first consider the merits and drawbacks of each type before choosing one.

In general, mortality projections use extrapolative approaches that are based on historical patterns and trends. Some projections may use only statistics to extrapolate mortality rates, others may involve expert opinion/judgments, and others still may focus on extrapolating the causes of death in order to form a process-based extrapolation.

In the United Kingdom, actuaries considered using the mortality curves identified in section 4.1.3.1 for projections. The U.K. actuaries applied a time series analysis and extrapolated each of the fitting parameters to make projections. Their research found this approach relatively ineffective because it lacks stability in projecting the parameters of the underlying models.^[A-36]

Actuaries built another class of models that specifically project mortality rates. Instead of obtaining the best fit to current data, these models aim to capture structural changes over time. This process is simpler than the complex process of projecting best-fit curves into the future. Many researchers have found historical mortality to be remarkably stable over time, prompting them to utilize these statistical extrapolation models.

A third class of models, a process-based approach, relies on an extrapolation of the causes of death (instead of historical mortality rates). The problem with this model is its reliance on causes of death, for which data may not be reliable or readily available. Gaille and Sherris noted long-run equilibrium relationships (i.e., dependencies) exist between the five main causes of deaths across ten studied countries. As noted above, the common assumption of independence between mortality rates for causes of death is unrealistic, and new forecasting mortality models should take this dependency into account. They also observed that countries have differing patterns of improvement across causes of death, which led them to conclude that a future shock in some cause-specific mortality rate (e.g., a cure for cancer) will not have the same impact across countries.^[A-132]

Literature discussing the selection of an appropriate statistical extrapolation model is quite involved, and currently there are not many presentations on the topic—perhaps because of the topic’s heavily technical nature. The current lack of information on the subject would make it a good area of focus for symposia conferences in the future.

As interest in projection models has gained traction, a number of more subtle considerations also arise that are just as important as selection of the projection model itself. Some of these subtle considerations include the handling of outliers and the construction of prediction intervals.

2. Aggregation level

Actuaries have analyzed the potential of forecasting age-specific mortality rates at a disaggregated level and reconciling the aggregation of those individual forecasts. In a study performed by Shang and Haberman, a functional time series forecasting method is compared to the Lee-Carter method. The functional time series forecast outperforms the Lee-Carter method based on forecast accuracy criteria of mean absolute forecast error and root-mean-squared forecast error. After a comparison over a 15-period expanding window analysis, the outperformance was driven by two differences in the models. First, nonparametric smoothing techniques used for the functional time series forecast, specifically a penalized regression spline with a partial monotonic constraint, deal with noise at older ages. Second, more than one component is used to achieve improved model fitting.^[A-168]

In addition, Shang and Haberman investigated which grouped forecasting method would be best for reconciling to the disaggregated forecasts and the fully aggregated forecasts. Based on regionally disaggregated forecasts from Japan, this paper demonstrates that the bottom-up method for forecast reconciliation outperforms the optimal combination method. The bottom-up aggregation method is to forecast data series at the most disaggregated levels and then to perform a simple aggregation in a summing matrix. The alternative optimal combination method uses independent forecasts for all series computed independently and reconciles resultant forecasts to satisfy aggregation constraints via the summing matrix. The optimal combination method combines the independent forecasts through linear regression by generating a set of revised forecasts that are as close as possible to the independent forecasts but that also aggregate consistently within the group. It is notable that the bottom-up approach works well when the data have a high signal-to-noise ratio. The paper suggests the optimal combination method works better when the data have a low signal-to-noise ratio.^[A-168]

Kingkade notes that the methods used in the Shang-Haberman study might not be realistic since exposures are kept constant within cohorts throughout the window analyzed. If those exposures do change, it might be worth investigating a cohort survival projection.^[B-43]

This method of disaggregation to forecast mortality can be easily applied to fixed-term annuity products. When the Shang-Haberman study applied projected mortality rates to an example annuity, it found slight pre-differences, which can have a large impact on a portfolio.^[A-168]

Kingkade notes that the bottom-up method is usually associated with slightly lower annuities prices than the other methods for the given dataset.^[B-43]

3. Modeling mortality improvement rates

Actuaries are often interested in models that project mortality improvement rates instead of predicted mortality rates because the changes in mortality rates are useful in assessing longevity risk. Improvement rate projections also allow actuaries to compare populations with very different levels of mortality. While many academic papers have been written to build robust models for projecting mortality rates, much less research has focused on developing a robust model for improvement rates. Current models that directly predict mortality improvement rates require ad hoc assumptions that leave room for a more robust mathematical approach. More research should be done to build better mortality improvement rate models because they are important tools for actuaries in the industry.^[A-164]

Hunt and Villegas attempted to create such a model by adapting approaches to model mortality rates to be able to find the improvement rates. They selected a Poisson distribution to model the number of deaths at each age and year. This method reduces much of the noise that can be seen in other attempts at modeling improvements by looking at model-estimated central death rates instead of differences in empirically observed mortality rates.^[A-164]

The method suggested to estimate parameters is referred to as the “fitted” method, which uses a maximum likelihood technique to estimate parameters. This method also allows for parameter uncertainty to be investigated, allowing for better analysis on the robustness of the model. When applied to actual datasets, the paper proves that

the method it uses for parameter estimation improves the parameter uncertainty and changes the best estimate of the model for mortality improvement rates because of the enhanced estimation technique.^[A-164]

The Hunt and Villegas model can be applied to many of the models that have been developed to model mortality rates. The paper includes modeling only constant improvement, the Lee-Carter model, the CBD model and the APC model, each with and without the constant improvement term included. Using the “fitted” method described changed the central projection of mortality improvement rate for the Lee-Carter model.^[A-164]

Justin Struby indicated that some practitioners are required to put boundaries around assumptions. He encouraged all researchers to spend more time around the practical aspects of the uncertainty around those future estimations.^[B-33]

4.1.6.2 Important Considerations for Extrapolative Techniques

This section summarizes some of the considerations one must consider when applying the projection techniques from above.

1. Considerations for extrapolative techniques

- ▶ **Outliers:** The mortality rate time series, or the time series for other factors such as smoking prevalence, often has outliers in the data points that can heavily influence the best estimate and estimated volatility of projected mortality rates. Outlier detection and adjustment techniques can be used to lessen the influence of outliers and develop a more robust best estimate. Methods identified in the conferences include time series outlier detection and adjustment mechanisms,^[A-23] as well as the use of quantile regression in place of least squares regression to lessen the influence of outliers in the estimation process.^[A-89]
- ▶ **Structural changes:** Although the time series data for mortality rates has been fairly stable historically, some symposia presenters have detected structural changes in the time series, e.g., a permanent increase in the mortality improvement rates. Statistical methods are presented to both detect such changes and to handle any such effects in analysis. The detection and understanding of structural changes help inform the historical time periods that should be used for calibrating the extrapolations.^{[A-64] [A-89]}
- ▶ **Prediction intervals:** As projections inherently involve uncertainty, often it is just as important to properly develop a range of projected outcomes as it is to develop the best estimate. Some papers note that prediction intervals produced by the Lee-Carter model appear to be very narrow. It has also been observed that point-wise prediction intervals can understate the uncertainty that a practitioner wishes to capture. As a result, it is suggested that professionals use time-simultaneous prediction intervals and Chebyshev bands instead. Further information on this consideration is provided below.^{[A-81] [A-92]}
- ▶ **Cohort effects:** The existence of cohort effects is well documented and researched in U.K. literature, and some papers presented consider how cohort effects can be incorporated into extrapolative models. The existence of the cohort effect is less clear in other countries.^[A-54]

According to Larry Pinzur, the U.S. has a clear cohort effect with a “golden generation” born around 1935. The baby boomers, on the other hand, have much lower mortality improvements by comparison to the cohorts around them.^[B-37]

Sam Gutterman points out that it can be difficult to effectively extrapolate patterns that appear to be cohort effects because after periods of mortality deterioration there is often corresponding improvement that follows.^[B-37]

It should be considered if the abnormal mortality improvement rates experienced by the cohort will eventually converge to a long-term improvement factor used by other cohorts, as projected by the Office

of the Chief Actuary in Canada, or if the abnormal mortality improvement rates will be sustained through time, as projected by the U.K. Government Actuary's Department.^[B-8]

- ▶ Joint models: Some have explored the use of extrapolation models that can combine different populations, thinking that the larger dataset would be more credible and useful for modeling correlations between different populations.^[A-90]

In particular, researchers have studied how joint models can aid in calibrating age-period-cohort models and provide a high degree of flexibility to combine data-driven extrapolations with expert judgment.^[A-137]

Johnny Li also mentions how joint mortality models, by design, are very suitable for use in the quantification of population basis risk in longevity hedges.^[B-16]

Even if there is no theoretically optimal model or set of parameters to construct an age-period-cohort model, Gutterman argues that a reasonable set of relationships can be obtained from designing this type of model. Specifically when applying this to smoking habits, a clear cohort and period effect is seen.^[A-163]

- ▶ Parameter uncertainty: There is inherently uncertainty in the parameter estimation process, and the inability to recognize this issue can lead to predictions that imply more certainty than may be appropriate as demonstrated by the width of the prediction interval. To counter this effect, parameter uncertainty could be reflected to create more representative prediction intervals.^[A-89]

Parameter uncertainty can have a large impact on accurately predicting future rates. One method typically used to combat uncertainty is using the largest number of observations possible to calculate mortality rates and improvement rates. Actuaries typically adjust those rates to be applicable to the population being modeled based on judgment. An alternative approach that could cut parameter uncertainty would be to develop better methodology to estimate parameters in the model. Hunt and Villegas describe a bootstrapping approach to refit the parameters in a Poisson model. This "fitted" approach reduces confidence intervals and shifts best estimates to be more in line with what the data suggest.^[A-164]

- ▶ Disease dependency: Estimates of the rise in life expectancy with the hypothetical elimination of various diseases have been a part of standard actuarial/demographic analysis for decades. However, diseases are not independent of each other, and their dependency should be taken into account in an ideal projection model. In particular, S. Jay Olshansky noted that cause-elimination life tables could result in biased projections of life expectancy due to disease dependence:^[B-13]
 - ▶ Overestimating life expectancy is possible since those hypothetically saved from death by one disease are being placed back into the risk pool with an altered profile as their bodies experience competing risks from other diseases due to the dependency.^[B-13]
 - ▶ Underestimating life expectancy can be possible as well. Since diseases are dependent, if death rates are declining due to improved risk factors for fatal diseases, then risk-factor modification would have an amplified effect by favorably influencing multiple diseases simultaneously.^[B-13]

Gaille and Sherris showed disease dependency does not operate in the same way across different countries. They concluded cause-elimination models from one country's population should not be used to extrapolate across another country's population.^[A-132]

- ▶ Disaggregation: Mortality forecasts at the subnational level often suffer from poorer data quality and/or missing data when compared to national forecasts. However, subnational forecasts are helpful for policymakers and actuaries.^[A-168]

Some actuaries believe disaggregated data are credible and will yield more specific and accurate forecasts for mortality. It is important to consider whether data can be credibly disaggregated and forecasted out. If

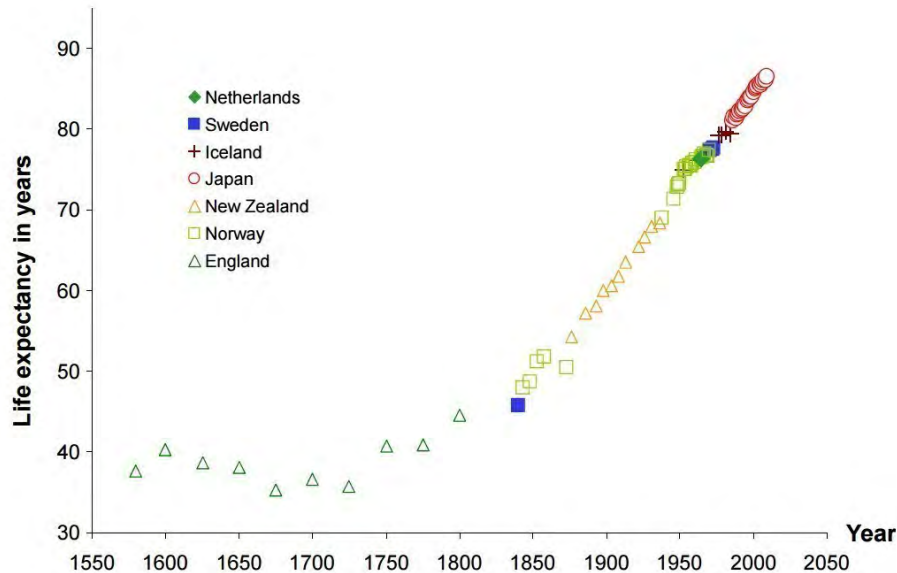
so, then selecting the appropriate method to aggregate those individual and grouped predictions will be important to reconcile to a fully aggregated forecast.^[A-168]

2. Mortality improvement and plateau

- ▶ Continuity of life expectancy increases: A key point of discussion in the longevity projection debate is whether life expectancy can be projected constantly and permanently into the future or will it eventually reach a plateau. Dr. James Vaupel supports the former notion—that life expectancy has increased constantly in recent history and will continue to do so. According to Dr. Vaupel, this linear extrapolation of mortality improvement rates has been able to predict all increases in global life expectancy from the early 19th century onward. He notes how every past method used by national organizations, as depicted in Figure 4.1.6-01 below, has failed to predict historical life expectancies and even the ultimate limit to human life expectancy. However, linear extrapolation has been the only method to not fail historical forecasting. While it is generally accepted that past improvements cannot forecast future improvements, the resulting progress from past improvements has been linear and is expected to remain linear for the foreseeable future, as it is believed society will continue experiencing breakthroughs, including the following:^[B-1]
 - ▶ Progress made against cancer, dementia and developing genotype-specific therapies
 - ▶ Regenerating and rejuvenating tissues
 - ▶ Replacement of deleterious genes
 - ▶ Nanotechnologies possibly enabling introduction of “nano-robots,” capable of physically combating diseases and fixing other medical problems

On the other hand, Stephen Goss, Chief Actuary for the U.S. Social Security Administration, noted how researchers and clinicians who are actually developing new technologies are less optimistic about mortality improvements from future innovations. He also notes that past improvements in life expectancy have been attributed to avoidance of deaths at younger ages and that, for the later part of the 20th century, mortality improvements have been shifting from occurring at younger ages to occurring at older ages. This implies larger health breakthroughs will be needed at these older ages to sustain the improvement levels observed in the 20th century.^[B-8]

Figure 4.1.6-01: Global Historical Record Life Expectancy

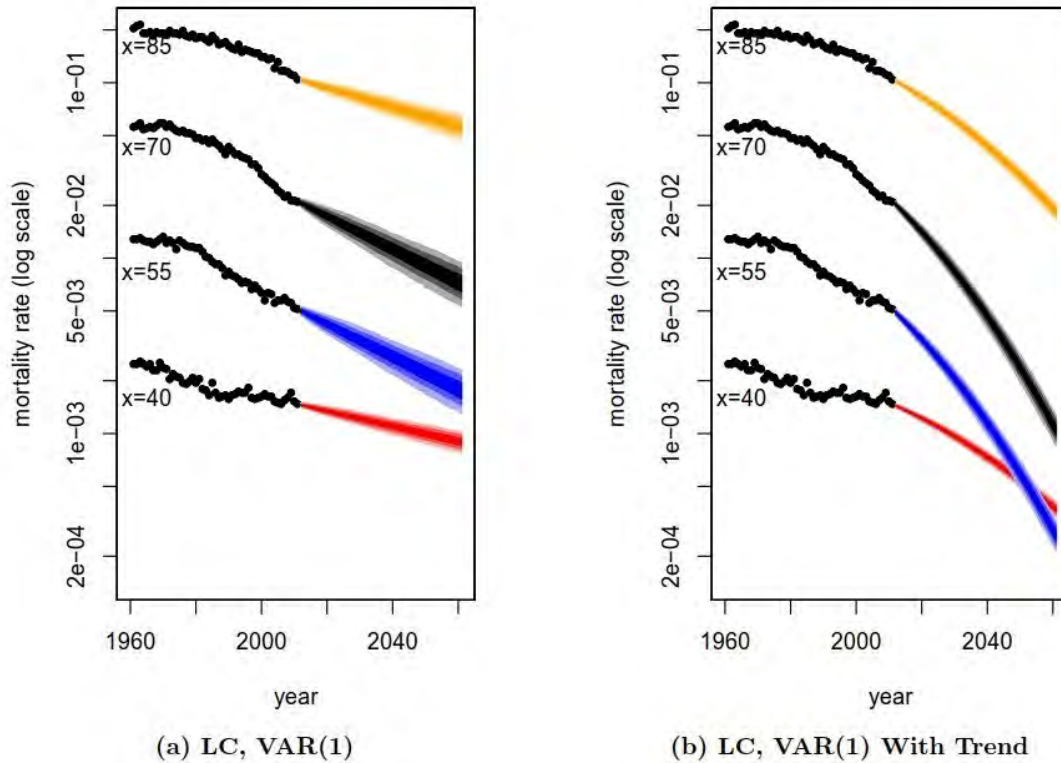


S. Jay Olshansky takes a more biological approach to the argument, indicating that the human body and biological makeup aren't designed to last significantly longer than current levels. Even if medical breakthroughs continue to reduce individual risk factors and causes of death, they will have a diminishing impact of longevity as frailty, disability and other impacts of aging will become increasingly impactful risk factors. He argues this can't be ignored when using actuarial approaches to extrapolate previous trends.^[B-44]

Olshansky argues that "I don't think our biology has changed at all. Our technology has changed quite dramatically, and we're now getting to see the expression of sort of the best mortality schedule that we can see in long-lived populations, but (I would argue) we're reaching a point of diminishing returns, and those gains in life expectancy will decline. They will decelerate, and in fact, (I have argued that) they will reverse, and we have already started to see this among some subgroups of the population—a decline in life expectancy."^[B-29]

When Hunt and Villegas built a time series model to forecast mortality improvement rates, they tested two methods of projecting period indexes. The first method is a vector auto-regressive model in the first differences as used in another paper by Haberman and Renshaw. The second method is a vector auto-regressive model around a linear trend that acknowledges upward trends in the primary period index. The upward trend approach caused a quadratic behavior in the log-mortality rate forecasts and led to accelerating improvements in mortality rates. In some models, that caused "mortality crossovers" where younger ages had higher mortality than older ages. This seems to be biologically unreasonable, and the authors decided to reject the method assuming that the linear trend in mortality improvement would continue. A graphical representation of this can be seen in Figure 4.1.6-02.^[A-164]

Figure 4.1.6-02: Forecast of Mortality Improvement Rates



Kingkade commented about the VAR(1) model that doesn't use the linear trend factor and pointed out that it appears the same mortality crossover might occur around 2060. He recommends trying to constrain some of the parameters to prevent that from occurring.^[B-43]

According to a study by Gbari et al, the tail weight of empirical data supports a lighter tail distribution than negative exponential. Interpretation of this finding is that an ultimate age does exist. The authors interpret that ultimate age to be a reasonable upper bound on a policyholder's lifetime for the purpose of actuarial calculations. It is then practical to assume that remaining lifetimes conform to the negative binomial distribution to close the life table.^[A-161]

3. Prediction intervals^[A-89]

The following sections illustrate why the considerations from above are important by applying projection modeling techniques to U.S. SSA data and assessing the results with and without these adjustments.

We implemented the time-simultaneous prediction interval and Chebyshev bands for both the Lee-Carter model and the Cairns-Blake-Dowd (CBD) model and compared the results to the original Lee-Carter model point-wise prediction interval.

Figure 4.1.6-03 on the following page compares the projected mortality rates using a Lee-Carter model for a person aged 65 today. The 2.5 and 97.5 percentile bands are shown using the point-wise method, as well as the time-simultaneous and Chebyshev methods. The areas between the bands are set to cover 95 percent of the distribution.

Observations:

- ▶ The prediction intervals under the Lee-Carter model are fairly narrow and stay narrow over time, i.e., the level of uncertainty remains constant over longer projection horizons. This result—that predictions are as certain 40 years out as they are 20 years out—is counterintuitive. One technical explanation for this is that the Lee-Carter model may be too structured: the uncertainty implied by the model is given by the improvement index parameter; as this generally decreases with age, uncertainty can be understated especially for older ages.
- ▶ Although not readily apparent from the graphics, there is actually a material difference between the time-simultaneous bands and the point-wise prediction intervals. On average the difference is more than 5 percent, with largest differences of over 9 percent. The prediction bands are not symmetric as there was more variability at higher levels of improvement than at lower levels of improvement (i.e., the potential for higher improvement than expected is greater than the potential for lower improvement than expected). The difference is more pronounced when one considers how the uncertainty may actually be used. Consider the following example: an insurance company may set the capital levels to cover the 97.5 percent path. On average, the 97.5 percent improvement is 20 percent higher than the mean improvement rate under the point-wise prediction intervals but is 25 percent higher under the time-simultaneous prediction intervals. The 5 percent difference in liability values actually translates to a 25 percent difference in capital levels $[(25\% - 20\%) / 20\%]$.

Figure 4.1.6-03: The Prediction Interval Generated by the Lee-Carter Model

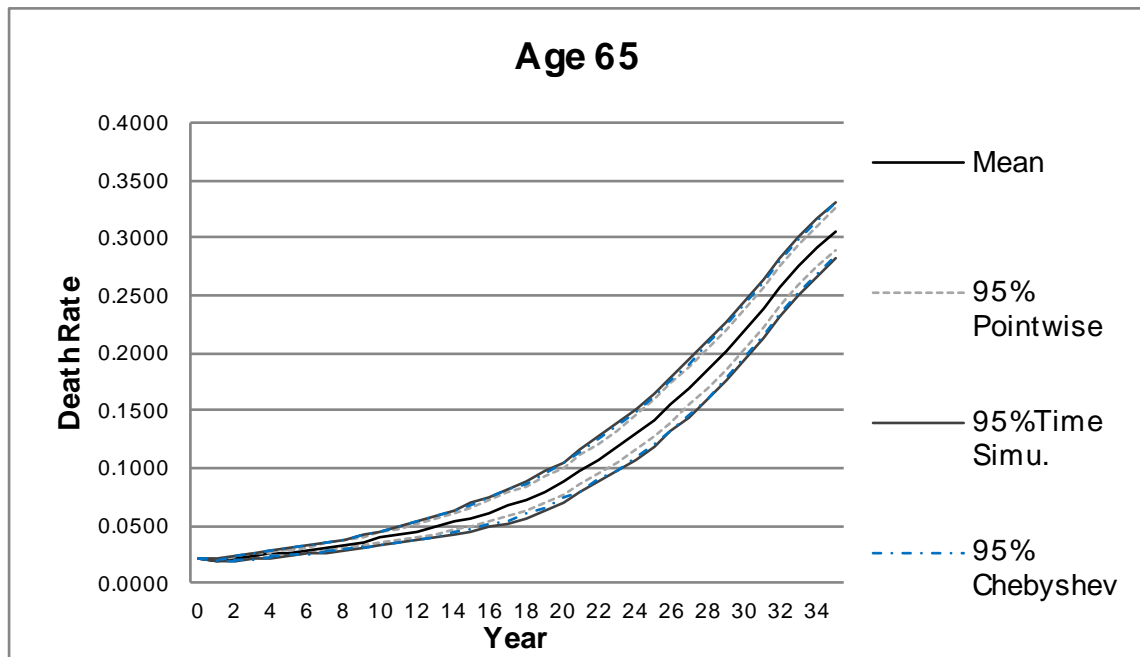


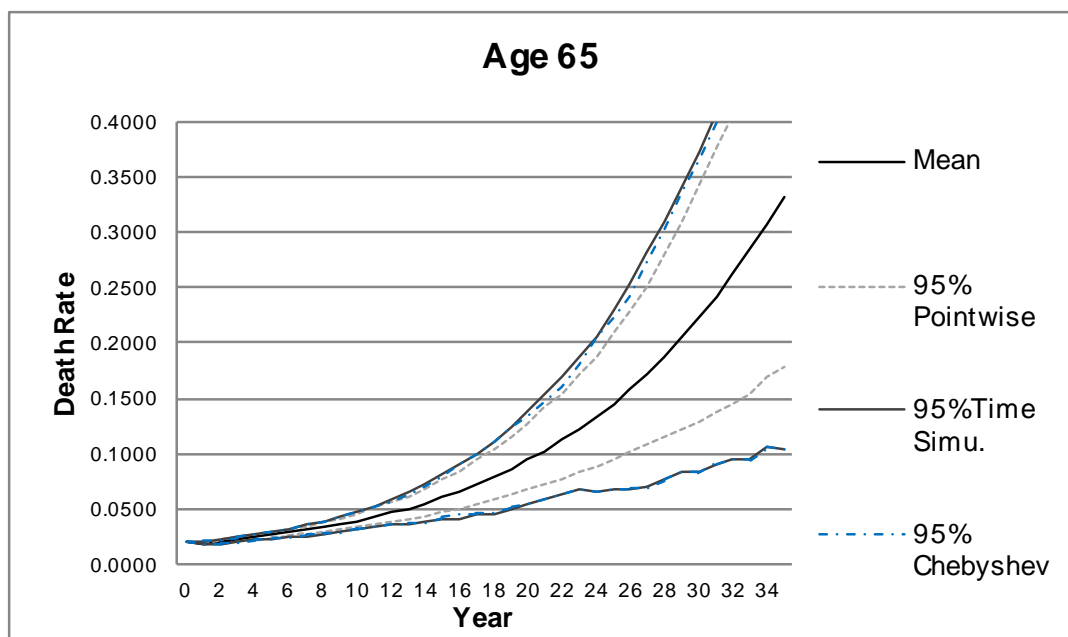
Figure 4.1.6-04 on the following page shows the corresponding results for the CBD model (M5), which is similar to the Lee-Carter model but incorporates “period” effects in addition to “age” effects. The 2.5 and 97.5 percentile bands are shown using the point-wise method, as well as the time-simultaneous and Chebyshev methods.

Observations:

- ▶ The prediction intervals under the CBD model are much broader: on average, 97.5 percentile mortality rates are 40 percent lower than the best estimate, and the difference grows over time to 70 percent.

- ▶ There is a clearer differentiation between the point-wise prediction intervals and time-simultaneous prediction intervals. The difference is more pronounced on the lower end of the mortality rates, where the time-simultaneous prediction is 20 percent lower than the point-wise prediction, and grows to over 40 percent. Again, the difference is more pronounced when considering the implied capital levels an insurance company may hold—in this case, the average capital level would be 50 percent higher under the time-simultaneous method than under the point-wise method.
- ▶ This example helps to illustrate that both the selection of the base projection model (in this case, Lee-Carter versus CBD) as well as the prediction interval metric (point-wise versus time-simultaneous) can significantly impact the calculated results such as capital levels. In our theoretical example, the use of a CBD model leads to capital levels two to three times higher than those under a Lee-Carter prediction, while the prediction interval metric can lead to a further 25–50 percent difference. Other model differences can further compound these differences.

Figure 4.1.6-04: The Prediction Interval Generated by the CBD (M5) Model



4. Outliers

Another area that was popular with symposia presenters was the topic of trends and outliers in the mortality data. The paper “The Lee-Carter Model for Forecasting Mortality Revisited”^[A-23] provides an excellent reference on outliers identified in the U.S. and Canadian data, which practitioners may find helpful. The next few pages investigate a relatively simple method that aims to lessen the impact of outliers through a small change in the parameter estimation process. The symposia paper’s authors, Siu-Hang Li and Wai-Sum Chan, propose that professionals estimate parameters in extrapolation models by using quantile regression rather than the more typical least squares regression, arguing that the former is a more outlier-robust method.

In the original Lee and Carter paper, the drift term for the mortality index, k_t , is estimated using least squares (LS) (recall the Lee-Carter formula is $\log(m_{x,t}) = \alpha_x + \beta_x k_t$). The resulting estimation is very sensitive to the first and last years of the data and not robust against outliers and extreme abnormal values.

Under the quantile regression (QR) method, estimation is matched to the specific quantiles (e.g., the median) of the response variable, unlike the LS method, which provides estimates that approximate the conditional mean of the response variable. The motivation for the QR method comes from the recognition of outlier events such as the 1918

Spanish flu epidemic and the 2003 SARS outbreak. It should be noted that the goal here is not to ignore the complexity of outlier events, but rather to develop a robust estimate that represents a more “normal course of business”—one that is not influenced by extreme events.

Under QR, the mortality index is fit to ARIMA(0,1,0), and the drift parameter is estimated using the median (not the mean, as in LS) of the observed differences in k_t . The drift uncertainty is calculated using the sample standard deviation of the observed differences, just as it is in LS.

We modeled the number of deaths using the Poisson model commonly employed in the mortality modeling literature, as proposed by Brouhns et al (2002). We used data from the Social Security Administration’s historical mortality rates database for the period 1900 through 2007 for males. This serves to estimate initial parameters using maximum likelihood. Next, we simulated 1,000 scenarios using both LS and QR.

The drift parameters between LS and QR (the mean and median respectively) showed small differences:

	Drift μ	Drift Uncertainty
LS	-1.58	3.78
QR	-1.71	3.78

The difference between drifts suggests the possibility of outliers in the underlying data that may have increased mortality rates and thus the mortality index using an LS method.

In the following graphs (Figure 4.1.6-05 and Figure 4.1.6-06), we use the same dataset to show the difference in mortality rate estimation (q_x) under both QR and LS approaches.

Figure 4.1.6-05: Difference Between QR and LS by Age

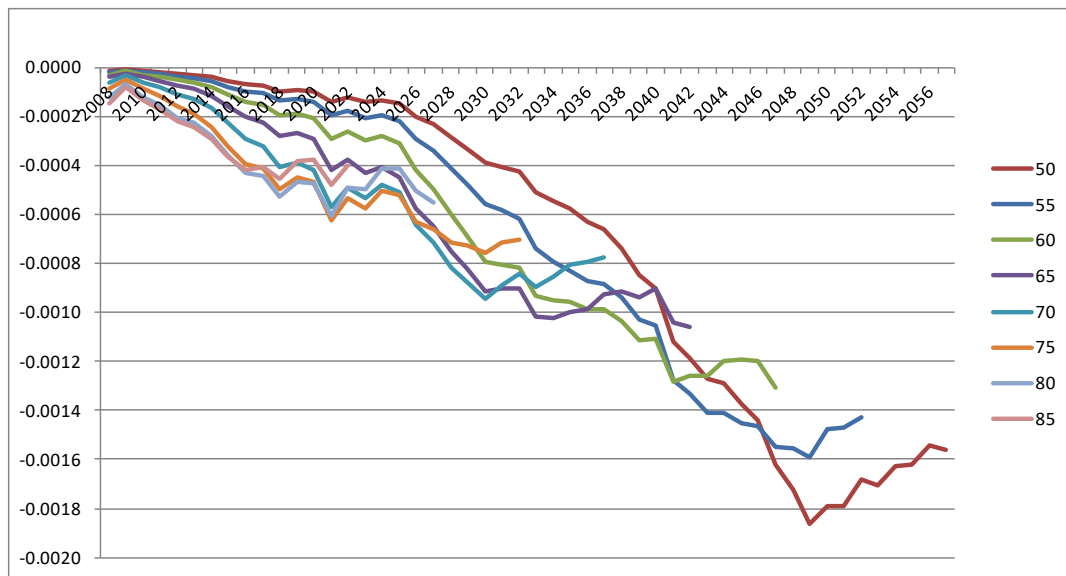
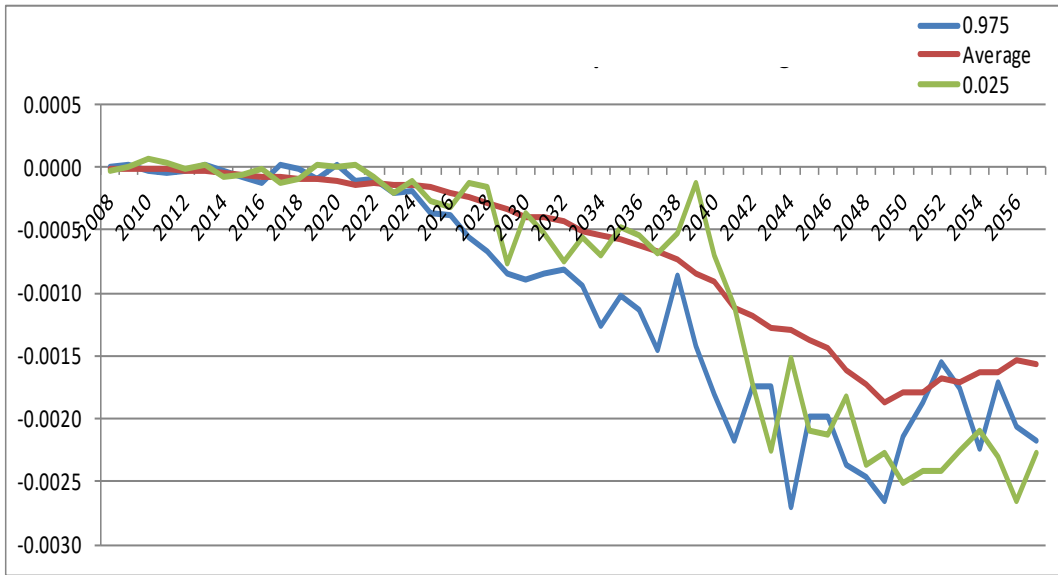


Figure 4.1.6-06: Difference Between QR and LS at Age 50



Above, the QR average estimates of q_x tend to decrease over the projection period—a consequence of the lower drift (-1.71) assumed in QR. In addition, the 9.75 and 2.5 percentiles show more volatility in the late years, which is a result of the compounding volatility in ARIMA(0,1,0). Still, both percentiles are lower for QR than for LS.

In Figures 4.1.6-06 and 4.1.6-07, we show the impact of both models in life expectancy for newborns:

Figure 4.1.6-06: 2007 Newborn Life Expectancy Distribution

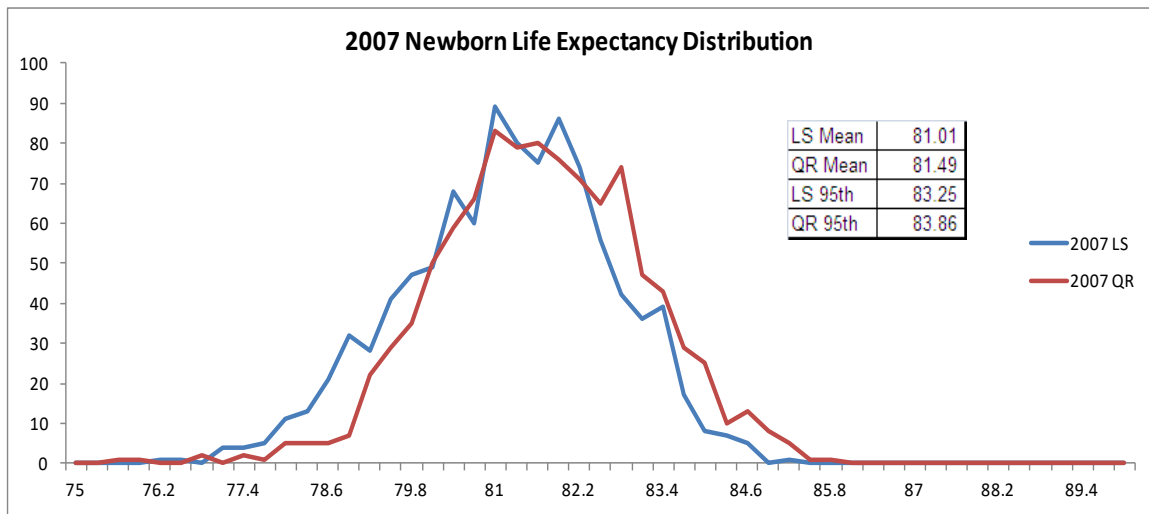
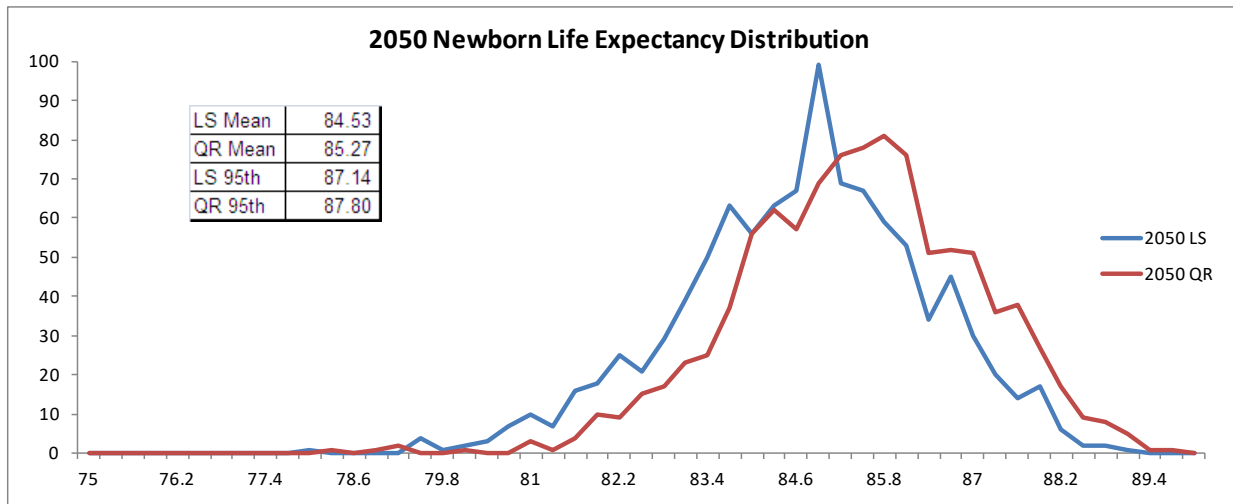


Figure 4.1.6-07: 2050 Newborn Life Expectancy Distribution



Here it is apparent that QR can lessen the impact of outliers by using the median of the observed Lee-Carter mortality index when projecting central death rates. The uncertainty measure (Drift Uncertainty) is also impacted by using QR to the effect that, in the presence of outliers, its estimate is higher than under LS, resulting in more variability in the results. Both effects are desirable in actuarial considerations.

The graphs presented in this section demonstrate that the forecast performance of the Lee-Carter model can be improved by implementing a simple method such as quantile regression.

4.1.6.3 Validation Techniques

There are relatively few data sources available to validate the forecast produced by the models described above. As a result, the focus of many technical papers has been on exploring different techniques to enhance the predictive power of the resulting forecast.

Dr. James Vaupel cautions practitioners who compare improvement rates for a particular age group from different time periods. In particular, age 80 from 1950 is not the same as age 80 in 2015. A way to circumvent this issue would be by comparing ages when the force of mortality was the same in the studied periods or by comparing the ages when the remaining life expectancy is, for example, 10 years in the studied periods.^[B-1]

Below are some highlights on how social security programs validate their projection of mortality improvements:

- ▶ The U.S. SSA Office of the Chief Actuary, which projects mortality by cause of death in order to obtain projected aggregate mortality, considers past improvement trends within each category and substantiates that the projected individual mortality improvements are reasonable. Industry experts are also consulted on the future outlook in new biomedical advancements.^[B-8]
- ▶ To improve understanding on the validity of projections, the Canadian Office of the Chief Actuary analyzes sensitivity of projected mortality rates through implementing different long-term mortality rate assumptions. In particular, the mortality rates are analyzed using a combination of a deterministic model based on judgment with a stochastic time series model.^[A-154]

The Shang-Haberman study uses retained components; components were retained only if the functional principal component decomposition is determined by explaining at least 99 percent of the total variation, and R^2 values to determine goodness of fit for the models were analyzed.^[A-168]

4.1.6.4 Relevant Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

<i>Appendix Reference</i>	Paper
A-23	The Lee-Carter Model for Forecasting Mortality Revisited https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xi.pdf
A-35	Coping with Longevity: The New German Annuity Valuation Table DAV 2004 R https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xvi.pdf
A-36	Mortality at Advanced Ages in the United Kingdom https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxi.pdf
A-54	A Study of the Lee-Carter Model with Age-Shifts https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6a-huang.pdf
A-64	Testing Deterministic Versus Stochastic Trends in the Lee-Carter Mortality Indexes and Its Implications for Projecting Mortality Improvements at Advanced Ages https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6a-chan.pdf
A-81	Temporal Evolution of Some Mortality Indicators: Application to Spanish Data https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1b-debon.pdf
A-89	Assessing and Extending the Lee-Carter Model for Long-Term Mortality Prediction https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2b-liu.pdf
A-90	Coherent Mortality Modeling for a Group of Populations https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2b-yang.pdf
A-92	Simultaneous Prediction Intervals: An Application to Forecasting U.S. and Canadian Mortality https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-3b-li.pdf
A-132	Causes-of-Death Mortality: What Do We Know on Their Dependence? https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-arnold.pdf
A-137	Coherent Projections of Age, Period and Cohort Dependent Mortality Improvements https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-borger.pdf
A-154	Mortality Projections for Social Security Programs in Canada https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs4-chief.pdf
A-161	Extreme Value Analysis of Mortality at the Oldest Ages: A Case Study Based on Individual Ages at Death https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gbari-poulain-dal-denuit-paper.pdf
A-163	Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gutterman-paper.pdf
A-164	Mortality Improvement Rates: Modeling and Parameter Uncertainty https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-

<i>Appendix Reference</i>	Paper
	hunt-villegas-paper.pdf
B-1	Summary of Panel Discussion on the Advancing Frontier of Human Survival https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1-soa-informal-discussant.pdf
B-8	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
B-13	Discussant Comments for Session on Behavior and Causes of Death: Impact on Mortality and Mortality Modeling https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-olshansky-discussant-comments.pdf
B-16	Discussant Comments for Session on Mortality Age Patterns: Trends and Projections https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-lid-discussant-comments.pdf
B-29	Session 3A Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3a-transcript.pdf
B-33	Session 4B Informal Discussion Transcript https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4b-transcript.pdf
B-37	Session 6A: Mortality Improvement Approaches https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6a-transcript.pdf
B-43	Discussant Comments for Session on Mortality Projections https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-kingkade-discussant-comments.pdf
B-44	Discussant Comments for Session on Mortality Inequality: Impact of Socioeconomic Factors https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-olshansky-discussant-comments.pdf

4.2 Part 2: The Social and Economic Implications of an Aging Population

Aging populations create opportunities and challenges for both the private and public sectors. While the basic issues are very similar in many countries, the solutions vary. Big questions today include: How does population aging change the mix of products and services needed? When and how should people be able to retire and how much retirement support should come from public programs? How will long-term care be provided and financed? What should be the role of the family? Some countries provide much more generous public benefits than others, but often these are being cut back as the populations age. Many countries need to deal with the appropriate roles of the individual, government and the private sector as solutions emerge. For individuals interested in looking at different solutions by country, the OECD (Organisation for Economic Co-operation and Development) and the Mercer Melbourne Global Pension Index are good resources to get started.

Anna Rappaport, FSA, EA, FCA, MAAA, Anna Rappaport Consulting

Increasing longevity has been creating new challenges and opportunities for society at large and particularly for the retirement income industry around the globe. As a result, we have to start re-evaluating how we allocate individual, family and societal resources so we can most effectively support our growing life-spans. Society also needs to think about what the labor force will look like and the products and services needed by the aging population. Symposia papers highlight a number of trends that have emerged or are expected to result from continuing increases in longevity. These include:

- ▶ Integration of seniors into the workforce with new retirement designs and programs as pre-retirees continue to postpone their retirement
- ▶ Large increases in the number of elderly and the proportion of elderly in the population of developed countries
- ▶ The strain on private pension and retirement savings plans as engines for savings and capital accumulation
- ▶ The strain on public pension systems and other programs offering support for the elderly as they compete for public resources
- ▶ Increasing relevance of retirement planning for lower income individuals
- ▶ Increasing need for long-term care in retirement years and demand for innovative housing strategies for supporting the aging of the elderly
- ▶ Increasing shortages of both voluntary and paid caregivers
- ▶ Growth and increasing cost and utilization of health care systems, particularly due to the growing number of diseases with high old-age prevalence such as Alzheimer's
- ▶ Growth of financial solutions targeting elderly needs, including target-date investment funds, fixed and variable annuities, long-term care insurance and, in some countries, health insurance
- ▶ Increasing demand for affordable individual insurance products with guaranteed income and ability to effectively manage longevity risk
- ▶ Rising demand from institutions desiring longevity risk protection through the use of reinsurance, capital markets solutions and pension de-risking strategies

Symposia paper “Living to 100: Socioeconomic Implications of Increased Longevity” also notes potential socioeconomic implications should longevity continue to increase. Some of the discussion points mentioned include:^[A-146]

- ▶ Increased investment in higher education as value of education increases over time due to longer life expectancy
- ▶ Social acceptance of extended longevity, even if medically possible, if the quality of life that follows is poor
- ▶ Potential for multiple careers to become more common in the workplace, partitioned by periods of additional education

These changes will have large impacts on all of society, but they will be particularly troublesome to those age 80 and over (who are almost twice as likely to have a severe disability as their younger counterparts), not to mention the oldest of the elderly (who are most likely female, unmarried and poor).^[A-20]

Females will experience unique difficulties due to higher life expectancies and different life histories from males. About two-thirds of people over the age of 85 in the U.S. are single women, and for people over 100, about 85 percent are women.^[B-31] Within the U.S., the following challenges have been identified:^[A-106]

- ▶ Outliving assets is a larger concern for females than males due to their higher life expectancies and, in aggregate, lower pension benefits due to their different work histories from males.
- ▶ As women are traditionally younger than their spouses, they are more likely to experience the loss of a spouse and an ensuing decline in standard of living. Furthermore, women are more likely to need paid care since their spouses aren’t alive anymore to take care of them.
- ▶ Twenty-four percent of widowed retirees have faced four or more shocks, which are large unexpected expenses. Of retirees overall who have experienced at least one shock, more than one-third had their financial assets reduced by more than 25 percent.^[A-166]

Some countries are seeing progress. In Canada, previously the gap between male and female life expectancy was increasing. It is now beginning to narrow.^[A-172]

Another group disproportionately impacted is people with below median income or lower income. While it may seem obvious that this is an at-risk group due to their lack of disposable income to save for retirement, more needs to be done to assess how successful they truly are in retirement and what resources are needed to aid them:

- ▶ Data from the Health Inequality Project show there is a 15-year difference in life expectancy for a 40-year-old male at the bottom of the income distribution versus at the top.^[B-35]
- ▶ Disparities between men and women decrease as income level increases, meaning low-income women are at an even higher risk.^[B-35]
- ▶ In the past 50 years, life expectancy has moved very little for men and even decreased for women at the bottom part of the income spectrum. This is due to the fact that gains in life expectancy are accruing mainly over the top half of the income and wealth profile.^[B-39]
- ▶ The U.K. analyzed life expectancy at age 65 by area based on level of deprivation and the difference between the most and least deprived areas was a four-to-five-year lower life expectancy.^[A-172]

It is evident that low-income individuals with low education levels are not as healthy, and interventions need to be targeted at how to determine and address their barriers to living a healthier life.^[B-39]

As experts attempt to respond to the challenges and opportunities created by increases in longevity, conflicting viewpoints have emerged. Some of the most contested issues appear to be:

- ▶ As people need to work longer to provide their financial security, how will jobs and the employment relationship adapt to fit more seniors in the workforce?
- ▶ Should the standard retirement age change, and at what pace? How and when will people retire, and what will retirement mean?
- ▶ As retirement needs are unique for each individual, what are the benefits and limitations of rules of thumb for retirement planning?
- ▶ What is the appropriate role of government, employers and individuals in providing retirement income and support for health and long-term care?
- ▶ How can society encourage and support the aging at home of the elderly population and informal support networks within communities?
- ▶ What is more important—duration or quality of life? Is living longer a desirable goal, especially if it is accompanied by inadequate wealth and concerns regarding how to manage one’s savings, or loss of mental faculties and a requirement for institutionalization?^[A-67]
- ▶ Employers and insurance companies struggle to experiment with innovative solutions due to barriers arising from strict legislation and regulations. How should the government modify its mandates to encourage innovation within the private sector and provide legal safe harbors to their experimental designs?^{[B-3] [B-9]}
- ▶ How can society better educate the public on how to achieve financial security, including the importance of retirement planning, the risk of outliving one’s assets, and the role of long-term care and health insurance in their long-term planning?
- ▶ How can the interests of financial advisors and their clients be better aligned?

The following sections summarize the implications of longevity on an aging workforce, retirement income programs, long-term care programs, health care systems and product innovations within the private industry to the extent presented in symposia materials. We note that considerable research has been done by the SOA and other groups on these topics beyond what is included here; the focus of this paper is solely on those articles presented for the Living to 100 symposia.

4.2.1 Seniors in the Workforce

It is in the best interest of the vast majority of individuals to work longer. It is also in the best interest of most economies and nations to have their workers working longer. If workers work longer, they will pay more taxes, contribute to GDP, rely less on entitlement programs, and ultimately become healthier and happier. It is in our best interest, individually and for our nations, to encourage people to work longer. In today’s rates of low unemployment, employers are more willing than at previous times to implement more flexible work arrangements and policies that are especially attractive to mature workers.[B-2]

Sally Hass, independent consultant

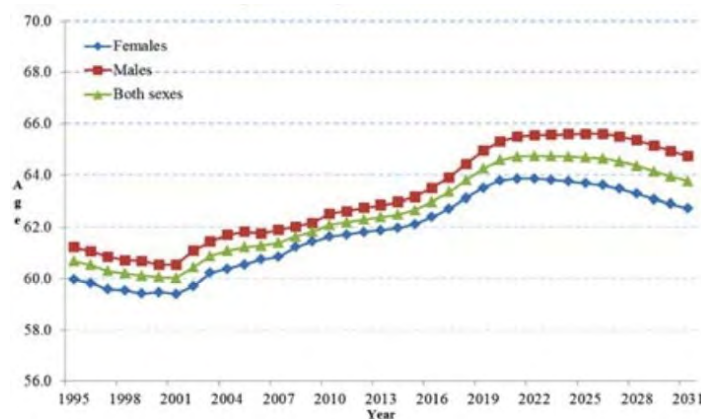
One of the many implications of extended longevity is seniors retiring at later ages than in the past. This will ultimately lead to a greater proportion of seniors in the workforce relative to any historical period. With rising health costs, increasing life expectancy, volatile global financial markets and potentially unstable retirement systems, it is becoming imperative for seniors to retire past the traditional retirement age. Numerous benefits from

the employment of more senior workers have been identified, including enhanced quality of the workforce and benefits to the economy as these individuals postpone their retirement and continue contributing to society.

However, as more seniors integrate in the workforce, there are several competing forces that need to be considered, such as the need and capability of individuals to work longer, social stigmas with elderly workers, difficulty in designing and implementing new retirement programs, and employers' reluctance to adapt due to uncertainties on how their operation will be affected. As societies design solutions to address these issues, it is important to recognize the interests and preferences of elderly workers themselves, as these solutions will affect them directly.

In Figure 4.2.1-01 below, Robert L. Brown shows the historical and projected average exit age from the Canadian labor force based on the Canada Pension Plan population. The baby boomers are already expected to retire two years later within the next decade.^[B-17]

Figure 4.2.1-01: Average Exit Age from Canadian Labor Force^[B-17]



Anna Rappaport identified current age discrimination legislation as one of the major obstacles in the U.S. society's adaption to a more senior workforce, which could prove to be a two-edged sword, as it both protects people and discourages innovation. Rappaport noted how the inclusion of seniors in the workforce will be hindered by legal barriers to organizations' experimental offering of innovative programs.^[B-3]

To facilitate the retention of elderly workers, people and employers alike need to start thinking differently about senior employment. It should be noted that, unless otherwise specified, the discussions below have been focused primarily on the U.S. market. Similar issues and circumstances also exist in other geographies with different legal environments.

4.2.1.1 Benefits in Employment of Seniors

Benefits of employing seniors are not only restricted to seniors themselves, but also to their employers and the government.

Benefits for seniors include:^[B-2]

- ▶ An improvement of their retirement financial resources and financial security
- ▶ Contentment and self-satisfaction:
 - ▶ In a survey of 200 employees at one company, Sally Hass identified the majority of respondents stated they wanted meaningful work in their last years of working.

Benefits to employers for hiring and retaining their senior employees include:

- ▶ A high correlation between an older workforce and customer satisfaction, something that is especially desired by retail stores^[B-3]
- ▶ Lower turnover as older workers' tenure is three times longer than the tenure of younger workers^[B-4]
- ▶ Lower risk of losing knowledge across generations of their workers and, consequently, increased knowledge transfer across generations^[B-3]
- ▶ Building affinity with elderly customers who will continue to make up a larger part of their future customer base as baby boomers continue aging^[B-4]
- ▶ A positive reputation among customers for being community supporters^[B-4]
- ▶ Reducing longevity risk in their pension obligations as their employees start retiring later^[B-4]
- ▶ Elongating the careers of existing talent and continue benefiting from their experience and knowledge^[B-3]
- ▶ Promoting the firm's growth and helping prepare the next generation of technical and managerial talent^[B-3]

Benefits to the government in facilitating employment of seniors include:^[B-2]

- ▶ The government will collect more income tax as pre-retirees are taxed more than retirees.
- ▶ Employed seniors will continue to contribute to GDP on a nationwide scale.
- ▶ The increasing dependency of the aging population on entitlement programs will slow down as retirement is delayed.

Retained baby boomers in the workforce will help postpone the impending labor shortages from the incoming mass retirement of these generations of workers.^[B-2]

4.2.1.2 Challenges Faced by Senior Employees

By remaining a part of the workforce into later phases of their lives, senior employees will challenge the status quo of what has been the norm for numerous decades. This will bring many challenges that include:

- ▶ Losing technical skills over the years after having taken on managerial roles for the more recent part of their careers: If they want to return to the workforce as an individual contributor rather than a manager, they will have to be willing to improve their technical skills.^[B-2]
- ▶ Having their employers maintain their defined benefit pensions despite decreasing wages for working less through flexible scheduling: Even if the defined benefit formulas are adjusted, it will take time until this information flows through the entire range of pre-retirees.^[B-3]
- ▶ Having health constraints. Although the need is present for employees to retire later, not all people can be expected to work longer because of the state of their health. Some retirees are simply not mentally or physically fit for working longer. The need exists for tying health behaviors to longevity in new, innovative ways so people are healthy enough to work longer and retire later.^[B-2]
- ▶ Taking a job for which they are overqualified and, if they are hired, reporting to a younger boss: This is especially important as younger bosses might believe their job security is threatened if they hire an outstanding employee to report to them.^[B-4]
- ▶ Overcoming preconceptions about the elderly in the workforce and maintaining a positive mindset despite the perceived age bias.^[B-4]

- ▶ Staying positive during the job search: Data from the U.S. Government Accountability Office show it takes twice as long for an older worker to get rehired once the person is out of work.^[B-4]
- ▶ Altering their ideal choice of firm and opting for the more age-friendly employers.^[B-4]
- ▶ Modifying their personality to embrace new technology and be accepted by younger workers.^[B-4]

Anna Rappaport mentioned the following findings from her focus groups on resource-constrained retirees with a medium-level of assets and who had retired voluntarily:^[B-2]

- ▶ The great majority of them had been “pushed” to retire due to difficult job environments, family issue, and health problems. Only very few were retiring to meet their dreams.
- ▶ The median age at which these retirees had retired from their main long-term job was 58, which is significantly lower than the expected retirement age of 65. This finding has also been found consistent across surveys. Based on a 2015 SOA survey, the median age is 60, slightly better than 58, which, however, is still far below the estimated median age people say they expect to retire at, which remains at 65.^[A-166] Furthermore, Wells Fargo reports that 49 percent of people retire earlier than they originally planned.^[B-36]

In today’s world where employers tend to hire people over 50 for non-managerial/junior roles only when there are not enough applicants in their preferred age range, it is important for elderly workers to maintain a positive outlook as they facilitate the gradual introduction of elderly people in the workforce.^[B-4]

4.2.1.3 Challenges Faced by Employers

Such a paradigm shift will also create challenges for the employers of seniors. To prepare themselves for the future, employers will need to ask themselves a number of difficult questions:^[A-105]

- ▶ What challenges and opportunities do the aging society and changing workforce create for the management of talent?
- ▶ What challenges are created for the management of active employees and retiree benefits?
- ▶ Does the aging of parents create special challenges for the employers of their children, who may be part of the sandwich generation?
- ▶ Are there barriers against innovation within retirement programs that discourage employers from seeking solutions?
- ▶ Is phased retirement a good idea, and how should it be supported and managed by employers?

In a heavily regulated world, some legislation might restrict the flexibility employers have for exploring solutions and making an informed choice. Although regulations have been created for protecting seniors against age discrimination, they have also been found to discourage innovation:^[B-3]

- ▶ Current regulations have potential to bring on lawsuits against firms that carry out research on their own workforce. This restricts companies from learning on arguably their single biggest collective investment: human capital. In particular, a study found only 25 percent of the Fortune 500 companies had researched and analyzed the data on their workforces.
- ▶ Experimental designs and retirement programs are held back by legal barriers and concerns for mass lawsuits.
- ▶ Bona fide terminations, required to get lump-sum distributions and pension payments, are abrupt and quick. There is the need for gradual phaseouts from the workforce rather than true termination.

- ▶ Although the Pension Protection Act authorized phased retirement plans, very few employers have adopted these new plans.
- ▶ While employers can easily educate employees about retirement, they cannot easily advise employees on retirement plans as on retirement planning as they can get sued if they do not give their advice with caution and carefulness. Being a relatively unnecessary liability, this can discourage most employers.
- ▶ In informal settings, retired chief executives from major organizations admitted their firms were not hiring older workers due to the fear of frivolous age-bias lawsuits.

Talent strategies that are effective for the business vary depending on the company's business profile. Mature organizations in low-growth mode usually undertake the "build strategy" for talent; they nurture talent at home and maintain low levels of employee turnover. Success of this internal labor market (ILM) structure depends on the periodic availability of a relatively high number of jobs and positions for its own employees to apply for and fill. The dynamics of this ILM are at risk of becoming stalled when employees delay their retirement. The ensuing low promotion rates and low quantity of lateral moves invite the possibility of early career employees, who bring new skills and perspectives required for future business success, to leave the firm in search of career growth. Delaying retirement has the potential to negatively impact these types of mature organizations in the absence of growth.^[B-3]

In the end, the employer itself might be an obstacle when it comes to implementing new retirement strategies.^[B-3]

- ▶ Age of leadership: Younger leadership will not be as inclined to adopt new retirement solutions as opposed to older leadership, who will be encouraged to since it will affect them sooner.
- ▶ Profitability of the company: Companies in volatile markets will not devote as much time to research these solutions further.
- ▶ Expanding too quickly: Even if the desire is there to explore solutions for an aging workforce, rapid expansions spread their resources thin, making it hard for the company to invest resources in exploring solutions.
- ▶ Type of industry: Employers who require skill sets not being learned as frequently by students (e.g., machinist, welding, manufacturing) will invest more in an aging workforce than those who require skill sets being learned frequently by students.
- ▶ Product life cycle: Short-cycle firms will not be interested in adapting careers to an aging population, as opposed to long-cycle firms, which might, for example, be building airplanes, where it is difficult to find an experienced employee who has built numerous products as they take relatively long.

Other challenges for employers include:

- ▶ Preparing for a change that will take a multiyear time frame to implement: Sally Haas identified that firms usually aim to finish the creation, design and implementation phases of a new retirement plan within a multi-month instead of a multiyear approach.^[B-3]
- ▶ A sufficient talent pipeline and growth of economy: With new staff readily available, employers will not be willing to adjust to an aging workforce.^[B-2]
- ▶ Lack of trust developed from their employees: Employers cannot keep on breaking their promises made to their employees when their pensions are not what they expect.^[B-2]
- ▶ Flexible determination of work term for employees: There are pre-retirees who may want to leave their corporate job and take on a nonprofit job instead.^[B-3]

4.2.1.4 Proposed Solutions for Addressing Challenges

Solutions to address the challenges stated above are far and few as these concerns are relatively new. However, symposia discussions have noted the following possible suggestions:^[B-3]

- ▶ Statistics on workforce quality should be published in financial statements by mandate. This will help investors gauge if the company has talent and potential, as well as allow companies to carry out much-needed research on their workforce.
- ▶ Legislations and regulations should be revisited and reviewed carefully and confirm they are not restricting employers when it comes to undertaking new solutions. Diversity-related laws and regulations should not end up functioning as an obstacle to learning.

To accommodate more elderly workers in the workforce, society will need to consider adopting innovative solutions that align the interests of seniors with those of their employers. Since these new designs will imply pre-retirees work longer, their expectations and preferences for work should be considered as society constructs possible solutions:

- ▶ Some pre-retirees have expressed interest in being demoted, rather than promoted, when contemplating a new position. Having spent the majority of their more recent working life in managerial positions, pre-retirees are more interested in becoming individual contributors rather than managers.^[B-2]
- ▶ A survey conducted by Sally Hass on 200 U.S. senior workers from one company found that the respondents wanted input as to what work they would be assigned. They were mainly interested in finding meaningful work.^[B-2]
- ▶ Some pre-retirees want to be able to work not just from home, but also from unconventional places such as a park or a café.^[B-3]
- ▶ Several studies have shown pre-retirees' biggest concern about retirement is not monetary; around 25 percent of pre-retirees mentioned it was to remain productive and useful.^[B-2]

1. Phased retirement

As the name suggests, phased retirement involves a gradual transition from being a full-time member of the workforce to a less participative employee and, eventually, to a retiree. These programs are relatively new and are being tested by employers. Don Fuerst notes the following four components of a phased retirement plan:^[B-3]

- ▶ Leave-of-absence program: Retirement-eligible employees can request an unpaid leave of absence for a full year, but with the commitment of returning back to employment status before they formally retire. This provides their employees with the opportunity to experience retirement and assess their level of satisfaction with the experience.
- ▶ Part-time employment program: Pre-retirees are able to request a reduced work schedule as long as they work a minimum of 20 hours a week. Vacation and sick leave are then prorated based on these hours worked, and retirement accruals are based on actual hours worked and salary that was earned.
- ▶ Casual employment: The firm can rehire retirees as needed, with the retirees retaining the flexibility to accept the return offer or not. Ideally used for surge work, this provided the firm with the benefit of rehiring ex-employees on temporary contracts who do not need to be brought up to speed or trained and can contribute immediately.
- ▶ Consulting: Retirees in very specialized and highly technical areas were hired back as consultants as needed, such as a complex project requiring knowledge from workers with decades of experience.

Anna Rappaport mentions how phased retirement is already present in many workplaces, but not through formal programs as have been advocated. A few ways informal phased retirement is seen are the following:

- ▶ Through self-employment: People who have started their own companies often do not go from running a business full-time to completely retired and removed in one step. Usually there is a gradual shift as the current owner passes the business to her/his successor.^[B-25]
- ▶ One profession that allows for flexibility and this sort of phased-retirement is nursing. This applies to any job, such as consulting, where employees can pick and choose the shifts they take and have the flexibility to scale back their hours if need be.^[B-25]

Solutions such as phased retirement help retirees not only with their financial health but also with their social health as well. Many people want to continue working not simply to bring in extra money, but because they want to maintain consistent social interaction with new and various people.^[B-39]

Companies are just beginning to explore these types of solutions. Fuerst suggests further research on how this would affect the phased retirees' eligibility for health care under the new Affordable Care Act and Social Security benefits.^[B-3]

2. Other options

The following recommendations should also be closely considered by employers:

- ▶ Flexible schedule:
 - ▶ Since people work 50+ years over their lifetime, Gary Mooney comments on how work in their elongated work years cannot be 49 weeks of work every year and only 3 weeks off.^[B-2]
 - ▶ Sally Hass noted how out of 200 interviewed pre-retirees, the majority not only wanted a reduced work schedule, but flexibility as well that allowed them to work 10 hours one week, 40 the next, none the week after and so on. In order to introduce flexible scheduling, Hass recommends for employers to change their benefit eligibility rules. For example, instead of stating pre-retirees have to work 25 hours a week, it should state they have to be scheduled to work 25 hours a week, but variations are possible and should be discussed with their manager.^[B-3]
 - ▶ Rob Brown recommends employers redefine their pension system, as current payout structures, including those of defined benefit plans, discourage flexible schedule with decreased retirement benefits.^[B-2]
 - ▶ In order to accommodate these flexible schedules, perhaps youth, whose unemployment rates remain high, can fill in the inconsistent gaps. If this approach is to be taken, software and models already exist that can handle a variety of work situations where people do not work many hours (e.g., flight crews).^[B-2]
- ▶ As adults, especially females, are retiring early due to the need to provide elder care support for their parents, companies should consider enhancing their employee assistance programs with improved elder care support benefits. Knowing their loved ones are being taken care of will allow pre-retirees to work longer.^[B-3]
- ▶ Offering long-term care insurance not only to their employees, but also for their parents.^[B-3]
- ▶ Monetary incentives, as shown by research, do not have significant effects on the retention of a worker.^[B-3]
- ▶ Providing more meaningful work to the employee and keeping in mind that "meaningful" is subjective.^[B-3]

- ▶ More flexible employment: Someone who is post-retirement age may not be able to be a police officer or firefighter, but still has the capability to work in other roles within those forces and maintain their place of employment.^[B-25]
- ▶ Employers could model Japan, where when an employee retires, the employer helps them find a second career to continue working in a different capacity.^[B-34]

4.2.2 Social Security Support for Retirement

Social benefit programs are very important to the welfare of older citizens. As population demographics change and people live to older ages, pay-as-you-go programs must be adjusted to reflect the emerging reality. Raising retirement ages is a common part of proposed adjustments. This is often politically very difficult.

Anna Rappaport, FSA, MAAA, FCA, EA, Anna Rappaport Consulting

Past trends in longevity have brought challenges to the financial health of social security and public support for retirement across multiple geographies around the globe. These challenges are only expected to continue as increasing longevity trends are forecasted to be sustained for the foreseeable future.

Most notably, the balance between retirees and non-retirees has been changing across multiple geographies due to various factors, including declining fertility and mortality rates. This is particularly evident in the U.S., where such decline occurred after baby boomers began to retire, and now presents serious financial concerns for the U.S. Social Security system. Concerns also exist regarding people's failure to properly save for retirement, as well as the quality of the public program's benefits.

Social support systems are structured very differently among countries, both in the way they are funded and in the way benefit payments are structured. Social security systems may be supplemented by other societal programs to help targeted groups of aging citizens. Many countries, both in the developed and developing world, are facing challenges as they prepare to address the impact of increasing longevity on their retirement systems.

4.2.2.1 Challenges Faced by Social Security Systems

Increasing longevity affects a fundamental balance in society—the balance between contributors (workers who provide goods and services) and beneficiaries (retirees who consume without working). Upsetting that balance by increasing the number and proportion of retirees creates a growing burden for governments that offer retirement income systems and other social supports.^{[A-20] [A-63]}

1. Societal support for retirement in developed nations

In the U.S., the historical decrease in mortality and increase in fertility have endangered the solvency of Social Security (the Old-Age, Survivors, and Disability Insurance program). The program, which began in 1935, named 65 as the normal retirement age when life expectancy at birth was 61 years and life expectancy at age 65 was 12.5 years. In the 2014 symposium, many argue the program is not sustainable now that the life expectancy at birth is 77 years and life expectancy at age 65 is 18 years.^[A-63] From 1970 to 2010, life expectancy increased by eight years, while retirement age barely changed. From 2002 to 2012, the actual retirement age remained the same.^[B-36]

Furthermore, the oldest old currently receive nearly half of their income from Social Security while only 18.3 percent comes from pensions and retirement.^[A-142] To further demonstrate the dependency on Social Security as the main source of income for many retirees, 50 percent of those 70 and older said they could easily afford an expense of \$1,000, while only 30 percent of all adults answered this way.^[B-46] Partly as a result of Social Security, the prevalence of men in the U.S. above 65 who have retired has increased from 25 percent to over 80 percent from the beginning of the 20th century to the end of the 20th century. One hundred years ago in the U.K., 7 in 10 men worked until age 65; now it is 1 in 10.^[B-25] However, there has been a recent reversal in the long-term pattern of

declining workplace presence of the retired, although the term “retired” seems more ambiguous with part-time work during retirement becoming more common.^[A-140]

In particular, Stephen Goss, Chief Actuary for the U.S. Social Security Administration, notes how a larger part of the population above age 25 will include seniors as baby boomers continue retiring until 2030. Even after baby boomers pass away, the proportion of elderly people is only expected to keep increasing. Goss notes how this higher proportion of elderly people will be the cause of the main challenges to be faced by the U.S. Social Security Administration. Figure 4.2.2-01 shows this shifting age structure on the U.S. population.^[B-8]

In Canada, long-term projections show that the country’s public retirement-income provision is currently financially sustainable. Population aging will naturally increase public pension spending, but both the rate of growth and current expected lifetime are lower than those of many OECD countries. Moreover, the earnings-related schemes (Canada/Quebec Pension Plans) have built up substantial reserves to meet these future liabilities. In contrast, private pensions, especially among low- and mid-level earners, are less than complete. While the lowest earners will achieve target replacement rates via public pensions, mid-level earners will not. While mid-level earners should be able to fill their pension gaps with voluntary retirement savings, there are still concerns about the government plan’s shortcomings.^[A-99]

This debate has implications for the most vulnerable populations—elderly women living alone experience some of the highest poverty rates in the U.S. This is troublesome, as 46 percent of women age 75 and older live alone.^[B-26] Existing financial products that can mitigate this risk are not attractive to many people. The challenge will be to develop vehicles for pooling longevity risk that will appeal to these individuals.^[A-66]

2. Adequacy of societal coverage in developed nations

There have been comparisons on the adequacy of societal coverage in the form of retirement income, health care and long-term care (LTC) across Canada, England, France, Germany, Sweden and the U.S. These countries are some of the richest in the world and have social programs in place to aid their aging populations. Although these countries provide pension income at least equal to 50 percent of general living expenses, some of these countries’ programs, namely U.S. and England, appear to be inadequate. The basis of this result is the ratio of the state pension (S.P.) in relation to general living expenses (GLE) and drug and care expenses, together making up total expenses (T.E.).^[A-141]

Figure 4.2.2-01: Adequacy of Societal Coverage for LTC

Comparison	Score	Label
S.P. < 50% GLE	0	Completely inadequate
50% GLE ≤ S.P. < 100% GLE	0.33	Somewhat inadequate
100% GLE ≤ S.P. < T.E.	0.67	Somewhat adequate
100% T.E. ≤ S.P.	1	Completely adequate

Identifier	Canada	England	France	Germany	Sweden	U.S.
C.N.	0.33	0.33	1.0	1.0	1.0	0.33
C.Y.	0.67	0.33	0.67	1.0	1.0	0.33
S.N.	0.33	0.33	1.0	0.33	0.33	0.33
S.Y.	0.67	0.33	0.67	1.0	1.0	0.33
Index score	0.5	0.33	0.84	0.84	0.84	0.33
Label	Not adequate or inadequate	Often inadequate	Mainly adequate	Mainly adequate	Mainly adequate	Often inadequate

Legend

C.N. = Couple not requiring LTC
 C.Y. = Couple with one member requiring LTC
 S.N. = Single female not requiring LTC
 S.Y. = Single female requiring LTC

In Canada, it is expected that 25 percent of those who are 65 in 2017 would be still alive in 2050. This is already the fastest growing segment. Furthermore, 5 percent of the 1950 cohort will live until 100. A problem more prevalent in Canada is smaller cohorts are now replacing larger cohorts in the workforce due to baby boomers being born in a more condensed period. This means a smaller group must support a large proportion of people in special services,

health services and pension plans. To illustrate this point, in Canada there are only 1.6 or 1.7 children per woman. This issue is perpetuated further due to immigration, where approximately 36 percent of those reaching 65 in 2015 were born outside of Canada.^[B-40]

There is also a discussion of sustainability from the perspective of the state as current adequacy is meaningless if it is not a sustainable long-term solution. An example is France, which is currently providing adequate benefits but is unlikely to be able to continue providing similar benefits even with reasonable reform.^[A-141]

3. Other nonfinancial initiatives in developed nations

There is also a global initiative to make retirees more comfortable in retirement, in a social, rather than financial, way. For example, cities can apply to the World Health Organization to be designated an “age-friendly” city. To achieve this both the community and government must be actively involved in making changes and creating a plan to offer an age-friendly environment. A great example of the success of this is in Madrid, Spain, where leadership analyzed environmental, social and economic factors that lead to active aging. This led to a group advocating to the municipality for a piece of land to build communal housing. It was an extensive process working with architects to provide a communal and private aspect for each member. In the U.S. there are various WHO age-friendly cities, including New York City. In New York there is one person designated in city government to work with each of the five boroughs to develop short-, mid- and long-term goals. Some projects that have resulted from this are plans are in place to improve street crossing and sidewalk access and add crosswalk countdown clocks in the Bronx as well as Manhattan. In Manhattan the community has also created a multilingual neighborhood resource guide.^[B-38]

Different factors that gauge how “age-friendly” a neighborhood or city is are:^[B-38]

- ▶ How the environment accommodates old people:
 - ▶ Access to community and health care
 - ▶ Effective, affordable and accessible transportation
 - ▶ Accessible and safe housing
 - ▶ Safe, inviting, welcoming and accessible outdoor spaces and buildings
- ▶ The community’s ability to engage people and forge relationships:
 - ▶ Social participation
 - ▶ Respect and social inclusion
 - ▶ Civic participation and employment
 - ▶ Communication and Information

4. Societal support for retirement in developing nations

Although the tide may be shifting, in Mexico in the recent past, there have been two main predictions for population dynamics: rapid demographic aging and continued migration to the U.S.^[A-65]

Mexico’s retirement income system is insufficient in coverage and quality of benefits. One large problem with the system is its heavy allocation of benefits to citizens least in need. Pensions mimic the country’s uneven income distribution, with the richest citizens collecting more benefits than the average citizen.^[A-65]

In recent history, Mexico transformed its pensions from defined benefits to defined contributions, hoping to provide universal coverage, job creation and income. However, it became evident that the reform has been unsuccessful, as it has failed to make significant improvements in any of those areas.^[A-65]

Census reports indicate that the Indian population has approximately tripled during the last 50 years, and the number of elderly Indians has increased more than fourfold. In addition, India is experiencing rapid urbanization, and an increasing number of women are participating in the workforce. These factors have led to the erosion of the joint family system and the emergence of nuclear families. In addition, the Indian population seems more likely to spend its financial resources on the education of its children than in its own retirement savings. Finally, unhealthy lifestyles are causing widespread tuberculosis, asthma, cancer and cardiovascular problems amongst elderly Indians, reducing their ability to work into old age. The Planning Commission of India found that approximately 92 percent of working Indians do not receive any formal old age income at retirement and are at risk of sinking below the poverty line without access to adequate post-retirement income. In response to this startling statistic, one symposia paper argues that India must make pensions more available, invite the participation of private players in the pension space, introduce need-based pension products and increase consumer awareness about retirement income.^[A-34]

Bhattacharya identified that, in India, the success of a government-sponsored retirement income system depends on two critical factors. First is the ability and willingness of the working class to make adequate savings in order to maintain the same standard of living during their old age. Second is the availability of the economic, financial and regulatory frameworks that meet the expectations of the savers by offering risk-adjusted returns. In order to encourage retirement savings, financial experts must design suitable retirement schemes for the major percentage of Indian workers that are no less attractive than any other saving instrument. The buildup of assets in these funds can be used judiciously to build up infrastructure facilities, develop debt and capital markets, arrange education, etc. The availability of better infrastructure facilities imparts a higher level of efficiency to the business entities. The inflow of large sums for a long duration would reduce the volatility of the stock markets, which are presently dominated by the foreign institutional investors (FIIs) and the speculators. The principal financial markets would then be expected to impose better corporate governance in the Indian corporate world, leading to higher risk-adjusted returns to those holding pension assets.^[A-34]

In Singapore the culture, which is reflected in government social policy, is focused on individual responsibility. Therefore, there are few programs offered through the government to help support elderly populations during retirement. Singapore attempts to push its citizens to save by requiring them to put 20 percent of their income into savings and the government then contributes 16 percent for a total of saving 36 percent of their income. Despite this large amount of savings, Singapore continues to see its elderly population lack the funds necessary to support retirement. These savings were originally meant to be used solely for retirement, but over time the types of expenses that could be paid for via these contributions continued to increase, such as for mortgage payments as well as hospitalization and medical expenses. While many are asset rich when they retire due to using this money toward mortgage payments, they are ultimately left with very little savings. As a result, a crisis remains in Singapore, where the elderly population does not have enough saved to retire.^[B-28]

It is important to note that while countries with emerging markets, like India and China, do not currently have many retirement income obligations, they must plan carefully for the future when they will. If they fail to do so, their government-sponsored programs will eventually suffer. Previous attempts at solving these types of problems, like pre-funding, will fall short because of the working class's resistance to sacrificing its own pay for the elderly. As a result, experts will need to develop innovative solutions to avoid retirement income crises.^[A-116]

4.2.2.2 Suggestions to Address Challenges Faced by Social Security Systems

1. Tying retirement eligibility age to remaining expected lifetime

Geoff Rashbrooke concludes pay-as-you-go pensions are not as financially feasible in countries with aging populations. One way to address this issue is to increase the retirement age so that eligibility for government-sponsored retirement income benefits is delayed among older populations.^[A-102]

Jacob Seigel suggests that increasing the retirement age to where an individual retiring has a life expectancy of 10 to 15 years corresponds much more closely to the survival expectancies at age 65 of the U.S. population when Social

Security was introduced than the current survival expectancy at age 65.^[A-63] This idea is also supported by changes in the type of work that we do: The current generation of elderly individuals is able to remain in the workforce for longer periods of time than were the comparable populations of 1935 who worked hard, lived hard and died at an earlier age.

The U.K. is currently attempting to implement this policy. Its intention is to review the plan every five years and adjust accordingly based on how life expectancy has changed. The goal is to have citizens draw from the U.K.'s version of social security, SPA (State Pension Act), for about one-third of their adult lifetime, with "adult lifetime" starting at age 20. They must give a 10-year notice before making the change; therefore, it will likely be a while before it is implemented.^[A-172]

However, tying general retirement eligibility age to a longevity-related factor might prove unfair and unreasonable without considering the following factors:

- ▶ People at lower income levels haven't experienced as pronounced improvements in their standard of living, health status and life expectancy.^[B-8]
- ▶ White and non-white subgroups with minor education are actually living dramatically shorter lives.^[B-2]
- ▶ Dr. Sandra Timmermann notes how the mental health and functional capability of elderly workers should also be considered. Currently, many people retire early due to health reasons. Tying retirement eligibility age to remaining expected lifetime does not necessarily imply the resulting retirement eligibility age is one where the elderly worker is still able to both physically and mentally work. Dr. Timmermann concludes there is a clear need to tie these health observations to longevity in new, innovative methods.^[B-2]

Some believe that raising the retirement age will not solve the retirement income problem, though, claiming that individuals in need of more retirement money will not be responsible enough to save adequately, even if given more working years to save.^[A-20]

2. Gradually increasing the retirement eligibility age

Brian Burnell, author of "Retirement and Retirement Ages in Canada Revisited," examined the effect of a gradual increase in retirement ages in order to attempt to maintain the "senior dependency ratio" at or close to its current level. The term "senior dependency ratio" refers to the proportion of the population at or above the customary retirement age (currently 65) to the number of people in the "working age group" (currently 18 to 64).^[A-70]

He uses the Canadian population to show that after allowing for continuing immigration at relatively high levels, the customary retirement age would need to increase to 70 by 2025 in order for this ratio to remain close to its current level. A "customary retirement age" as high as 74 may be necessary by 2050 to maintain a 20 percent senior dependency ratio.^[A-70]

In the U.S., the age for receiving full benefits under Social Security is being raised gradually from age 66 in 2009 to age 67 in 2027 in two-month increments. This increase in the age of retirement is consistent with the facts regarding historical increases in longevity.^[A-63] However, there are consequences to increasing the retirement age. It has been shown, using the U.S. system as a proxy, that extending the age of eligibility has a significantly greater adverse effect on those with low socioeconomic status. Furthermore, these results hold under arguably optimistic assumptions as to future movement in mortality rates. Only in the case of eventual convergence is there any reduction in the unfairness, and the literature discussed here is not particularly hopeful in this regard.^[A-102]

3. Phased retirement strategies

The encouragement of phased retirement programs (refer to section 4.2.1.2 for more details) is becoming a high priority for developed nations, as a vehicle for a much greater degree of flexibility in retirement arrangements in general. However, in order for fundamental changes in the provision of benefits from government-sponsored

retirement income programs to succeed, some major changes are needed in the outlook and attitude of employers and employees and to the rules and regulations that govern the operation of pension plans in Canada (for the purposes of this article) and other developed nations.^[A-70]

Historically, men have experienced a substantial long-term decline in the labor force participation at higher ages for both voluntary and involuntary reasons. This trend has recently reversed, but more time is needed to see its impact across generations. Continued changes to the status quo with reforms such as ADEA (Age Discrimination in Employment Act) and amendments to social security (increased retirement ages) will be critical in creating a sustainable retirement plan as longevity continues to expand. Alternative plans to transition from full-time work to part-time work before a total exit from the labor force are becoming more common, although often informal. This can be seen in the rising percentage of those aged 65+ who are working—13.2 percent in 2008 versus 10.4 percent in 1990 for males and 8.9 percent in 2008 versus 7.0 percent in 1990 for females.^[A-140]

4. Proposed introduction of micro-pensions in India as a retirement savings vehicle

India is undergoing a period of social change. There has been a shift away from the joint family system, leaving the increasing number of persons in old age vulnerable in the absence of a broad government retirement income system.

Author Prakash Bhattacharya postulated that India might benefit from micro-pension plans that would cover the large segment of people from the unorganized sector. A small contribution from each member into a common fund, or set of funds, would provide a measure of retirement security. At the same time, the combined contribution balance would support India's continued economic liberalization. It would generate a pool of assets that could be reinvested to generate economic growth or fund the infrastructure projects. The accumulation of a large amount of funds would be consumed as regular income in retirement. The successful outcome would be that these people may be saved from the threat of poverty during their old age, although many of them are maintaining a satisfactory standard of living during their working life.^[A-69]

5. Government-supported solutions

The U.S. government currently sells treasury inflation-protected securities that partially address the retirement income needs of retirees. Jonathan Forman notes that delaying the receipt of Social Security benefits until full retirement age or later is equivalent to purchasing an annuity from the Social Security Administration. It had been suggested for retirees in the U.S. to apply for Social Security and then suspend it, which allows you to have a higher Social Security benefit. However, there is newly implemented regulation to limit this approach.^[B-36]

It seems plausible for the government to offer starter retirement savings accounts and to issue annuities (or provide guarantees).^[A-142]

- ▶ Retirement savings accounts: U.S. Treasury could sell no-fee retirement bonds for workers to build secure retirement savings.
- ▶ Longevity bonds: U.S. Treasury could issue bonds with coupons varying by longevity relative to a certain benchmark.
- ▶ Annuities, pooled annuities and tontines: The government is in an optimal position to sell pooled annuities so that participants share in the longevity risk because they already collect data on every person who currently receives benefits.

Canada has had success with its expansion of social security, the Canada Pension Plan. This is a contributory plan, which is not fully funded, but rather has sustainable contributions. An individual earns benefits at 25 percent of earnings, and it is planned to increase this to 33.33 percent. This new tier of benefits will be fully funded. In some ways it is like a defined contribution plan. One will not receive benefits until the benefits are paid for. This helps

avoid intergenerational transfers, which is a major issue in places such as the U.S. According to a study in the U.K., Canada is one of a few OECD countries that do not have a savings gap for future generations.^[B-25]

4.2.2.3 The Implications of Longevity on Societal Support for Retirement

With the changes that longevity brings to retirement income, governments will need to re-evaluate their fiscal burdens to plan for the future. If they do not, they will simply lack the funds needed to pay benefits owed to citizens. A thorough re-evaluation that considers all institutions relevant to retirement income will be necessary.^[A-116]

So what are some of the most important changes that longevity will bring? First, if governments are unable to afford to pay retirement income benefits to an increasing number of elderly people, workers will be forced to defer retirement. Second, the economy will restructure to fit the changing needs of society. For example, with more elderly people—one of the most illness-prone groups in a population—there will be higher demand for health care services and professionals. This example reveals yet another issue—that governments will need to reassess their distribution of care because of significant, longevity-induced changes to the health care industry. There will be other political changes, too. One obvious change is the increase in elderly voters. This will lead to the emergence of more pro-elderly politicians who will push for a number of new programs or continuation of underfunded programs, like elderly-friendly entitlement programs.^[A-116]

4.2.3 Challenges for Retirement Systems

When retirement ages are fixed and life-spans increase, periods of benefit payment under [defined benefit] plans also increase. That is like a continuing plan improvement and may be one of the factors contributing to the decline of DB plans. In contrast, if retirement ages were set to reflect a period to the end of life, they would gradually increase and the value of benefits would stay about the same. I believe that if retirement benefits had been defined in that way, there would be more DB plans today. One way to deal with this gradual increase in benefits has been to switch to DC plans and avoid dealing directly with the issue.

Anna Rappaport, FSA, MAAA, FCA, EA, Anna Rappaport Consulting

Increasing longevity and lack of proactive behavior from the public has created financial security concerns for retirement systems. The shift away from defined benefit plans have led to pre-retirees being exposed to the risk of outliving one's assets, as well as risks within the financial markets. People are failing to effectively plan for retirement, in part due to lack of education regarding retirement planning and misunderstanding of retirement programs, including social security.

In response to this lack of proper retirement planning, financial advisers have heavily relied on rules of thumb to communicate more effectively with their customers. However, these rules of thumb should be used with caution as retirement needs and solutions are unique to each individual.

While looking at the issues from this perspective, it is again important to keep in mind the disproportionate burden on women in retirement because they have a longer life expectancy and at the same time typically work fewer years than men. This means they have less in retirement savings, less in social security and less pension benefits.^[B-34]

4.2.3.1 Challenges Faced by Retirement Systems

In many developed countries, the retirement world of the future is challenging because of the decline in defined-benefit plans, low savings rates in the U.S., increased longevity and the failure of many people to effectively plan for retirement. To demonstrate, only 38 percent of workers have a workplace pension, with only 24 percent having a pension in the private sector. This is split between 12 percent having defined contribution (DC) and 12 percent having defined benefit (DC).^[B-25]

People are also living longer. Life expectancy in 1900 was 47, and if someone reached age 65 they could expect to live an additional 12 years. In 1965 life expectancy increased to 70, and at age 65 longevity was expected to be an additional 15 years. Most recently, in 2000 life expectancy was 77, and at age 65 one could expect to live another 18 years.^[A-157] In Canada for 20-year-old women there is about a 60 percent chance they live to 90, and about 8 percent of Canadian men and 14 percent of Canadian women will live to 100.^[A-172] An important shift from previous years is that 58 percent of the increase of the total life expectancy for men is due to increased life expectancy at age 65. Before, much of the total life expectancy increase was due to reduction of the mortality rate at a young age. For women the same measurement is 65 percent. By 2031 these numbers are expected to increase to 69 percent for men and 76 percent for women. Overall, longevity at age 65 for women is 88.8 and for men 86.6 years.^[B-26] The financial burden has increased as the cost of living increases and as people receive more care overall and more sophisticated care.^[A-157] In prior generations planning for retirement meant planning for 10 or 15 years. Now retirement entails a much longer period, and people are struggling to adjust.^[B-39]

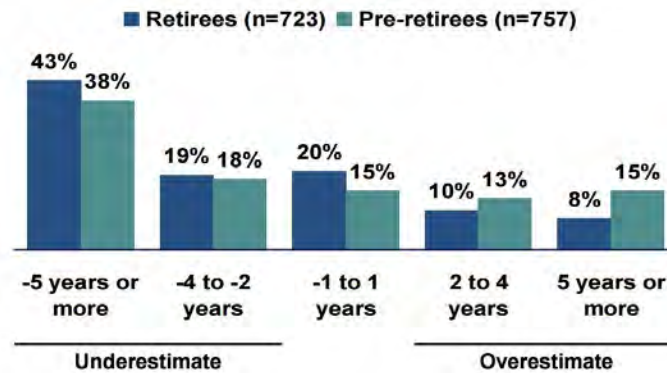
1. The employee's perspective: challenges

As the shift from defined benefit plans to defined contribution plans continues, more employees are exposed to the recently volatile markets and taking on the risk of retiring without enough money. This has raised the need for them to take initiative and start planning actively for their retirement. However, research on what the public knows about retirement and retirement planning shows significant gaps in knowledge and many misperceptions.^{[A-31] [A-97]}

- ▶ There is relatively little understanding of longevity risk. Many retirees do not recognize outliving assets as an issue.
- ▶ Pre-retirees misunderstand what their primary sources of income will be in retirement. They underestimate the importance of social security and overestimate the level of retirement resources provided by personal savings.
- ▶ Employees had assumed that their defined benefit plan would be permanent; however, as employers have cut or frozen defined benefit plans, employees have been left scrambling, trying to figure out how to afford retirement.^[B-31]
- ▶ As employers switch from defined benefit plans to more defined contribution plans, the gap between what people should save and what they actually save increases.^[A-166]
- ▶ People tend to underestimate both their out-of-pocket medical expenses and their own need for long-term care, believing that others will be more likely to incur these expenses.
- ▶ The average balance of a couple at retirement is less than \$200,000, which is far below Fidelity's estimate of out-of-pocket health care expenses for a retired couple.^[B-34]
- ▶ Even by cutting down on expenses and perhaps saving a little extra for retirement, that still does not eliminate the risks of high-cost, big-risk incidents, such as needing long-term care.^[B-31] Shock events are the largest driver of asset depletion for retirees.^[A-166]
- ▶ The number of people who think buying risk-management products, such as long-term care insurance, health insurance and annuity products, is a good idea is greater than the number of people who actually buy these products.
- ▶ While many individuals are now heavily responsible for managing their own retirement assets and planning, many have basic misunderstandings about the financial market and investment products. Their understanding of how to invest may also decline with increasing age if they have any dementia.
- ▶ Many people are forced to retire earlier than they plan to, sometimes for reasons of health, sometimes because of job loss and sometimes for other reasons.

- ▶ Robert Painter notes a study revealing that Americans have a low level of financial literacy. When surveyed, however, Americans self-rated themselves as having a high level of understanding of financial literature. This disconnection results in people not investing enough resources to their financial education.^[B-9]
- ▶ Many employees use their savings account balance as a decisive factor when determining their retirement date, instead of focusing on their prospective income during retirement.^[B-9]
- ▶ There is only a 29 percent chance that a median income household will have a positive amount of wealth at death.^[A-166]
- ▶ People are reluctant to buy an annuity for life as they believe it is a long time and they are not sure how long they will live. This creates a challenge for security at very high ages. However, they have identified their interest in protecting themselves against longevity risk.^[B-2]
- ▶ Anna Rappaport shared how, when respondents were asked to estimate the population life expectancy, the majority underestimated it. This was consistent across retirees and pre-retirees. Figure 4.2.1-02 shows the number of years respondents underestimate or overestimate population life expectancy.^[A-147]

Figure 4.2.1-02: Respondent Estimates of Population Life Expectancy



- ▶ Despite it being more advantageous to claim social security later in life, many people claim social security early and do not evaluate their options objectively. In particular, out of the oldest baby boomer population segment, currently aged 67, 85 percent had been identified to have already claimed their social security benefits, with most them having taken it when they were 62.^[B-2]
- ▶ Sixty percent of pre-retirees and retirees have admitted to not being familiar with annuity products.^[B-9]
- ▶ Many people are not exposed to saving for retirement or what saving for retirement looks like unless they have an employer-sponsored scheme. However, many people do not have access or are not given an employer-sponsored scheme, so it is necessary to find a way to reach those people.^[B-28]
- ▶ Self-employed individuals have the lowest amount of retirement savings because they are in the mindset that they will continue to work and therefore pour their resources into their business without thinking of the long term when they can no longer work.^[B-28]
- ▶ Fifty-two percent of American retirees own no investments.^[A-166]

While it is a growing issue people are retiring earlier than planned, many do not have a choice. Between the ages of 55 and 62, of those not working by 62, one in five will lose their job, one in four face a significant health decline, one in five lose a spouse and one in four ends up quitting to care for a parent.^[B-36]

Based on the listed information, it is evident people are not adequately measuring their costs in retirement. According to Fidelity, the present value of the cost to fund Medicare premiums and out-of-pocket medical expenses

for a couple age 65 in 2016 is \$260,000. This does not even include long-term care costs, which are increasingly expensive.^[B-34]

Another issue the baby boomer generation faces in retirement is the financial condition of their children and the implications of the millennial generation. In this new generation, many graduated college with debt and went through the recession, which had negative effects on earning potential. Many parents have taken on part of their child's debt, which may impact how they plan for retirement.^[B-34]

However, studies suggest there is no clear relationship between more debt and saving less for retirement. When looking at those with student debt and those without, there was no significant difference in their contributions to retirement plans. This could be explained by the fact that their student debt allowed them to get a degree, which increases earning capacity. People with student debt are still buying houses and contributing toward retirement. One explanation could be there seems to be a trend of newer generations buying fewer cars.^{B-39]}

In regard to financial security, the Stanford Center of Longevity found that today, one in three young adults is near poverty, whereas 14 years ago it was only one in four. Poverty was defined as 200 percent of the federal poverty level by their Sightlines Project.^[B-39] Some elderly want to work longer and save more; however, due to ageism in the workplace, they cannot.^[A-157]

2. The employee's perspective: financial products

Even with all of the information, selecting the best product(s) for managing an individual's retirement income is not always straightforward. The optimal strategy depends on each individual's personal situation and risk preferences, and experts do not necessarily agree on what strategy is best for a given personal profile and set of risk tolerances.^[A-106]

Broad guidelines can be established. The authors of the paper "Living to 100: Survival to Advanced Ages: Insurance Industry Implication on Retirement Planning and the Secondary Market in Insurance" used stochastic analysis to determine the optimal allocation of insurance and investment products for an individual. It was shown that the optimal solution incorporated a significant number of immediate annuity products, that a portfolio that combined insurance and investment products almost always outperformed a portfolio of strictly investment products, and that the optimal solution always included the purchase of catastrophic illness protection.^[A-52]

However, for people who have decided to purchase a specific type of product, challenges remain. Individuals choosing to buy financial products have to make trade-offs. For example, the purchase of an annuity offers a guarantee of lifetime income, but the buyer gives up control over the assets, liquidity and the potential of a bequest. Variations of annuity products offer several types of guarantees, including lifetime income, inflation protection, protection from investment risk, etc. Each type of risk protection has a price attached to it, and some of the buyers who experience the risk will make out much better because they chose the product. Other buyers will make out less well. For example, people who live very long will do better with annuities, and people who die quickly will do poorly.^[A-106]

A paper from the 2014 LT-100 symposium, "Perspectives on SOA Post-Retirement Risk Research and What It Tells About the Implications of Long Life," also shares perspectives on key issues from the middle-class lens:^[A-147]

- ▶ Most of the financial services industry focused on providing retirement advice is financially incentivized to focus on clients with greater income and wealth. As a result, there is a gap in the availability of helpful advice for much of the middle market.
- ▶ Rules of thumb are often promoted, but when taken in the wrong context can lead to costly missteps. Many misconceptions are discussed in a report issued in 2005 called "Public Misperceptions About Retirement Security."
- ▶ Lack of interest in annuitizing wealth is largely driven by a protection bias to protect their assets

- ▶ There is a lack of disability coverage, which could derail one's planned retirement security.

Robert Painter, global head of insurance and annuities at a global financial institution, noted how since insurance is commissioned more than annuities, this has led to distributors discouraging their clients from annuitizing when it might actually provide their financial stability during retirement. Although the point of sale should be the point of recurring education, the current fee structure encourages the distributor to make the point of sale the first and last interaction with the client. This contrasts from other commission structures, such as in Australia where advisers get paid when they follow-up with their client every two years.^[B-9]

3. The employee's perspective: savings

David Blanchett noted that in the U.S., utility is maximized by planning savings and consumption such that lifetime consumption is as smooth as possible. Therefore, it is critical to determine an appropriate estimate of the total amount of savings required to fund retirement, which is often not easy. For additional details, please see section 4.2.3.2.^[A-124]

Despite numerous informative presentations to 401(k) plan participants, one company found they consistently failed to transfer the importance of current issues with financial planning. The participants, who recognized the existence of the issues, expected their financial advisers to fix them. The investment firm also concluded the success of target dated funds can be attributed to lack of interest from the public in understanding equities; they prefer products which they do not have to learn as much financial literature and can divert their attention elsewhere, which is an essential feature within target dated funds.^[B-9]

As modern-day employees are busy with competing priorities, society has taken the approach of simplifying knowledge for their convenient consumption and not relying on employees' proactiveness. Consequently, there are detrimental effects to this approach:

- ▶ Financial rules of thumb (e.g., 4 percent rule) have been created in order to simplify the time-consuming retirement planning process. However, many employees take this as a golden rule and fail to recognize this generalization does not apply to the entire population and can vary across individuals. It is still optimal for them to perform self-assessments and determine their own needs and solutions.^[B-9]
- ▶ Automatic enrollment in 401(k), as well as target-date retirement funds, has given employees the false impression that their retirements are taken care of.^[B-3]
- ▶ Despite all the consequences that come with simplifying retirement solutions, considering 80 percent of the population is probably never going to get a financial planner, the need for these simplifying approaches exists and is better than having none at all. For example, the 4 percent rule can quickly put things into perspective for an employee with no motivation to invest time in retirement planning. This is perhaps the best way to penetrate the general, non-proactive population.^[B-9]

Finally, individuals seeking advice or buying financial products need to be careful about fraud. There are many scams and people seeking to defraud older people who are trying to manage their money. Many people show they do not consider or are not concerned about the possibility of fraud or being taken advantage of financially as they enter retirement. However, 17 percent of Americans 65 and older have been victimized via inappropriate investments, unreasonably high fees for financial services or outright fraud.^[A-166] It is important to be careful that the advisor is focused on your interests and is not simply focused on the product with the highest commission or fee.^[A-106]

Many people do not realize the intangible benefits work offers them. In a survey, most pre-retirees said the thing they would miss most about retirement was a steady paycheck. However, when asking retirees what they actually miss most about working, it was the social connections. This is a key issue: keeping people engaged beyond retirement. One way to maintain this level of social engagement into retirement is by designing work in community environments, such as volunteering. One research supports an idea that being socially isolated is about the same morbidity and mortality risk as smoking and twice the risk as obesity. Mortality is 2.3 times greater for men with

smaller networks and 2.8 times greater for women. Social connections range from your spouse or partner to family to organizations and clubs.^[B-39]

4. The employer's perspective

It is very difficult for individuals preparing for retirement to decide how to structure their financial portfolio to best protect themselves from outliving their assets. It is just as difficult to compare products across carriers as there is very little consistency in mortality assumptions from carrier to carrier. The more accurate information that we can circulate on mortality and longevity, the better decisions people can make.

Inconsistencies between how an individual views their own mortality and how an insurance company views the mortality of a similar group of individuals can greatly influence decision-making. Overestimating—or more commonly underestimating—life expectancy can lead an individual to make inferior decisions.

Scott Witt, FSA, MAAA, a fee-only insurance advisor

Flexibility from employers to undertake innovative approaches is fairly limited, mainly due to potential lawsuits arising from current legislations.^[B-9]

- ▶ U.S. pensions are subject to extensive regulation that limits plan sponsor options and can create complexity. The Employee Retirement Income Security Act and other legislation sets forth a number of requirements designed to protect the interests of employees. When requirements are ambiguous or where the environment is changing, the combination of legislation, regulations and potential for litigation serves as a barrier to innovation.
- ▶ Benefit plans are sponsored by employers, including businesses, not-for-profits and public sector entities. Benefits are designed to support the human resources philosophy of the organization and its need to attract and retain the employees needed for the organization. While some employers use innovative benefits to support their employment proposition, many do not. For a large number of U.S. employers today, changes are implemented as required and only to the extent necessary. They prefer to follow others and not take risks with regard to regulatory penalties and legislation.
- ▶ Although it is possible to involve annuities in defined contribution plans, the steps required from the employer to implement this change are numerous and complex. This process needs to be automated.
- ▶ Flexibility given to employers on innovative retirement strategies has proven successful in the past. For instance, employers' transition from mutual funds to target dated funds was undertaken only when the Department of Labor announced it will grant employers legal protection against lawsuits if they move to a more target dated balance approach.

Other challenges faced by employers include:^[B-3]

- ▶ Spiking abuses in retirement benefits: As retirement income from defined benefit plans is determined from an employee's salary in the person's last working years, there is the risk of employees working excessive overtime in order to have this additional pay counted into the average.
- ▶ Dominance from finance departments when it comes to crucial decision-making: Haig Nalbantian noted how companies' decision to move away from defined benefit plans is influenced mainly by feedback from finance. He also recommends employers to be careful in not allowing human capital management decisions to be influenced extensively by any sole department.
- ▶ Shift from DB plans to DC plans: Although the shift from defined benefit plans to defined contribution plans has reduced the volatility of employers' financial statements, this benefit does not come without its negative consequences. As this shift starts exposing more employees to the volatile markets, pre-retirees become concerned with leaving the firm and not having enough money. As a result, they end up staying

and decreasing the number of promotions and lateral moves available to younger employees. Consequently, the low number of open positions will hurt companies that rely on “built-talent-from-within” strategy, as statistical modeling has shown high-potential, high-performing people will be more likely to exit the organization if they encounter these choke points. Young talent will leave, and then when these temporary senior workers leave, the company will lack both talent and experience.

As the population ages, the labor force will also age. While there has been relatively little adaption to major changes in life-spans over the past 100 years, the authors’ view is that these changes in life-spans and the changes in population age mix will require much greater changes in the years to come.

4.2.3.2 Suggestions to Address Challenges Faced by Retirement Systems

1. Address challenges with individual actions

There are several ways that Americans can enhance their futures in retirement. They include:

- ▶ Retirement and retirement savings plan designs that recognize that people need help in saving for retirement. Within the context of defined contribution plans, features such as automatic enrollment, sound default investment options, and automatic provisions to direct pay increase the savings plan. These default options will address the need to build assets for retirement, but not the need to manage funds after retirement.^[A-31]
- ▶ Increased education and supporting research to facilitate that program designs are effective. It is important that this education covers management of investments and withdrawals in the distribution phase.^[A-31]
- ▶ Maintaining an appropriate level of employer contributions to retirement programs whether they are defined benefit or defined contribution.^[A-31]
- ▶ Guaranteeing that social security provides a sound basic layer of benefit. The studies discussed here reinforce the importance of social security and the need to moderate reliance on individual efforts.^[A-31]
- ▶ Not claiming social security benefits early but claiming them later instead and consequently receiving a higher income stream. This relates to how a retirement age of 62 is still being considered among the majority of the U.S. population. The public should start considering retiring later than the age 62 as both a possibility and a strong recommendation.^[B-2]
- ▶ Supporting the integration of phased retirement strategies into employer-sponsored benefit plans.^[A-70]
- ▶ Correctly estimate the total amount of savings required to fund retirement. Currently, the common approach is to first apply a generic replacement rate to pre-retirement income, such as 80 percent, to get the desired retirement income need. That need is assumed to increase annually at the rate of inflation for the duration of the retirement, which is generally assumed to be a fixed period, such as 30 years. In the study “Estimating the True Cost of Retirement,” David Blanchett argues how the assumption that growing retirement needs can be estimated linearly with inflation is not the best. It is important to not oversimplify the projected post-retirement expenses. In particular, Blanchett notes that:^[A-124]
 - ▶ While a replacement rate between 70 and 80 percent may be a reasonable starting place for most households, the actual overall replacement rate can vary considerably, from under 54 percent to over 87 percent depending on the level of pre-retirement household income and expenses that discontinue after retirement.
 - ▶ Real retiree expenditures are not constant and do not rise in nominal terms simply as a function of inflation. The retirement consumption path will be a function of the household-specific consumption basket as well as total consumption and funding levels.

- ▶ Households not consuming retirement funds optimally will tend to adjust them during the retirement period.
- ▶ While many retirement income models use a fixed time period (e.g., 30 years) to estimate the duration of retirement, modeling the cost over the expected lifetime of the household and incorporating the actual spending curve can result in a required account balance at retirement that can be significantly less than the amount required using traditional models.
- ▶ Assuming a constant expenditure level after retirement is too conservative; a more accurate model would show post-retirement consumption decrease. Blanchett's Monte Carlo simulation model then goes on to predict a target savings rate that is up to 25 percent lower than traditional models.
- ▶ It is noted how current models for retirement expenditure, which typically assume a simple target replacement rate, do not account for pre-retirement income increasing with age throughout a person's work life.
- ▶ Written commitment for increasing their financial contribution for the next year. Christine Fahlund identified employees as unwilling to increase their contribution for the current year due to perceived affordability issues, yet they were willing to do it for the upcoming year.^[B-9]
- ▶ Manage or review retirement fund and financial situation regularly, preferably at least once a month.^[B-39]
- ▶ Focusing on income needed during retirement as opposed to accumulating a meaningless number by the start of retirement with little understanding as to what retirement income quantity is actually implied by that number.^[B-9]
- ▶ Becoming more accountable as employees start allocating more money into defined contribution plans and individual retirement accounts.^[B-9]
- ▶ Speaking with a financial adviser:^[B-9]
 - ▶ Only 28 percent of consumers without an adviser feel they are prepared for retirement. In contrast, consumers engaged with an adviser are two to three times more likely to express their retirement preparedness.
 - ▶ Retirees have been found to be very short-term focused, considering only what is going to impact them today. Since advisers focus on long-term issues (health care and longevity), they can complement retirees' current perspective and provide for a more thorough approach to retirement planning.
 - ▶ Due to differing time horizon perspectives between advisers and retirees, it is vital for advisers to first address the short-term issues before engaging in the ensuing long-term discussion.
- ▶ Do not assume asset depletion is the only way to deal with a financial shock and discuss with a financial adviser before making the decision to drain assets. Investigate other possibilities such as a reverse mortgage.^[B-36]
- ▶ Letting employers know there are solutions for incorporating annuity options into defined contribution plans. Anna Rappaport comments on how there does exist a guide for employers on how to incorporate annuity options, annuitization and income into defined contribution plans.^[B-2]
- ▶ Retire later. In a simulation done by Vickie Bajtelsmit, her analysis suggests that by delaying retirement merely four years to 70, instead of 66, people will need about one-third less saved by the age of 66 to be 90 percent confident they will be able to afford all their post-retirement expenses.^[B-31]

- ▶ Either downsize or get a reverse mortgage. This could reduce the amount needed in savings by age 66 by \$50,000 and \$130,000.^[B-31]
- ▶ Prioritize retirement over helping family members, for example, a child’s college fund. Rather than saving to pay 100 percent of college expenses, save to cover 75 percent and put the rest of what would go into the college fund into retirement savings:^[B-31]
 - ▶ If parents do take out loans for their children, try refinancing loans for better, lower interest rates or plan to have a majority, if not all, of the loan paid off prior to retiring.
- ▶ Minimize high-interest-rate debt by getting rid of it before retirement or in early retirement.^[B-31]
- ▶ Have protection in place for temporary loss of income, whether that be something such as disability income insurance before retirement or having an emergency fund.^[B-31]
- ▶ Begin planning for “shocks” or unexpected, large expenses, such as housing repairs, dental costs or becoming widowed during retirement. This will reduce stress during retirement when these shocks do occur. More than 10 percent of those who experience a shock reduce their spending by more than 50 percent.^[A-166]
- ▶ If investing, do not invest in equities with funds needed in the next five to seven years.^[B-31]
- ▶ Ensure fixed expenses in retirement are covered by fixed assets, defined benefit pensions and social security. Do not invest money in risky investments and depend on that to pay for expenses you know will continue throughout retirement.^[B-36]
- ▶ Spend less now and do not wait until retirement, especially for moderate- to higher-income households, because individuals can retire successfully with 20 percent less saved by cutting their expenses by 15 percent.^[A-166]
- ▶ While studies show much of the population is able to absorb unexpected costs during retirement by cutting expenses or re-mortgaging their house through either a forward mortgage or a reverse mortgage, there are three expenses retirees inadequately plan for and cannot merely absorb through these cost-saving and revenue-producing methods:^[A-166]
 - ▶ Long-term care needs
 - ▶ An adult child with mental illness or other condition preventing them from working
 - ▶ Getting divorced in retirement
- ▶ Maintain flexibility of financial capital throughout retirement and explore different ways to make illiquid financial capital assets liquid.^[B-36]
- ▶ People are not saving enough but are finding different ways to generate income in retirement.^[B-40]
- ▶ Apply the Actuaries Longevity Illustrator, which helps estimate life expectancy:^[B-35]
 - ▶ Available to everyone for free
 - ▶ Does not give you an exact age, but rather a likely range
 - ▶ Offers joint life expectancy for couples planning for retirement
 - ▶ Offers probability of living to a specific age
 - ▶ Gives chances of survival in single and joint lifetime

- ▶ Gives probability of living a certain number of years

2. Address challenges by U.S. government

The U.S. government could also consider the following to address the challenges faced by retirement systems:

- ▶ There is a need for introducing a broader set of guaranteed products (including annuities) into the defined contribution space. This requires the government to recognize its benefits from a social perspective and expand the Pension Protection Act as a result. In particular, the government has to heavily limit sponsors' liabilities if they incorporate guaranteed products in their portfolio.^[B-9]
- ▶ New regulations and infrastructure should be implemented that require the public to contribute to their retirement:^[B-9]
 - ▶ In particular, Australia's superannuation system requires a certain portion of wages paid by the employer to go into externally managed trusts which people can choose from. With the current contribution rate being 9–10 percent of income, soon to be 12 percent, these funds cannot be accessed until age 60.
 - ▶ Australia also has essentially aligned adviser incentives with their clients as there is no up-front fee for consultation; advisers get paid when they contact their client every two years. This discourages advisers from constructing client solutions that give them the best commission and may not be the most optimal for the client's needs.
- ▶ The Financial Industry Regulatory Authority (FINRA) has to review its legislation on information disclosure. Christine Fahlund notes how when one firm adopted the Monte Carlo approach for stochastic simulation on investment returns for more accurate results, FINRA required the firm to provide a full, lengthy disclosure on Monte Carlo's incorporation, as most people do not know this mathematical approach. However, the firm was not required to provide any disclosure if it assumed a constant return on investments, which is unrealistic.^[B-9]

3. Address challenges by private sectors

Members of the private sector could also consider the following to push people to save more for retirement and address the challenges faced by retirement systems:^[B-28]

- ▶ Provide the correct incentives for the population to save:
 - ▶ Introduce prize-linked savings: While various banks and credit unions already offer these, more companies offering this kind of saving will provide further incentive for people to save leading up to retirement.
 - ▶ Advertise the dangers of not saving enough: While many companies have attempted to glamorize saving through different ad campaigns, the best way to get people to save may be to demonstrate what could happen if they do not save enough.
- ▶ People typically go about planning their retirement in two ways. Financial advisers will ask what a retiree expects their costs to be, then works with the retiree on how to save enough to cover costs. However, the more frequently used approach is for an adviser to analyze a pre-retiree's income and assets and discuss what the person can realistically save.^[B-36]
- ▶ There is an inequality that must be addressed between those who are financially illiterate and not saving enough and those who are well off and can afford management services.^[B-40]

- ▶ From an employer perspective, it is in the best interest of companies to get their employees thinking about and saving correctly for retirement. If people are not financially prepared for retirement, then they will have to wait longer to retire. This can negatively impact a company's productivity because they now have someone in a role they do not want to be in as they may be mentally ready to retire but simply do not have the funds. Thus, the company must forgo hiring a new employee who is excited about the role.^[B-39]
- ▶ Studies show women drive 70–80 percent of all purchases and make up 85 percent of all consumer purchases (purchases for daily living). Furthermore, women purchase about 60 percent of new cars and influence about 85 percent of auto decisions. They also play a significant role in health care decisions, such as insurance provider and health care provider, and are more likely to spend more time as the sole financial decision-maker. Even with all this purchasing power, there are still not enough resources and solutions geared toward helping women in retirement as they must make less money last longer.
- ▶ The private sector should take note and drive more products toward older single women because it will benefit them as well.^[B-34] To demonstrate the negative impact not doing so can have, the Retirement Income Industry Association (RIIA) reports 65 percent of women go to a different financial planner when their husband passes away because financial planners focus on the husband and do not listen to or consider the wife's needs. It is in private companies' best interest to prioritize women more to retain business better and provide better overall service.^[B-36]

For product innovations from the private industry to address challenges within the retirement systems, please see section 4.2.6.

Ultimately, if consumers cannot be encouraged to engage in further self-education over retirement planning, the need is then created for the government, private sector and public sector to find ways to better educate consumers.

4.2.4 Challenges for Long-Term Care Systems

As people age, many will need long-term care. With greater numbers of older people living longer, the demand for long-term care will certainly increase. Long-term care is provided and financed by a combination of personal, public and private programs with very different solutions in different countries. There are many unresolved problems in the U.S., with few people having good plans for financing long-term care in place. In addition, these programs are proving very costly for governments and insurers to support. As a result of the poor experience to date and uncertain, but projected continuing high future costs, there are fewer and fewer risk transfer vehicles available as time passes. The result is that more and more of the cost burden is shifting to the individual and, by extension, to the Medicaid program. This is not sustainable for the long term given the current and projected state and federal budget deficits.

Loretta Jacobs, FSA, MAAA

There are products and approaches for managing LTC costs that are available to individuals outside of government programs, in particular, LTC insurance and continuing care retirement communities. The costs of these options can be greatly reduced to the extent that care can be provided at home by family members and friends. In the U.S., Medicaid programs pay for some LTC costs for many people without assets or income. However, as Medicaid programs are funded by a combination of federal and state funds, they are under severe financial pressures.

It is difficult for governments to offer LTC programs as well due to concerns over how to optimize the program and be fair to the public at the same time. Furthermore, the U.S. insurance industry is experiencing substantial challenges offering LTC insurance due to higher claims and lower investment returns than assumed in the original pricing. This has led to poor financial experience and multiple rounds of rate increases throughout the industry.

Most developed countries are currently showing the signs of an aging population. One sign is an increasing number of seniors, some of whom are becoming less able to perform the activities of daily living (ADLs) or the instrumental

activities of daily living (IADLs), often because of cognitive decline or dementia. Surveys indicate that many respondents are concerned about the potential costs of LTC and believe that the government should help individuals cover LTC costs.^[A-78]

Approximately 133 million people in the U.S. are living with at least one chronic condition that could eventually lead to requiring long-term care; therefore, the need to amend long-term care systems' challenges is imperative.^[B-31] The average age to move into assisted living is 85, and the average age in assisted living is 87.^[B-26] Death from dementia and Alzheimer's has become more prevalent over the last decade. The U.K. has seen an increase in deaths due to dementia and Alzheimer's, with those diseases combined being the number one cause of death for males 75+ and the second highest cause of death for women 75 and older.^[A-172]

There is a comorbidity between loneliness and long-term disability or illness. This is alarming because one-third of Americans 65 and older live alone, while half of those 85 and older do. A study in Canada found that married beneficiaries tend to live longer and the impact of marital status outweighs that of income level. While researchers found that those with higher income tend to live longer, men who are married and have low-income typically outlive men who are single, but have a high income, by nearly a year. Similar results were found for women as well.^[A-172] Only 20 percent of people in the U.S. live in a home where they are married and have children.^[B-39]

There is a growing need for solutions to address the challenges described in the following sections. Common themes include facilitating the aging of the population at home and encouraging informal support networks within communities. LTC challenges for the public can be greatly alleviated if people are informed and educated on their long-term care options and how to effectively manage the risks.

4.2.4.1 Challenges for Long-Term Care Systems

Considering that 70 percent of people age 65 will one day have some long-term care need that they will have to pay for, it is vital for the government and private sector to collaborate on more innovative and affordable products for the benefit of society.^[B-6]

1. Challenges for the public

It is challenging for individuals in the U.S. to choose and afford the right set of products that best suits their situation.

Confidence in U.S. insurance companies with regards to LTC has been shaken due to insurers having difficulty in producing accurate assumptions when pricing their LTC products. Higher-than-expected claim costs, coupled with persistently low interest rates, has led to multiple premium rate increases on their LTC products.^[B-6]

In addition to choosing a product that optimally fits the individual's need, the buyer needs to be concerned about the financial strength of the company selling the product and how much experience the company has with this line of business. All of these products require payment of benefits far into the future. As a result, it is common to see insurance companies selling off LTC blocks of business.^[A-106]

Within the U.S., there will be a higher demand for home care workers as women, the traditional home care workers for their families, continue to make up a larger part of the workforce. According to the AARP, there is approximately \$500 billion in uncompensated caregiving in the U.S.^[B-25] In addition, Generation X is not large enough to take care of the baby boomer generation, which will reach their 80s by the mid-21st century. The Alliance for Healthcare Reform is projecting 10–12 million direct care workers will be needed in the next 10 years.^[B-6] An AARP article written in 2013 predicted a caregiver support ratio problem, projecting out to 2030. In 2013 there were 7 people between ages 46 and 64 who were available to care for the 80 and older population. However, by 2030 the AARP predicted this would decrease to 4 people. Some countries are already seeing a shortage. These are areas popular for retirement where people are moving in their old age, but their families and younger generations are not moving with them.^[B-26]

Currently only 10 percent of long-term care provided in the market is paid for with private long-term care insurance, with most being provided on an informal basis by family and friends. This demonstrates further the need to develop adequate programs for long-term care.^[A-166] In 2016 the median cost of assisted living in the U.S. was \$44,000 per year, and by 2020 it is projected that cost will increase to \$51,000 per year.^[B-26]

Primary residences and their associated equity have the potential of funding an entire retirement through reverse mortgages in the U.S. However, there exist concerns that as boomers continue aging, the number of homes up for sale may far outpace the number of homes being bought. Consequently, real estate prices may decrease, with studies predicting a loss of about a third of home equity for individuals. The value of home equity also depends greatly on the economy, such as what happened during the 2008 financial crisis.^[B-6]

2. Challenges for the government

Creating a viable program is a difficult task. In the U.S., Congress created the Community Living Assistance Services and Supports (CLASS) Act to relieve financial strain on Medicaid LTC and to provide more in-home care for the elderly. However, because of easy access to other social programs, like Medicaid, which provide similar benefits, CLASS was not able to be structured as its proponents originally expected.^[A-80] Demonstrating the difficulty of establishing a viable program, CLASS was repealed in 2013.

Affordability of LTC products for middle income families continues to be an issue as the market is faced with high-deductible health plans implying \$12,700 of family out-of-pocket costs. The median net worth of Americans 75 and older, including home equity, is \$156,000. Therefore, they are not moving into assisted living facilities because they cannot afford it. This problem will be amplified with baby boomers since currently their median age retirement portfolio is \$136,000.^[B-26] Based on a study from the Canadian Life and Health Insurance Association, the cost to provide long-term care for baby boomers until death, based on current government programs, will be about \$1.2 trillion Canadian. About half of this will actually be covered by government programs. The remaining \$600 billion will have to come from the individual. This figure, \$600 billion, represents 94 percent of all individual registered savings plans in Canada, meaning 94 percent of what the Canadian market has saved for retirement would solely go toward long-term care to cover all the expected costs.^[B-31] Considering 70 percent of people age 65 will one day have some long-term care need that they will have to pay for, it is vital for the government and private sector to collaborate on more affordable products for societal benefit.^[B-6]

With regard to social programs, governments are faced with the challenge of not being able to distinguish taxpayer from each another. This has led to the implementation of one-size-fits-all social programs, which are not necessarily the optimal approach for taxpayers.^[B-6]

The U.K. has seen misuse of current health care resources as a result of offering no support for social care costs, such as long-term care. Many elderly who should be in long-term care facilities often end up in hospitals and receiving care there because these costs are covered under government programs. The result is people are not receiving the appropriate care needed. If the government offers social care expense benefits, then people who are currently staying home to take care of their parents or other elderly family member will use government coverage to put that person in a long-term care facility, which will cause health care costs in the U.K. to skyrocket.^[B-25]

3. Challenges for the private sector

As people prefer to stay at home and receive home health care or rely on technologies to provide at-home care, coupled with the large cost of long-term care, soon the U.S. will see a surplus of long-term care facilities.^[B-34]

With innovations making it easier for people to “age in place,” the private sectors, health care providers, LTC operator and LTC insurers now face the issue of whether or not this is necessarily a good thing. Many people refuse to move out of their homes and into long-term care facilities, even if it is in their best interest to do so. Some have aired concern that by providing benefits and services making people comfortable longer in their homes, they are then pushed even more to believe they do not need assisted care or to move to a facility. However, this is a

personal issue and difficult for companies themselves to address. Therefore, companies are now having to balance what is truly in the best interest of the policyholders.^[B-34]

4.2.4.2 Suggestions to Address Challenges Faced by Long-Term Care Systems

1. Individuals

Within the U.S., the hospitalization and health care cost of seniors falling has been projected to reach \$55 billion by 2020. Falls are mainly attributed to lack of accessible bathrooms in seniors' homes. For those approaching retirement, it is recommended for them to make home modifications (e.g., stair lift, handrails) early on, as opposed to doing it later on in retirement when it might not be financially feasible. Cindy Hounsell also found that, out of those who sold their homes, the happiest seniors were those who gave up their homes by choice instead of being forcibly removed due to not being able to meet their financial obligations.^[B-4]

If retirees are having trouble meeting their financial obligations in the U.S., the following should be considered:^[B-6]

- ▶ Move in and live with their offspring
- ▶ Secure a reverse mortgage and use the payments to supplement their pension
- ▶ Sell their primary residence and move into active adult qualified housing, which would cost less than the sold property, and could use the extra proceeds to supplement their income

Informal support networks are an option for those who cannot financially afford long-term care for their loved ones but are willing to exchange time and favors with each other. Coordinating between neighbors and friends for quick favors when they are not around is one possibility. Another is participating in a time bank system where they exchange hours of service with each other.^[B-4]

Use more sharing-economy services if they cannot afford in-home caregiving. Cost analysis shows that using these services, rather than paying for assisted living, is cheaper, especially for the more frail and with the additional care an individual needs. However, an issue to overcome is access. These services require smartphone access and must be deliverable to where the person is.^[B-34]

2. Government

In the United Kingdom, a substantial portion of the senior population may need long-term care protection. A mandatory (social) insurance program, financed by the government, may do well to protect the population from LTC-related financial problems. Over the next 40 years, a 10 percent increase in tax revenue could cover long-term care costs in the United Kingdom, assuming conservative projections into the future.^[A-78]

Most of the U.S. population are not aware of the difficulty associated with becoming eligible for Medicaid and, thus, do not invest as much time into retirement planning, as they are under the impression of Medicaid being a fail-safe. The U.S. government needs to inform the population on the difficulty of becoming eligible for Medicaid.^[B-6]

Since two out of every three seniors buy Medigap coverage when they enroll in Medicare, the government should consider placing long-term care insurance coverage in a similar Medigap-type product. In comparison, only 5 percent of the public buys long-term care insurance. However, since 80 percent of the elderly receive home health care informally by family, it should also be considered how this percentage will be impacted by the addition of long-term care insurance.^[B-6]

The U.S. government could explore programs that encourage people to age at home, which, in turn, saves the government money from offering government-subsidized housing. An example is Medicaid Cash and Counseling, a program that provides cash assistance, which is then used on care providers of the retiree's choice.^[B-2]

One direction of the change in the long-term care market is to attempt to address the price problem by offering a smaller basket of benefits. There are two approaches. One is the short-term care policy. The other is combining the long-term care with Medicare supplement insurance. The state of Minnesota and the Bipartisan Policy Center looked at the second approach.^[B-31]

Medicaid's financial burden on the government has the potential to be reduced. Legislation exists within Texas and other states that requires Medicaid applicants, prior to their enrollment confirmation, to sell their life insurance in order to help finance their own long-term care needs.^[B-6]

The U.S. government could also consider implementing federal legislation that mandates adult children to take care of their parents if they need care. Having been already implemented in Pennsylvania and other states, it would pose a relief to the increasing demand for home care workers.^[B-6] Another way the U.S. government could promote adult children taking care of their parents is by providing tax credits to home care workers.^[B-28] To help address those who are forced to drop out of the workforce and therefore lose social security credit, the government could give those people social security credit for their uncompensated care.^[B-25]

3. Private sector

If aging at home becomes strongly encouraged among retirees, this will create new jobs such as home modelers and case managers. The private sector should be ready to fill in these jobs as the demand will be inevitably created if the baby boomers decide to age at home. In addition to a broader range of services available for seniors, business competition will also drive down prices.^[B-2]

As 9 in 10 people want to live in their homes for as long as possible, the need remains for innovations from the private sector that facilitate aging at home. With 80 percent of elderly wanting services right in their home, the demand for innovative products, such as self-taken blood pressure tests, is higher than ever.^[B-4] In 2015 and 2016, \$200 million in venture capital investment went to tech-enabled home care. This demonstrates the private sector's interest in helping develop this kind of care.^[B-26]

The private sector has introduced technology-enabled products, such as artificial intelligence and geolocation portable devices, to aid people in their care at home.

4. People

The more services backed by big brands that can replace where an in-home caregiver would be hired, the easier aging might be.^[B-34]

A developing interest in the U.S. LTC industry is the opportunity for collaboration between the private sector and the government. If the private sector offered a combination of products that includes long-term care, it could get a broader range of people to buy this bundled product and hopefully achieve a lower cost per person.^[B-31] Governments could subsidize lower-income individuals and support informal home care programs.^[B-6]

For solutions regarding affordable housing options, see section 4.2.6.

4.2.5 Challenges for Health Care Systems

As the population ages, they need more medical care. At the same time, medical research is leading to new technologies and opportunities for improved care. A great deal more surgery is feasible on an outpatient basis, and smaller and handheld devices are making diagnostic equipment more accessible and portable. New drugs are also helping many people. We need to seek out ways to make medical care more efficient as we capitalize on these developments.

Anna Rappaport, FSA, MAAA, FCA, EA, Anna Rappaport Consulting

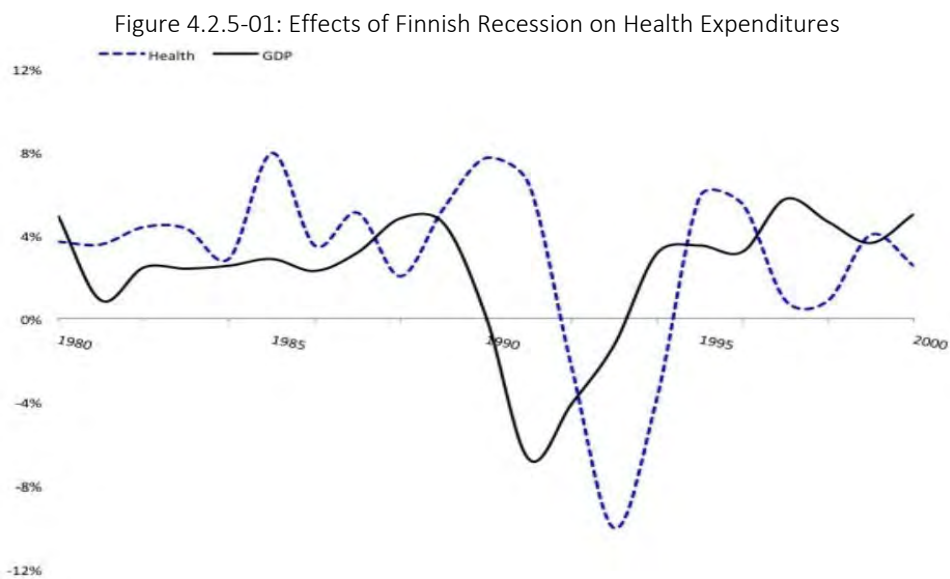
Before the Affordable Care Act (ACA), 25 percent of those not covered under Medicaid or Medicare simply went without health coverage.^[B-32] When looking at health insurance coverage over the past few decades, there was a gradual decline in coverage until 2014.^[B-39] As the ACA was introduced and the issue of access was addressed, cost is now a larger and more pressing issue.^[B-32] Health care expenditures increase faster than the consumer price index, making up a larger portion of the gross domestic product (GDP) each year.^[A-157] In the 1960s, health care was about 5 percent of overall GDP, and by 2008 costs had risen to 16 percent of GDP.^[B-36]

The changing age structure in industrialized countries is raising concern among policymakers over the funding of Social Security programs, including health care. The aging of the population has worried governments about increases in public spending on health care. Furthermore, longer life-spans will have large health care implications and, in particular, a higher cost to society.^[A-32]

According to the research of one author, the U.S. is shown to lead all other industrialized nations in the share of economic output devoted to health care. In 2007, approximately \$2.25 trillion—one-sixth of America’s GDP and more than the entire economy of all other countries save Japan and Germany—was spent on this endeavor. By one account, over 90 percent was spent on treating illness and less than 10 percent on preventive care.^[A-47]

Within the U.S., there is a need for providing health care at a reasonable cost to the public as some can’t afford the high deductibles in their plans. There is a clear need for optimizing the use of funds and coverage for different socioeconomic groups.^[B-6]

It should also be noted that in one reported study there exists a lag between the variance in total economic activity and health care activity. This is evident in Finnish studies where a correlation between a three-year moving average GDP and health expenditures lagged by two years. Figure 4.2.5-01 illustrates this lag for a past Finnish recession. One of the main causes for such lags is the complex and cumbersome systems by which medical care is financed.^[A-150]



4.2.5.1 Challenges for Health Care Systems

In the United Kingdom, population aging raises some difficult questions about the ability of health care systems to achieve their objectives: Can satisfactory care be delivered at a reasonable cost, can the health of the population be protected and maintained, and can access to health care and opportunities for a long and healthy life be accessible equitably?^[A-119]

Given the growing size of health care expenses, a debate around the allocation of resources between health care and other priorities also exists. The question exists as to whether it is better to pay more for improvements in health care as science and technology help make them available or to apply those resources to public goods of equal or greater importance that require us to limit health care expenditures—or at least to limit public expenditures, if not also private.^[A-119]

There is currently a self-intensifying process. Cost of living is increasing, and health care is evolving with new medical technology. This then leads to higher health care costs and increased longevity, which in turn leads to higher national health spending and more retirement years to provide for. In the 50 years prior to 2010, health costs increased 8.4 percent annually in the U.S. while the cost of living increased by only 4.1 percent. This means there is a residual 4.2 percent of growth in health care costs unexplained by inflation.^[A-157]

To quantify the increase in health care costs, the author of “What if Mortality Was to Diminish Much More than Was Forecast? Implications for Financing Social Security” looked to Canada and, in particular, the province of Quebec where the age effect is evident when comparing various components of per capita public spending. In 2003, public per capita spending on social security represented less than \$5,000 Canadian for people under age 55 (excluding education) and rose sharply to over \$25,000 for people aged 85 and over. In the latter group, health care and social services costs represented 65 percent of total public spending on social security, compared with 25 percent for the 65 to 69 age group.^[A-32]

With the very presence of a health care system, utilization will increase, therefore increasing expenses as well. For example, if a person had 18 physical therapy sessions covered by Medicare or Medicaid, would that person take advantage of all 18 sessions allowed? Or would the person only use the two sessions he/she felt necessary? Furthermore, with few providers in this space, their prices can remain high. Within the ACA, Americans require the approval of a gatekeeper to confirm they actually need these services; however, this is an additional cost. Other regulations and services enhance quality but are nonetheless costly.^[B-46]

Polypharmacy, when someone takes five or more prescription drugs permanently, has drastically increased for people 75 and older. While this is not necessarily bad, since these drugs help individuals live longer, it is extremely costly.^[B-39] The drug market is essentially unrestrained, which causes problems with drug prices.^[A-17]

The following are major drivers of increase in health care costs:^[A-157]

- ▶ Mental health diagnoses and treatments have to be covered by insurers, which are some of the most expensive treatments.
- ▶ There is an increase in use of MRI, PET and CT scans, which are complex and have a high unit cost in the U.S.
- ▶ Newborn coverage is increasing in cost.
- ▶ Diabetes testing and treatment, such as the price of insulin, are more expensive.
- ▶ Diagnostic and screening tools continue to increase.

Another demonstration of struggles with increasing health care costs is the private sector. Daniel Bailey explains how many companies invested money into collecting data on policyholders to determine which were profitable and which groups were most expensive. Certain states had community ratings for large group HMOs, for example, and with time many of the employer plans eventually switched to being self-funded. Today about half of U.S. health care is funded through self-funding.^[B-32]

In addition, an increasing shortage of doctors and nurses in Canada may lead to a change in government policy, for example, allowing doctors to practice across disciplines, easing licensing for immigrants in certain professions and changing the delivery method for services (public versus private, inpatient versus outpatient). In addition, research is needed to assess the social and economic benefits of preventative care as a means to relieve pressure on the

existing health care systems. Lastly, these are challenges not unique to the developed world; therefore, it will be important to determine how best practices and efficiencies that emerge from developed countries will be cascaded most effectively to developing countries.^[A-110]

Numerous studies—both those presented at the symposia and elsewhere—have associated lower mortality beyond age 50 with possible reductions in health care costs because medical interventions at the end of life are usually more costly for young people who receive treatment with the most advanced technology. Still, even with an aging population, governments must anticipate a future increase in health care spending because home care and LTC costs will drive health care costs up as an increasing number of elderly people demand them. However, the increase in health care costs should be significantly lower than the increase due strictly to the increase in the number of elderly people and general population aging.^[A-32]

Given this context, it is important to examine the consequences of changes in cohort size and lower mortality when financing social security with pay-as-you-go systems, a managing mode favored by governments. Population aging will accelerate soon, resulting in a heavier burden on the working population, which has to foot the bill.^[A-32]

The level of an individual's healthiness, unlike death, is difficult measure. Even if questions are standardized across the population such that relativeness of answers is possible, there is still a lack of consistency across answers. James Vaupel highlighted how men assess themselves at a higher health level than women, yet males have a lower life expectancy than females. This type of inconsistency exists not only across gender, but also across countries and cultures.^[B-1]

Increased health expenditures do not necessarily imply a poorer quality of health. Vaupel noted how increased health expenditures can be observed if the population experiences a lower mortality rate; these additional individuals who are "saved" then contribute to higher health costs through their needed pacemakers and artificial limbs to survive, which would result in less deceased people but higher health costs.^[B-1] This trend was also noted by Stephen Goss, Chief Actuary for the U.S. Social Security Administration. He explains that for Medicare and Medicaid in both 2003 and 2009, there was a spike in the percent of GDP they made up, and in those same years there was a notable decrease in mortality. While this relationship may not be causal or related, it may be worth further analysis.^[A-172]

Similarly, increased government expenditure on health care does not imply an improved population health. Rob Brown states how increased spending on health care implies the government is cutting back on other social services that provide health and income equality. These reduced services would then be main drivers for a decrease in the life expectancy of those affected.^[B-2]

Trying to predict health care costs and their growth has proven to be extremely difficult. As Stephen Goss recalls, in a panel discussion at an earlier symposium, there were discussions to set a growth rate for health care costs that was equal to GDP growth rate plus 1 percent. However, it was quickly realized this was not feasible because eventually health care costs would be at a growth rate equal to 100 percent of GDP. However, no alternatives were agreed upon, and they stayed with projecting Medicare costs at a growth rate of GDP-plus-one for several years, which Goss argues makes no sense.^[B-32]

There is a need for optimizing use of funds and coverage for differing socioeconomic groups in the U.S. In particular, the poor have been identified by Steve Schoonveld as not being able to afford the \$12,000 out-of-pocket cost required under the Affordable Care Act for certain health conditions.^[B-6]

4.2.5.2 Suggestions to Address Challenges for Health Care Systems

One thing that has worked in limiting health care costs in the U.S. with the ACA is the sustainable growth rate (SGR) formula, which limits the increases in physician payments to a relationship with GDP. Putting more research into what the best SGR is could help to better estimate what the cost of health care will be as well as limit it.^[B-32]

Health expectancy, or the expected future healthy lifetime, may be a resource for doctors and other health care professionals in providing useful information on the future health needs of a population. It may also be a useful resource to help individuals think about planning for future needs and product developers think about financing products. Health expectancy technology allows meaningful calculations to be done for any combination of age, gender and ailment. For example, in the paper “Health Expectancy,” the authors use this information to develop incidence rates to predict the need for assisted living and skilled nursing facilities.^[A-115]

In addition, health expectancy technology can also be used to counsel seniors. In particular, the authors make the following observations:^[A-115]

- ▶ Healthy periods are generally far longer than expected by the subjects, even where ailments exist.
- ▶ Healthy periods are generally about the same for males and females, but unhealthy periods are longer for females than for males.
- ▶ Health expectancy at ages 90 and 95 continues to be very favorable for seniors. Even at 95, the healthy period ahead is 2.50 years for males and 2.42 years for females.

This information can help the elderly make informed decisions about housing, their ability to continue to drive, their ability to continue to work, and the likelihood of their need for “assisted living” and “skilled care.” Such information also may encourage healthy habits, as alternate calculations can show the effects of losing weight, quitting smoking, medical treatments, improving socioeconomic conditions, etc.^[A-115]

The following studies are aimed at increasing healthy life-spans, not necessarily increasing longevity, but rather delaying the effects of aging. Both emphasize that the last two years of life are where the highest health care expenditures are seen by a significant amount. Furthermore, they argue that current medical practice treats one disease at a time, rather than looking broadly and attempting to treat an overall problem. These studies provide both explanations and possible solutions by treating old age as the underlying problem to all the other chronic diseases that typically come with old age.

- ▶ Dr. Nir Barzilai^[A-173]
Metformin is the first-line medication for the treatment of type 2 diabetes. The hypothesis is that you can target aging as a mechanism for diseases, and targeting aging will delay diseases and other phenotypes associated with aging. He also argues that metformin is the best tool to target the effects of aging because it is generic, safe and cheap and is currently being used regularly.

The first impacts of metformin were seen in treating type 2 diabetes and other chronic conditions. After age 60 the number of people with three or more diseases increases exponentially. Typically in old age one does not have simply one chronic condition. A person gets one disease, treats it, then soon after, another disease occurs and is treated, and the cycle goes on. Metformin has been shown to delay type 2 diabetes as well as cardiovascular disease with a 30 percent effect. People who have type 2 diabetes and take metformin have 30 percent less incidence of cancer. When looking at four different groups, people with type 2 diabetes taking sulphonylurea, people with type 2 diabetes taking metformin, people with type 2 diabetes taking neither drug and people without type 2 diabetes, those who had diabetes and were taking metformin showed 17 percent less mortality, even compared to those who were completely healthy.

Ultimately, Dr. Barzilai found that metformin was effective in delaying the diseases associated with aging. The next steps are working with the FDA to approve this as a sort of treatment for aging and then, it is hoped, get pharmaceutical companies to put research and development into metformin.

- ▶ Dr. Judith Campisi^[A-174]
As mentioned previously in this summary, Dr. Campisi found that a biological process called senescence drives aging in older life. In early life it helps to prevent mutations from developing into cancer, but in older age it drives old-age diseases. Senescence causes inflammation, which is a hallmark of aging tissue; can

destroy tissue; and disrupt normal tissue function. Chronic inflammation damages immune cells, and the phenotypes secreted by senescence cause the cells around to lose their function as well. All aging diseases are caused or exacerbated by chronic inflammation.

The struggle is how to address this newfound discovery because it is also shown in early life that senescence has positive impacts.

A more policy-focused solution that has been proposed to address increasing costs is block grants. Under this policy each state would be given money and would then determine how to administer health care to the state's people. At first, states would receive the same amount as now; however, the amount each state receives would likely decrease over time. This is how Canada operates, where each province is responsible for delivering health care to that province.^[B-25]

4.2.6 Innovation Within the Private Industry

Although the 2014 symposium focused more on social adaptations to longevity, views and ideas are limited. The views noted below may not be consistent with each other as this section aims to be a compilation of the perspectives presented. Unless otherwise specified, all views described below are within the U.S. context.

As society continues to appraise longevity risk, higher health and retirement costs, and changing population demographics, both individual consumers and corporations will look towards the private industry to find innovative solutions that meet their evolving needs.

With rising innovation and technology, the private industry can allow retirees to have a better, more comfortable retirement. One example is ride-sharing services. Not only can seniors use this service, but they can participate. Twenty-five percent of a major ride-sharing company's drivers are retirement age. Throughout this discussion social isolation and loneliness have come up multiple times, and participating in a service such as ride-sharing could be a new way for seniors to stay connected.^[B-39]

Prospective insurance policyholders have been identified to want flexible, affordable products with guaranteed income. Furthermore, they also want insurance products that can effectively manage longevity risk and remove the risk of outliving one's assets. Employers are also readily participating in pension de-risking for removing longevity risk from their pension obligations. Mortality indices are a possibility as well for transferring longevity risk to the financial markets.

Actuaries, the traditional risk managers of the insurance industry, will be tasked with creating such innovations. This will require significant forecasting improvements to involve emerging longevity trends and predictors (see section 4.1), the impact of medical breakthroughs, and potential epidemics.

However, this innovation process is hindered by possible lawsuits arising from strict legislations and regulations. Furthermore, financial advisors in the U.S. may not act in their client's best interest due to current compensation structures.

4.2.6.1 Innovative Housing and Accessibility

As people age, they become increasingly more dependent on others for care and assistance if they choose to do so at home. Consequently, housing programs to facilitate the aging-at-home process are needed. The following innovative housing designs for seniors have been identified:

- ▶ Continuing care retirement communities: These include communities with housing and sometimes community centers, specially designed and constructed for elderly residents. As of the 2014 symposium, there were 1,900 continuing care retirement communities across the U.S., with 80 percent of these being nonprofit sponsored. The stable and predictable monthly fees provide the residents with housing, easy access to caregivers, low maintenance lifestyles and other readily available services (e.g., groceries, dining,

medical needs, elderly activities, transportation). In addition to giving seniors their independence away from becoming a burden on their families, it also provides social interaction between seniors that, according to a study, significantly increased their life-spans relative to those with limited social interaction.^[B-9]

- ▶ Universal design communities: These architect-designed community centers feature products and environments accessible to senior residents. The designs are constructed using funds from the senior communities in the area and benefit from the services offered by the community center.^[B-4]
- ▶ Home modifications: Hardware and home improvement stores can make it easier for people to find and purchase accessories, such as a bath rail, to modify their homes to be more conducive for the elderly. This way people renovating their homes can implement those accommodations prior to entering old age, allowing them to stay in their home once they do.^[B-28]
- ▶ Village model: This national community-based membership model draws on volunteers and community resources for supporting the aging at home of the community's elderly. The members of the community determine what services they will periodically pay for, which are then shared by all members (e.g., meals, home modifications, medical needs, elderly activities, transportation).^{[B-2] [B-38]}
- ▶ Co-housing: This is a community of homes for seniors gathered around a shared space.^[B-4]

The AARP describes its initiative, the AARP Network of Age-Friendly Communities, as livable communities. This is an affiliate of the WHO's Age-Friendly Cities and Communities Program, which designs tools to share best practices and develops helpful tools so communities can evaluate their livability and strive for changes.^[B-38]

Previously mentioned was a community built in Spain geared toward the elderly. The result was a neighborhood with communal dining rooms, communal garden, living room, meeting rooms and even an adult playground. Private companies should follow this path in creating living spaces specifically for older populations. An architectural firm in Nevada specializes in cohousing and has developed 60 projects across the U.S. as well as one in New Zealand.^[B-38]

- ▶ Adult playgrounds: Companies, or even the government, should look into the benefit of adult playgrounds. One issue facing society is not exercising enough, and adult playgrounds have shown to be an effective way to get people outside and moving. They are popular in Europe, South America and Asia, but have little traction in the U.S.^[B-38]

There's also been innovation around increasing the accessibility of buildings for seniors. Cindy Hounsell noted how in the past, making buildings accessible to seniors involved rewiring the entire building to install lifesaving supports. Hounsell expects the retrofitting of old buildings with wireless technology, a more economical method, will be possible within the next two decades.^[B-4]

4.2.6.2 Innovative Insurance Products

As consumer demand continually changes in today's fast-paced world, the private industry has the opportunity to capitalize on emerging markets and capture customers of tomorrow with beneficial solutions for their needs.

Nigel Nunoo, investment senior vice president of a U.S. life insurance company, noted how defined benefit and defined contribution plans present business opportunities for the aging population. Longevity risk in defined benefit plans are better managed by insurance companies, while defined contributions generally lack guarantees that can be provided by insurers.^[B-4]

1. Concerns and needs of consumers

In constructing products and strategies for consumers, the private industry has to study its customers carefully and identify their concerns and needs. These include:

- ▶ Desire for guaranteed products: Consumers are afraid of products without principal protection:
 - ▶ Most life annuities purchased by consumers include guaranteed payments between 10 and 20 years. In comparison, only 12 percent want a pure life annuity with the highest payout, and an even lower portion wanted an annuity with cost of living/consumer price index increase adjusted payments.^[B-9]
 - ▶ Downside protection could be offered in case of severe market crashes.^[B-4]
 - ▶ Guaranteed lifetime income could be offered while still giving policyholders the opportunity to have growth in their portfolios.^[B-4]
- ▶ Products middle-income families can afford.^[B-6]
- ▶ Flexible premium options: This is particularly important if trying to target younger populations with products mainly meant for elderly populations, such as long-term care insurance. Younger populations will be targeted more effectively if given flexible premium schedules.^[B-6]
- ▶ Products without unexpected modifications during the policy's life: For example, LTC products have experienced more premium rate increases than policyholders were expecting.^[B-6]
- ▶ Products that take away uncertainty in how long consumers need their retirement income until death. In particular, products that start paying at a high age (i.e., 85) are desirable as policyholders will know with more certainty how long their money has to last. For example, a retiree at age 65 who purchases a product that starts paying sufficient payments at age 85 will know the leftover income from the purchase only has to last 20 years.^[B-9]
- ▶ No-claim policies: If a policyholder does not incur a claim in a given year, rather than giving back part of the premium paid, no-claim policies allow the policyholder to use that premium amount towards self-care activities.^[B-28]

2. Annuity products

The private sector will also need to identify what types of products the general public understands and is familiar with as opposed to what new products might be confusing and discouraging customers from purchasing them, even if they are more beneficial than existing products.^[B-6]

In particular, the following should be considered for annuity products:

- ▶ The average age of immediate annuity buyers is 73, while younger buyers in their late 50s usually opted for the variable annuity with a guaranteed lifetime withdrawal benefit attached to it.^[B-9]
- ▶ Joseph Montminy identified 75 percent of income annuity purchasers are satisfied, with five out of six purchasers willing to recommend the annuity product to a friend or family member.^[B-9]
- ▶ The top reason for buying an annuity product is to supplement social security income or pension income. The purchasers' main concern was to fill the gap created by the difference from their income payments and expenses.^[B-9]
- ▶ According to Montminy, survey results suggests the market potential for guaranteed lifetime income products may be as high as \$650 billion.^[B-9]

- ▶ Enhanced annuities are popular in U.K. and trying to be introduced in Canada.^[B-34] Enhanced annuity provides benefit payments adjusted to lifestyle factors such as smoking or being overweight.
- ▶ Other annuity products insurers could start to explore and advertise more so people are actually buying them would be products such as impaired annuities and longevity annuities.^[B-31]

3. Potential innovative products

Items created (or to be created) by insurers include:

- ▶ Combination life or annuity and long-term care insurance: In any given scenario, the policyholder will receive one of the following: death benefit, long-term care benefit or cash value of the policy. This is ideal for middle-income families who can afford it and enjoy it due to its dual purpose.^[B-6]
- ▶ Unfamiliar products disguised as familiar products: Having noticed their consumers understand health care products much more than long-term care products, one insurer constructed its long-term care product to resemble a health care product to obtain consumers' trust and their purchase of the product.^[B-6]
- ▶ Tontines: Popular in the 17th century, tontines were an annuity-type product that offered a lifetime of income that would increase as other members of the tontine pool died off and their money was distributed to survivors. This would effectively pass on longevity risk to the participants. In the study "Optimal Retirement Tontines for the 21st Century: With Reference to Mortality Derivatives in 1963," Moshe Milevsky and Thomas Salisbury argue the following:^[A-126]
 - ▶ A tontine provides the infrastructure for policyholders to pool their individual longevity risks without guarantees. It also allows policyholders to use their own self-assessment of personal health for a possible information advantage when choosing the optimal product structure.
 - ▶ Depending on a policyholder's risk aversion, a modern tontine may actually be a better choice than a fixed annuity. However, more research still has to be done, such as product design and the optimal age to purchase a tontine.

In addition, Kai Kaufhold noted how re-launching this product should take into account the mortality variances across different socioeconomic groups. Since tontines let policyholders retain the longevity risk, it is important from both a regulatory and a consumer-protection point of view to account for uncertainties in the best-estimate mortality assumptions.^[B-10]

- ▶ Deeply deferred annuities: This would include annuities with a payout period that begins at an advanced age past retirement (i.e., 85).^[B-9]

Targeted at defined contribution participants, these annuities can be bought to cover all expenses past the advanced age. This significantly reduces longevity risk as now the policyholder's main concern is managing the money remaining from the purchase until the payments start.
- ▶ Pension de-risking: Companies managing their employees' defined benefit portfolios are seeking solutions to avoid volatile financial statements in unstable markets while still committing to their promise. Actuaries are being recognized as able to effectively manage the liability risk of defined benefits, including contingencies around the benefit, participant behavior, salary increases, inflation risk and longevity risk. This is particularly important when life expectancy has increased 20 to 30 percent for males and females over the past 30 years.^[B-4] In response, the insurance industry has created the following products for de-risking the sponsor's pension plan:^[A-140]
 - ▶ Buy-ins: The pension plan assets and the plan itself remain on the balance sheet, but the longevity, financial and demographic risk is transferred to the insurer using annuities. Essentially, the plan

sponsor has its variable pension plan assets replaced by fixed asset amounts determined by the insurer.

- ▶ Buy-outs: Insurers take a single premium up front from the plan sponsor in exchange for the insurer taking full responsibility of meeting the pension plan's future obligations. This removes the plan from the sponsor's balance sheet.
- ▶ Longevity swap: Longevity risk is transferred to the insurer by exchanging a fixed set of payments for actual pension benefit payments. Q-forwards in particular transfer payments based on the realized mortality rate. The plan remains on the balance sheet.
- ▶ Mortality indices: The emergence of longevity risk as an asset class has been slow, mainly due to the lack of transparency for investors and hedgers alike. The authors of "The CBD Mortality Indices: Modeling and Applications" proposed a model-based mortality index framework, akin to the implied volatility indices (VIX) on the Chicago Board of Options Exchange, as a solution. In particular, they consider the original CBD model that possesses the key criteria of being invariant with respect to new data and able to represent the varying-age pattern of mortality improvements. This criteria creates its potential to enhance the transparency and intuitiveness of mortality to investors and, consequently, facilitates the introduction of longevity-type derivatives.^[A-125] ^[B-10]
- ▶ Additional benefit for older insurer: One insurer provided a benefit that acknowledges the fact that as someone gets older, it takes more time for them to recover from a car accident. Policyholders have access to pool of \$2,500 to use on services, such as a cleaning person for the house, not covered under health insurance but may be necessary as the policyholder recovers at an older age from an accident.^[B-34]
- ▶ Driving evaluation after car accident: When a policyholder is in a car accident, one comprehensive driving evaluation conducted by an occupational therapist is covered under their plan. The insurance company does not see the results, but it reduces cost for the company as well as for the individual.^[B-34]
- ▶ Replacement-plus coverage: One major insurer has introduced a new product called replacement-plus coverage. This applies to policyholders who have experienced a loss in their home and have to rebuild that portion, such as a bathroom or kitchen. This innovative benefit allows people to pull from a pool of money to build a universal design, such as wider door frames or a side-by-side refrigerator. The purpose is to create a home people can stay in longer and to provide reasons for policyholders to start thinking about retirement and older age.^[B-34]

As the effects of longevity continue to unfold and the social implications become clearer, consumers will look to the private industry to formulate innovative solutions.

4.2.6.3 Challenges Posed by Legislation and Regulations

One of the main challenges with creating new, innovative products is ensuring they follow government legislations. This creates a number of barriers and obstacles for the private industry to overcome, which introduces the need for governments to revise their legislations alongside the private industry and identify how to optimally serve today's society.

1. U.S. regulations on defined contribution plans

U.S. regulations include a variety of barriers for innovative products in the defined contribution context.^[B-9]

- ▶ Harrison Weaver suggested a small amount from employees' paychecks be automatically invested into a longevity insurance contract. By having employees estimate their desired retirement income, actuaries can calculate how much money needs to be withdrawn from each paycheck to meet these future payments. However, the Pension Protection Act does not allow this type of model. In addition, current tax

implications have required minimum distributions in qualified money, meaning retirees are obliged by law to start withdrawing by age 70. This defeats the purpose of a longevity insurance contract.

- ▶ Expansion of the Pension Protection Act, as suggested by Robert Painter, would be required to introduce a broader set of guaranteed products into the defined contribution space. As of 2012, annuities made up less than 1.2 percent of the total asset distributions for 401(k)s. Currently, sponsors including guaranteed products in their employees' plans take on liabilities associated with their inclusion. To have more guaranteed products in the defined contribution area, Painter recommended the government limit sponsors' liabilities associated with their inclusion. Otherwise, sponsors have no incentive to take on this non-revenue-generating liability.
- ▶ The current steps required by employers to include annuities in their defined contribution plans has been labeled by Painter as numerous and complex. The process needs to be automated, which will consequently encourage more sponsors to include these beneficial products into their plans.

2. U.S. regulations on financial advisers

The Department of Labor (DOL) has adjusted the fiduciary rule to include financial planners, which could negatively impact access to these advisers for the middle-class citizen (please refer to the post-meeting update below). By categorizing financial planners as fiduciaries, much more time must be put into simply selling someone an annuity, for example. Along with this comes higher costs. With the amount of time that would be required for compliance-related tasks, cost of doing business and additional adviser compensation, the mass market client will no longer have access to these financial advisers. This is working against the overall initiative to get more people to a financial planner leading up to and throughout retirement.^[B-36]

(Post-meeting update: The current administration delayed the full implementation of the rules to July 1, 2019. In the meantime, as of June 21, 2018, the U.S. 5th Circuit Court of Appeals officially vacated the rule.)

3. Lack of objective risk classification

Some laws and regulations do not allow for insurance companies to distinguish between ethnic mortalities or, in some states, by gender. Rob Brown stated how this restriction, coupled with differing longevity trends among ethnicities and genders, can introduce inaccurate liability projections for insurers and, consequently, high pricing in order to try to mitigate probability of a loss. To be able to price annuities correctly and attract more demand, especially for deeply deferred annuities, objective risk classification needs to be allowed. Brown also commented on how the UK has developed a large profitable market through allowing risk classification.^[B-8]

4.2.6.4 Other Challenges Within the Private Industry

1. Distribution channels

There has been a consensus at the symposiums over how the current compensation structure in U.S. can discourage brokers and financial agents from acting in their clients' best interest in order to maximize their own commission. For example, Harrison Weaver comments on how longevity insurance contracts give agents a larger commission than annuities, except for index annuities; an index annuity sale can retrieve twice as large a commission due to it being a heavily commissioned product. Weaver concludes how the current compensation structure can lead financial agents to not recommending the right products for their clients.^[B-9]

2. Solvency of pension plans

With respect to the potential insolvency of pension plans, Sally Hass comments on how employees are leaning more towards lump-sum payouts from their pension plans as opposed to an annuity. In fear of their pension plans going

insolvent, employees are opting more for an option where they avoid that possibility. Consequently, Hass believes these lump sums are not being annuitized when they should be.^[B-2]

3. Correct customer service

Jodi Olshevski shares her experience with challenges and successes in how to engage with customers who are 50 and older. She explains how many people have an inherent bias when speaking to this population and details trainings her company offers to address that bias. All companies in the private sector could use these practices and continuously build their employees' skills in interacting with an elderly population. One big issue that customer service representatives, particularly in the insurance industry, may face is interaction with customer after they have had a major loss. These are things such as losing a spouse or divorce, and the customer must adjust their insurance plan accordingly. It is imperative the private sector continues to train and educate employees on how to best manage these situations.^[B-34]

4. Technological implications

Many times, technological developments are not adopted as well as originally thought. For example, *Mobile Health News* predicted that in 2018 many elderly would adopt wearable devices. However, the devices are largely abandoned. People will adopt only what they feel truly enhances quality of life.^[B-26]

Innovations such as self-driving cars, while potentially beneficial, also cause new issues. The hope with this new technology is it will make it easier to be older. If someone is uncomfortable driving at night or at all, that person can still be able to go grocery shopping and get around without needing someone else to drive. This could lower costs and increase general safety on the roads. However, this is the hope, and the path to getting there has many kinks to sort out. One major issue for insurance companies is if there is an accident with a self-driving car, who is held liable? Larger complications are issues such as what age is too young for someone to be in a self-driving car alone? What if, in old age, someone has access to a self-driving car but faces functionality issues preventing that person from walking to and from the car? These are just a few questions the private sector will need to address as technology continues to develop.^[B-34]

Along the same note, safety is a major concern for many and a significant barrier to the acceptance of new apps and innovations for the elderly community. Services provided such as ride-sharing, homestays and dog sitting, different ways people can expend their human capital using what they already have, may not be as useful or applicable to the current generation of retirees. People, especially older generations, are not as comfortable trusting strangers to drive them or to stay in their home (Airbnb), for example. Therefore, safety concern in general is a significant challenge to the private sector, because while some services could lead to an easier retirement, the retirees do not trust the methodology.^[B-36]

Moreover, the assumption is made when promoting these products to retirees that all older people have access to and are interested in the internet and technology. However, 40 percent of those over age 65 have not used the internet in the past year. In 2000, 93 percent of people 75 and older did not have access to the internet, according to Pew. In 2015 that decreased to just 50 percent. So while access and usage of the internet can change, there is still the assumption that people maintain their same cognitive functions as they grow older. This is not the case, as seen by the fact that at age 85, 20–40 percent of people have some sort of cognitive issue.^[B-36]

Using technology to replace human contact in elder care runs the risk of increasing loneliness and isolation with elders.^[B-38] But it also offers the ability to make connections. There is a concern that new technology is isolating and will be detrimental. However, the same was feared about TV 20 years ago and about radio three generations ago. The internet offers a place for people to create connections otherwise not feasible. They can engage with like-minded people of similar interests. This then does the opposite of creating a lonely and isolating environment.

Employers can also help with this by getting their employees involved in volunteer activities before they retire. Studies show that people who volunteer while they are working are much more likely to continue to volunteer in

retirement. Volunteering is a key way retirees can maintain social connections and avoid social isolation and loneliness.^[B-39]

4.2.6.5 Resources for Elderly

1. Nonprofit

- ▶ WISER
The Women’s Institute for Secure Retirement helps women better plan and prepare for retirement. One of WISER’s most important projects is the National Resource Center on Women and Retirement Planning, which is funded by the U.S. Administration on Aging.^[B-28]
- ▶ International Longevity Center (ILC)—Singapore
There are 17 ILC locations, including London; however, they are all slightly different. In Singapore, the ILC is part of a foundation that provides direct services to older people in the community.^[B-28]
- ▶ Self-Care on Health for Older People (SCOPE)
This program was piloted in Singapore from 2011 to 2013, and after its success the Ministry of Health adopted it and now includes it as one of the National Seniors Health Programme. The best outcome from the test pilot was increasing self-health groups created among those who attended the program, who then make changes in their health-seeking behavior.^[B-28]
- ▶ Medicare Rights Center
This service, which is a nonprofit and not operated by the government, offers counseling, advocacy, educational programs and public policy initiatives to make sure everyone is able to have affordable and accessible health care.^[B-28]

2. Government

- ▶ Eldercare Locator
This program helps people find resources for caregiving services for their parent or grandparent who may be living far away . It includes a website and help line where people are then given a social service agency in their area to help get them the care they need because they are unable to be there immediately.^[B-28]

4.2.7 Relevant Symposia Materials

For additional information on the topics discussed in this section, please see the following papers.

Appendix reference	Paper
A-20	Living to 100 and Beyond: Implications of Longer Life Spans https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-rappaport.pdf
A-31	High-Age Implications of Postretirement Risks https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xvii.pdf
A-32	What if Mortality Was to Diminish Much More Than Was Forecast? Implications for Financing Social Security https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-iv.pdf
A-34	Implications of an Aging Population in India: Challenges and Opportunities https://www.soa.org/essay-monographs/2005-living-to-100/m-li05-1-iii.pdf

Appendix reference	Paper
A-47	Health, Wealth and Wisdom—Living Long, Living Well: An Actuary Muses on Longevity https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-cowell.pdf
A-52	Living to 100: Survival to Advanced Ages: Insurance Industry Implication on Retirement Planning and the Secondary Market in Insurance https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5a-ranasinghe.pdf
A-63	Typology and Review of Measures of Human Aging, Longevity and Superlongevity, With Applications to U.S. Data and Some Implications for U.S. Public Programs https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4b-siegel.pdf
A-65	Economic Sustainability of Retirement Pensions in Mexico: Is There a Link With the Mexican-Origin Population in the United States? https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2a-chande.pdf
A-66	Evaluation of Approaches to Reducing Women’s Longevity Risks https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-3b-orth.pdf
A-69	Micro Pension Plan: Indian Perspective https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1b-bhattacharya.pdf
A-70	Retirement and Retirement Ages in Canada Revisited https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1b-burnell.pdf
A-78	Is Long-Term Care Social Insurance Affordable in Developed Countries? https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-andrews.pdf
A-80	The CLASS Act and the Future of Long-Term Care Financing https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-moses.pdf
A-97	How to Survive Living to 100: Ways to Improve the U.S. Retirement System https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4a-orth.pdf
A-99	Pension Reform in Canada in Canada—An Actuarial Perspective https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4a-brown.pdf
A-102	Is Raising the Age of Eligibility Fair to All? An Investigation of Socio-Economic Differences in Mortality Using Population Data https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g5-rashbrooke.pdf
A-105	Living to 100: Challenges and Opportunities for Employers https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5a-billings.pdf
A-106	Risk Management Issues for Individuals with Special Emphasis for Women https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5a-rappaport.pdf
A-110	Will There Be Enough Doctors, Nurses and Hospitals for Our Aging Populations? https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g6-discuss-transcript.pdf
A-115	Health Expectancy https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-albert.pdf
A-116	Summary of Panel Discussion on Implications of Increasing Life Spans for the Private Sector

Appendix reference	Paper
	https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxviii..pdf
A-119	Health Policy Challenges of Population Aging: Perspectives from the Oxford Institute of Ageing https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-key-howse-discuss-transcript.pdf
A-124	Estimating the True Cost of Retirement https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-blanchett.pdf
A-125	The CBD Mortality Indexes: Modeling and Applications https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-chan.pdf
A-126	Optimal Retirement Tontines for the 21st century: With Reference to Mortality Derivatives in 1693 https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-milevsky.pdf
A-140	How Well Have Retirement Systems Adapted to Longer Life? https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-rappaport.pdf
A-141	Mapping the Adequacy of Care and Support for the Elderly in Developed Countries https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-andrews.pdf
A-142	Supporting the Oldest Old: The Role of Social Insurance, Pensions and Financial Products https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-forman.pdf
A-146	Living to 100: Socioeconomic Implications of Increased Longevity https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-gorvett.pdf
A-150	Modeling Medical Cost Trends for Advancing Age in the Long Run https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-getzen.pdf
A-157	Health Technology, Health Care Cost, Longevity and Retirement Security: A Dynamic Upward Spiral and Challenge to Future Policy https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-bailey-paper.pdf
A-166	Financial Shocks, Unexpected Expenses and Financial Experiences of Older Americans (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-rappaport-paper.pdf
A-172	Mortality Projections from a Social Security Panel https://www.youtube.com/watch?v=CmnO5kPber8&t=2s
A-173	How to Die Young at a Very Old Age https://youtu.be/p0JqXXFWCzQ
A-174	Suppressing Aging and Extending Longevity: Will the Twain Meet? https://youtu.be/Beax-wE4gsA
B-1	The Advancing Frontier of Human Survival (informal discussion transcript) https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1-soa-informal-discussant.pdf

Appendix reference	Paper
B-2	<p>Perspectives and Implications to Stakeholders of Increasing Longevity (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1c-soa-informal-discussion.pdf</p>
B-3	<p>Developing a Winning Strategy to Address the Good, the Bad and the Wrinkled of Our Aging Workforce (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2c-soa-informal-discussion.pdf</p>
B-4	<p>Innovative Business Solutions to Respond to the Aging Society (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2-soa-informal-discussant.pdf</p>
B-5	<p>Data Sources and Projection Methods for Successfully Supporting the Needs of the Senior Market (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3c-discussion.pdf</p>
B-6	<p>Proactive Strategies for Managing Long-Term Care Needs in Retirement (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4c-soa-informal-discussion.pdf</p>
B-7	<p>Could Moses Live to Be 120? (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4-soa-informal-discussant.pdf</p>
B-8	<p>Mortality Projections From a Social Security Perspective (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf</p>
B-9	<p>Leaving Worries Behind: Risk Management Strategies for Individuals to Address the Economic Issues Related to Increased Longevity (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5c-discussion.pdf</p>
B-10	<p>Discussant comments for session: Innovative Retirement Products</p> <p>https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-kaufhold-discussant.pdf</p>
B-25	<p>Impact of Aging: Biggest Current Policy Challenges from the UK/US/Canada as a Result of Aging (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1c-transcript.pdf</p>
B-26	<p>Drivers of Future Mortality (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2a-transcript.pdf</p>
B-28	<p>Impact of Aging: What Can Individuals and the Private Sector Do to Address the Challenges Resulting from Aging? (informal discussion transcript)</p> <p>https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2c-transcript.pdf</p>

Appendix reference	Paper
B-31	Challenges and Strategies for Financing the Increasingly Long Life (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3c-transcript.pdf
B-32	Longevity in the Public Eye (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4a-transcript.pdf
B-34	Innovative Business Solutions to Respond to an Aging Society (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4c-transcript.pdf
B-35	Mortality and Longevity Research (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-5a-transcript.pdf
B-36	What is Different Today for Post-Retirement Financial Planning? (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-5b-transcript.pdf
B-38	The Changing Face of Elder Care (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6b-transcript.pdf
B-39	General Session II: Insights into Successful Aging (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsii-transcript.pdf
B-40	General Session VI: Senior Citizen in 2050 (informal discussion transcript) https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsvi-transcript.pdf
B-46	Discussant Comments for Session Longevity in the public Eye https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-4a-discussant-comments.pdf
B-49	Foreword https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-forword.pdf

5. Closing Remarks

As you read through the material presented at the Living to 100 symposia, it becomes clear that while much has been done, gaps remain in our collective perspective, which should be filled through future research.

To reiterate and to add to those highlighted in the sections above, there is a fundamental need to address the following ideas:

- ▶ How can we improve the quality of our data? How can we better identify the difference between the drivers of older age mortality and the symptoms of aging?
- ▶ How can we better understand the complex aging mechanisms and explain the influence of genetics on longevity?
- ▶ Given the limitations of the data currently available, how can we make sure our projections of future mortality are useful to industry and government professionals?
- ▶ How can actuaries viably project future mortality rates and other technical manipulations ensuring their usefulness and relevance to industry and government professionals?
- ▶ How can we determine the appropriate rate of improvement for a given population? What is a reasonable ultimate age at which it is appropriate to assume a mortality table should end, if at all?
- ▶ How can we work together as a profession to create a set of basic tools or methodologies that can be used as a starting point for everyone? How should we augment and use those tools for pension, insurance and long-term health products? How can we work, or leverage, the general insurance community and the international actuarial community?
- ▶ How can actuaries use these tools to help inform the discussion at the societal level? At the regulatory level?
- ▶ How will society adapt to the aging population? What should be the roles of the public and private sectors in addressing longevity's societal implications?
- ▶ What are the catalysts needed to solve the challenges facing the long-term care and pension industries in light of increasing longevity?

As the SOA prepares for the next Living to 100 symposia, we encourage practitioners to focus their attention on filling the gaps in our collective knowledge so we can move toward answering these crucial questions.

Appendix A: Census of Articles

- A-1 Title: Pensioner Mortality in the New York State Public Retirement Systems
2002 Author(s): James Fox
URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-fox.pdf>
This article looks at New York's mortality data going back to 1921. When analyzed, a smooth, asymptotic trend is noticed in mortality rates, and then forecasts were made for the New York State Retirement System. The results showed a steady increase over the next 30 years, adding four years on average to a 62-year-old. This change would not represent an immediate burden on the system.
- A-2 Title: Mortality at Advanced Ages in the United Kingdom
2002 Author(s): Adrian P. Gallop
URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-gallop.pdf>
While mortality rates have fallen in the United Kingdom significantly over the last 100 years, calculating mortality rates for people over 85 has proven difficult since that information is not published. More recent years have the gap in data starting at 90, which is still creating problems for advanced age calculations. This article provides a summary of the available data and discusses some of the problems that have arisen due to lack of data for advanced ages. Also discussed is the recent work by the U.K. Government Actuary's Department to construct a database of mortality rates.
- A-3 Title: Mortality of the Extreme Aged in the United States in the 1990s, Based on Improved Medicare Data
2002 Author(s): Bert Kestenbaum, ASA; B. Renee Ferguson
URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-ferguson.pdf>
The U.S. Medicare program provides the most extensive and high-quality data for very old persons in North America. These data are used for constructing the U.S. life tables for older ages every 10 years. The author articulates that even though this is the best available data, there are still errors that have a greater effect on older ages. This paper looks at ways to correct these errors and present them with their adjusted life tables.
- A-4 Title: Reported Deaths of Centenarians and Near-Centenarians in the Social Security Administration's Death Master File
2002 Author(s): Kenneth Faig, Jr., FSA
URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-faig.pdf>
The Social Security Administration maintains the largest collection of publicly accessed death records, called the Death Master File. This article discusses the sources of information in the Death Master File's public release in 2000. Geographically, specific centenarian samples drawn from the Death Master File public release can be validated using other resources.

- A-5 Title: Data Mining Techniques for Mortality at Advanced Age
 2002 Author(s): Lijia Guo, Ph.D., ASA; Morgan C. Wang, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-guo.pdf>
 This article discusses issues and methods for advanced age mortality using data mining. Data mining, an interactive information discovery process, is an emerging new technology with massive actuarial potential. Several factors were looked at in this study, and their influence on advanced-age mortality distributions is discussed. Using logistic regression techniques, models were built to project advanced age mortality distribution.
- A-6 Title: Estimating Mortality of Insured Advanced-Age Population with Cox Regression Model
 2002 Author(s): Zhiwei Zhu, Ph.D.; Michael Hoag, FSA; Stéphane Julien, FSA; Sufang Cui, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-zhu.pdf>
 The author uses the Cox model to estimate the mortality of advanced age (≥ 60) populations. A total of 66,989 policies issued from 1997 to 2000 from 14 insurances companies were used, and the mortality rate impact from multiple risk factors (issue age, product, gender, smoking status and duration) was modeled and compared both to actual data and the SOA 90-95 table. The author finds that a limitation of the COX model is that only count of claims can be generated through the estimation process.
- A-7 Title: Detection and Significance of Frailty in Elderly Insurance Applicants
 2002 Author(s): Robert J. Pokorski, M.D., FACP
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-pokorski.pdf>
 The author summarizes and identifies risk factors that are attributable to frailty through various studies. He concludes the risk factors to identify frailty are age, gender, functional and cognitive impairment, nutritional status, comorbid impairments, self-reported function, and difficulties with mobility, balance, and aerobic capacity along with country-specific factors.
- A-8 Title: Analysis of Mortality in a Small Sample of Older Adults
 2002 Author(s): Bruce L. Jones, Hyuk-Sung Kwon, Donald H. Paterson, David A. Cunningham, John J. Koval
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-jones.pdf>
 The authors analyze mortality in a sample of 441 adults from London, Ontario, Canada, aged 55 to 85 at the time the study was conducted. Researchers used a proportional hazards model along with a kernel estimator to obtain a semi-parametric model that describes how mortality varies by age and gender. The paper also concludes that while cardiorespiratory fitness was significantly related to mortality, further research is still needed to develop models that fit cardiorespiratory fitness into mortality.

- A-9 Title: Mortality for Retired Federal Employees and Their Survivors
 2002 Author(s): Michael R. Virga, ASA, MAAA, EA
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-virga.pdf>
 This paper presents data on the mortality and mortality improvement trends for 1,640,000 retired U.S. civil service employees and their survivors from 1980 to 2000 and analyzes the relationship to such factors as salary, annuity, total service, duration on the annuity rolls, retiree versus beneficiary and disability versus non-disability.
- A-10 Title: Emergence of Supercentenarians in Low Mortality Countries
 2002 Author(s): Jean-Marie Robine, James W. Vaupel
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-robine.pdf>
 This paper uses data from the International Database on Longevity, which warehouses supercentenarian data in low mortality countries, to analyze mortalities for ages 110 to 115. The authors show that the mortalities between ages 110 and 115 fall far below a ceiling of 0.6, a value previously proposed by other researchers. They concluded that their results strongly support the finding that mortality does not increase according to the Gompertz curve at the highest ages.
- A-11 Title: Mortality at Advanced Ages in Spain
 2002 Author(s): Maria Dels Àngels Felipe Checa
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-checa.pdf>
 This paper explores and provides a statistical description of Spain's national centenarian data (people who live beyond 100 years). Data inconsistency for higher ages proved to be a significant problem in the study. The author concludes that in light of the analyzed trends, it would be acceptable to forecast an increase in the centenarian population in Spain.
- A-12 Title: Dealing with Problems in Data Quality for the Measurement of Mortality at Advanced Ages in Canada
 2002 Author(s): Robert Bourbeau, Bertrand Desjardins
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-bourbeau.pdf>
 Data quality is severely compromised when dealing with advanced ages. The authors explore various methods to terminate life tables. One involves finding ways to validate a sufficient number of unbiased high ages at death to produce an accurate measure with the "generation method." Another is to establish convincing evidence as to the pattern of survival at the very high ages; mathematical techniques can then be used to generate the rates as an extension of mortality at ages 70 to 90 or 100. The authors postulate that it is clearly advisable to extend to the highest ages possible the exact measure of mortality based on bias-free observations.

- A-13 Title: Using Dynamic Reliability in Estimating Mortality at Advanced Ages
 2002 Author(s): Fanny L.F. Lin, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-lin.pdf>
 The author compares Gompertz mortality law and a model based on reliability theory using eight Taiwan complete life tables.
- A-14 Title: Approaches and Experiences in Projecting Mortality Patterns for the Oldest Old
 2002 Author(s): Thomas Buettner
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-buettner.pdf>
 The author describes first the use of a relational mortality model with a standard proposed by Himes, Preston and Condran to extend life tables beyond age 80. The author then focuses on the projection of mortality using the method proposed by Lee and Carter. After a description of each method, their performance and robustness are assessed. A final section adds observations regarding possible future trends in survival among the oldest old and necessary improvements of empirical data.
- A-15 Title: Oldest-Old Mortality Rates and the Gompertz Law: A Theoretical and Empirical Study Bases on Four Countries
 2002 Author(s): Jack C. Yue
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-yue.pdf>
 The author uses a standard operating procedure for testing the Gompertz assumption using yearly age-specific mortality data.
- A-16 Title: Living to Age 100 in Canada in 2000
 2002 Author(s): Louis G. Doray, Ph.D., ASA
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-doray.pdf>
 Statistical models are fit to Canadian datasets, using maximum likelihood theory to estimate the parameters of the models and obtain estimates of the standard error for the mortality rates. Mortality rates are then projected for people who will attain age 80 in the future.
- A-17 Title: Underlying and Multiple Cause Mortality at Advanced Ages: United States 1980–1998
 2002 Author(s): Eric Stallard, ASA, MAAA
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-stallard.pdf>
 From 1980 to 1998 there were substantial improvements in the health and mortality of people 65 and over. This paper evaluates age- and gender-specific patterns of change in underlying and multiple cause of death reports. The mortality measures used will be underlying cause of death, multiple cause death rates, associated cause death rates and death rates based on the joint occurrence of multiple cause conditions. The results of these evaluations are discussed in the context of existing models and used to forecast future mortality patterns.

- A-18 Title: Plastic Omega
 2002 Author(s): Gene Held, FSA, MAAA
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-held.pdf>
 The progress of the Human Genome Project is rapidly increasing knowledge about life at its most fundamental level. The head of the project believes that by 2030 the genes that control aging will be mapped, and clinical trials for drugs to slow aging could be underway. This paper discusses the subject of science's effect on aging as well as provides references for more detailed information. Staying on top of these types of advancements is critical to actuaries as they could invalidate existing assumptions, which may result in cascading errors in future projections.
- A-19 Title: Longevity Determination and Aging
 2002 Author(s): Leonard Hayflick, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-hayflick.pdf>
 The paper discusses the importance of research into aging rather than research on age-associated diseases. The author states that if aging research is to advance, it will not only be necessary to distinguish biogerontology from geriatric medicine, but it will also be necessary to distinguish aging from longevity determination.
- A-20 Title: Living to 100 and Beyond: Implications of Longer Life-spans
 2002 Author(s): Anna Rappaport, Alan Parikh
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-rappaport.pdf>
 This paper discusses the impact of increased longevity on spouse, family members, business opportunities and society as a whole. The authors use statistics from SSA and the U.S. Census Bureau to frame their argument.
- A-21 Title: Some Background from Census 2000
 2005 Author(s): W. Ward Kingkade
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxxiv.pdf>
 This paper presents the breakdown and background of the 2000 U.S. census.
- A-22 Title: Application of Mortality Models to Japan
 2005 Author(s): Masakazu Ozeki
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xiv.pdf>
 Using the Japan life table as input, four models—Heligman-Pollard, mixed Weibull, Lee-Carter and a simulation—are examined and their parameters determined. The strengths and limitations of each model are discussed.
- A-23 Title: The Lee-Carter Model for Forecasting Mortality Revisited
 2005 Author(s): Siu-Hang Li, Wai-Sum Chan
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xi.pdf>
 Mortality data from the U.S. and Canada are used to perform time-series outlier analysis on the key component of the Lee-Carter model, the mortality index.

- A-24 Title: Living to 100 and Beyond: An Extreme Value Study
 2005 Author(s): Zhongxian (Jerry) Han
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-vii.pdf>
 This paper describes parametric modeling for the elderly and oldest population. A classic threshold model is fitted to the data of each year using maximum likelihood methodology, separated by categories of year and gender. Then a model with transformed generalized Pareto distribution is fitted using a hyperbolic transformation, where the limiting age is introduced as a new parameter. The third model, a transformed exponential distribution, is shown to fit the data best. Log-likelihood functions for all models are given to find parameter estimations together with their confidence intervals. Last-k-years thresholds are specifically used to do a time series analysis of the limiting age in the 20th century. As a direct application, continuous mortality rates functions above the threshold can be derived from the model.
- A-25 Title: An Extreme Value Analysis of Advanced Age Mortality Data
 2005 Author(s): Kathryn A. Robertson, Debbie J. Dupruis, Bruce Jones
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxxiii.pdf>
 The authors explain the use of r-largest and peaks-over-threshold approaches to extreme value modeling. Generalized extreme value and generalized Pareto distributions are fit to the life-span data.
- A-26 Title: "Makeham-Type" Mortality Models
 2005 Author(s): Marie Redina L. Mumpar-Victoria, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xiii.pdf>
 The author analyzes the inverse-Makeham model and the modified-Makeham select model. The models' effectiveness in exhibiting patterns of mortality is tested by simulating the nonlinear models and estimating the parameters via non-linear regression using NLIN and SAS.
- A-27 Title: Data Quality of Oldest-Old Population in Taiwan: 2003 Census Ages 89 and Above
 2005 Author(s): Jack C. Yue
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxxi.pdf>
 Historically, census data have been insufficient for older ages because of low response rates. To address the problem, the Taiwan government interviewed people face to face over 89 for a special 2003 census and compared the results to the older age data acquired in the 2000 general census. The authors used the data to test the parameters of the Gompertz law using the bootstrapping method.
- A-28 Title: Seasons and Longevity: Mortality Trajectories among the Oldest Old
 2005 Author(s): Jean-Marie Robine, Siu Lan Cheung, Fred Paccaud
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxiv.pdf>
 Using data from Switzerland, the authors analyzed seasonal mortality. Results indicate that excess mortality occurs in the winter months (December through March) and that the mode and standard deviation of individual life durations are lower in the winter than summer.

- A-29 Title: Number of Centenarians in the United States Jan. 1, 1990, Jan. 1, 2000, and Jan. 1, 2010 Based on Improved Medicare Data
- 2005 Author(s): Bert Kestenbaum, B. Renee Ferguson
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxvi.pdf>
 Medicare Part B data are allowing a more reliable study of the centenarian population in the U.S. The authors show that the centenarian population has grown 4 percent annually between 1990 and 2000 and that the fraction of centenarians to those aged 75+ is larger than previously thought.
- A-30 Title: IDL, the International Database on Longevity
- 2005 Author(s): Jean-Marie Robine, Amandine Cournil, Jutta Gampe, James Vaupel
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxiii.pdf>
 Since the first symposium, "Living to 100 and Beyond: Survival at Advanced Ages," held in 2002, a collaborative effort has been made to assemble an international database on longevity, gathering validated longevity records for people having reached at least their 110th birthday. Different validation processes were then undertaken by the participating teams. By March 2004, more than 500 validated records had been gathered. This paper first evaluates the quality of data according to several criteria, such as the country of residence or the validation process undertaken, and then provides an estimation of the mortality trajectory up to age 114.
- A-31 Title: High-Age Implications of Postretirement Risks
- 2005 Author(s): Anna M. Rappaport, FSA; Monica Dragut
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xvii.pdf>
 This paper focuses on the risks of retirement and special issues that can arise for those at more advanced ages. Such major risks include outliving your retirement resources, unexpected health care costs and inflation. Economic risks (e.g., inflation) become more severe as life-span increases and are particularly important for people at advanced ages. The article concludes that public knowledge about retirement planning contains many misconceptions, and any system in which people are left too much on their own will result in difficulties especially at advanced ages. The author feels the best solutions to these problems are an increase in education, strong employer contributions and the maintenance of social security.
- A-32 Title: What if Mortality Was to Diminish Much More than Was Forecast? Implications for Financing Social Security
- 2005 Author(s): Robert Bourbeau, Bertrand Desjardins, - Jacques Légaré
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-iv.pdf>
 This article discusses the importance of examining the risks associated with financing social security with pay-as-you-go systems. As under this model, the increasing age of a population causes a heavier burden on the working population, the author postulates that the model no longer fits today's demographic profile. A pressing issue for policymakers today should be implementing a fairer system to help ease these burdens.

- A-33 Title: Shapes and Limits of Longevity in Mexico
 2005 Author(s): Roberto Ham-Chande
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-ii.pdf>
 The author discusses the levels and forms that mortality and survivorship are taking for the oldest old in Mexico, using population census from 1930 to 2000 and projects the population from 2010 to 2050. Then the author compares and analyzes the 100+ mortality pattern under Gompertz law and Hayward & Gorman. Finally, he suggests that research using better instruments to determine the maximum longevity in Mexico and the trends of life expectancies at all the ages is required.
- A-34 Title: Implications of an Aging Population in India: Challenges and Opportunities
 2005 Author(s): Prakash Bhattacharya
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-iii.pdf>
 This article addresses the aging population in India. Elderly Indians currently experience higher rates of certain severe medical conditions due to bad habits and unhealthy lifestyles as well as increased poverty from poor financial planning. These challenges are further complicated by inadequate health care facilities for older Indians. The author believes that many of the problems facing older Indians can be remedied by better education on the retirement planning front. The investments they make could not only allow them to retire more comfortably and receive better care, but could help boost India's economy to one of the strongest in the world.
- A-35 Title: Coping with Longevity: The New German Annuity Valuation Table DAV 2004 R
 2005 Author(s): Ulrich Pasdika, Jürgen Wolff
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xvi.pdf>
 Given the increased financial exposure to longevity risk, a subcommittee of the German Actuarial Society (DAV) examined in detail the adequacy of the current industry annuity valuation table DAV 1994 R, after which it was determined that a new industry table was required. The authors describe the development of the German Annuity Valuation Table DAV 2004 R, which has been used for the pricing and valuation of annuity business since January 1, 2005.
- A-36 Title: Mortality at Advanced Ages in the United Kingdom
 2005 Author(s): Adrian P. Gallop, Angus S. Macdonald
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxi.pdf>
 The paper discusses the problems encountered in estimating mortality rates at old ages in the United Kingdom for both the general population and those taking out insurance. It describes the current and past methodologies used to construct mortality rates at advanced ages for official population life tables and the CMIB (Continuous Mortality Investigation Bureau) mortality tables of insured lives. Possible methods for projecting mortality rates at advanced ages are also discussed.

- A-37 Title: The Interdependency of Increasing Life Expectancy and Driving Life Expectancy of Elderly Populations
- 2005 Author(s): Chao-Chun Leng, Min-Ming Wen
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-x.pdf>
 This paper analyzes the impacts of increasing longevity on driving life expectancy by gender and age group. Further, it estimates the mobility dependency and suggests better public policies should be developed to help the mobility of seniors.
- A-38 Title: Trajectories of Disability and Mortality Among the U.S. Elderly Population: Evidence from the 1984–1999 NLTCs
- 2005 Author(s): Eric Stallard, ASA, FCA, MAAA
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxvii.pdf>
 This paper employs a longitudinal form of the grade of membership (GoM) model to specify and estimate a multivariate model of the trajectories of disability and mortality among elderly respondents to the National Long-Term-Care Survey (NLTCs) of 1984 to 1999. The author shows that the model can be fitted to existing data and that the results are interpretable as generalizations of fixed frailty with linearly declining vitality.
- A-39 Title: Search for Predictors of Exceptional Human Longevity: Using Computerized Genealogies and Internet Resources for Human Longevity Studies
- 2005 Author(s): Natalia S. Gavrilova, Leonid A. Gavrilov
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-v.pdf>
 This paper analyzes data taken from computerized genealogies, SSA, census and internet resources to find predictors and determinants for centenarians. The paper starts with the detailed description of the data collection and verification process and then uses summary statistics and (multiple) logistic regression to find the correlations. The paper concludes that family factors (birth orders, region of residence and household property) and early life conditions are key determinants for exceptional human longevity. Finally, the paper analyzes the mortality patterns at advanced ages using the SSA DMF.
- A-40 Title: The Great Debate on the Outlook for Human Longevity: Exposition and Evaluation of Two Divergent Views
- 2005 Author(s): Jacob S. Siegel
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xv.pdf>
 This paper summarizes the debate of two views of human longevity in the U.S.: (1) a life expectation (at birth) of 100 years will be reached in the industrialized countries by the year 2060 and (2) life expectation is not likely to exceed 85 years by 2060. The topics to support the views also include the extension of the average recorded human life-span, the existence of limits to human life-span and life expectancy, the form of the trajectory of age-specific mortality rates at the highest ages of life, and the utility of developing projections of mortality on the basis of causes of death.

- A-41 Title: An Investigation of Select Birth Cohorts
 2005 Author(s): Richard MacMinn, Ph.D.; Richard MacMinn, Ph.D.; Krzysztof Ostaszewski, Ph.D. FSA, CFA, MAAA; Ranee Thiagarajah, Ph.D., ASA, MAAA; Frederik Weber
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxx.pdf>
 The actuarial term “mortality improvement,” known as an increase in longevity, has been a worldwide phenomenon throughout the 20th century. While this is an achievement for public health in general, it increases risks for the providers of retirement benefits. This article discusses whether select birth cohorts of unusually high improvements in longevity exist and, if so, where they exist within various countries. The article discusses the criteria for defining the cohorts and how to identify them and then studies their effect.
- A-42 Title: The Impact of the Equity Risk Premium and Population Aging on the Canadian Retirement Saving System
 2005 Author(s): Doug Andrews, FSA, CFA, FCIA, MBA
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-i.pdf>
 This article discusses the impact of increasing longevity on retirement systems in Canada; in particular, attention is paid to the rate of return on investments. Since most plans invest in equities, the return on the equity markets over the lifetime of retirees is extremely important. This paper reviews research regarding the equity risk premium, combines it with projected mortality data and then applies it to the Canadian retirement income system. The paper concludes that if lower estimates of equity risk premium materialize, when combined with increasing longevity of Canadian population, it will cause significant challenges to the retirement system.
- A-43 Title: The Effects of Advanced Age Mortality Improvement on the Valuation of Variable Annuities with Guaranteed Death Benefits
 2005 Author(s): Lijia Guo, ASA, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxv.pdf>
 Variable annuities with guaranteed death benefits are difficult to price given improvements in advanced age mortality. The hybrid mortality model presented in the paper offers a more accurate way to help value the products.
- A-44 Title: Analysis of Trends in the Age-Specific Shape of Mortality Curves for Populations in the United States and Japan
 2005 Author(s): Christine Dugan, Hande Gulumser, Richard Humble, Daniel Ryan
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xx.pdf>
 This paper discusses longevity trends in the U.S. and Japan by using the age-specific data from the Human Mortality Database. The authors fit models to past trends and then project future mortality based on forward projections of those trends. The paper concludes that the Weibull distribution provides a valuable model of age at death and the logistic function provides a valuable model of mortality rates for ages 50 and over.

- A-45 Title: Ending the Mortality Table
 2005 Author(s): Edwin C. Husted, FSA, EA, MAAA
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-ix.pdf>
 The author summarizes four common methods to end mortality tables and then describes the shapes of the mortality curves at old ages. The impact on a pension plan of each of these methods is demonstrated. Finally, the financial impact of using the first three methods on the U.S. Social Security data was presented. The author concludes that the chosen method does not have significant financial impact on large plans until the age of 115.
- A-46 Title: Estimates of the Incidence, Prevalence, Duration, Intensity and Cost of Chronic Disability Among the U.S. Elderly
 2008 Author(s): Eric Stallard, ASA, FCA, MAAA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-3b-stallard.pdf>
 This paper estimates the burden of chronic disability on the U.S. elderly population using gender-specific measures of long-term care service use, intensity and cost. Death rates were computed and analyzed for differences by age and gender, whereas rates of service use, intensity and cost were conditional on age and gender. This paper concludes that the HIPAA (Health Insurance Portability and Accountability Act of 1996) criteria effectively target the high-cost disabled subpopulation and that a substantial gender difference exists as females outspend males in a ratio of 2.8 to 1.
- A-47 Title: Health, Wealth and Wisdom—Living Long, Living Well: An Actuary Muses on Longevity
 2008 Author(s): Michael J. Cowell, FSA, ALM
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-cowell.pdf>
 This paper deals with the health costs associated with long lives. The U.S. leads all nations in health care spending with an annual spend of one-sixth of GDP. Also discussed is the correlation between health, wealth, geographic location and education. The article then combines biological and environmental factors using a mathematical approach and closes by examining the implications of uncontrolled increasing costs on our society.
- A-48 Title: Human Behavior: An Impediment to the Future Mortality Improvement: A Focus on Obesity and Related Matters
 2008 Author(s): Sam Gutterman, FSA, FCAS, MAAA, HonFIA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-gutterman.pdf>
 This paper focuses on human behavior and its effect on mortality with a focus on obesity: trends in different age, gender and racial groups are examined. The article also touches on how the long-term health effects of adolescent obesity are offset by medical advances and reductions in smoking. Understanding human behavior and its contributions to mortality is essential to accurate projections.
- A-49 Title: Is the Compression of Morbidity a Universal Phenomenon?
 2008 Author(s): Jean-Marie Robine, Siu Lan K. Cheung, Shiro Horiuchi, A. Roger Thatcher
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-04-cheung.pdf>
 This paper discusses the idea of morbidity compression. The studies examined produced varied results, but overall showed a compression of morbidity at older ages.

- A-50 Title: New Findings on the International Relationship between Income Inequality and Population Health
- 2008 Author(s): Robert L. Brown, Steven G. Prus
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2a-brown.pdf>
- This paper tests the hypothesis that higher levels of income inequality are directly related to lower levels of population health and examines the inequality-health relationship across life. Using data from around 2000 and correlation techniques, the relationship between income inequalities for various age groups was tested. The two datasets used were wealthy countries and a combination of wealthy and non-wealthy. Overall the data for wealthy nations did not support the hypothesis that higher levels of income inequality resulted in lower levels of population health.
- A-51 Title: Challenges on Improved Life Spans in India—The Actuarial Implications
- 2008 Author(s): N.V. Subramanyan
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2a-subramanyan.pdf>
- This paper analyzes the life expectancy trend in India and compares it to other countries in the world. The author indicates that for ages 85+, the principles for smooth graduation of q_x (Balducci assumption and Gompertz-Makeham's law) do not strictly hold true. The author also examines the social and economic implications of the increased life-span in India.
- A-52 Title: Living to 100: Survival to Advanced Ages: Insurance Industry Implication on Retirement Planning and the Secondary Market in Insurance
- 2008 Author(s): Jay Vadiveloo, Peng Zhou, Charles Vinsonhaler, Sudath Ranasinghe
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5a-ranasinghe.pdf>
- The authors discuss the optimal allocation of assets so that the financial objectives of retirees are met. The objectives as stated are maximize current spending levels and maximize estate value at death. The author concludes the optimum allocation involves both immediate annuities and investment products. The life settlement industry is also discussed.
- A-53 Title: Longevity Risk Pricing
- 2008 Author(s): Jiajia Cui
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5a-cui.pdf>
- Longevity risk is a serious solvency threat to pension plans and insurance companies. Longevity-linked securities are desirable instruments for buyers and sellers but are difficult to price and, therefore, not frequently traded in financial markets. Using the equivalent utility pricing principle, the authors develop the minimum risk premium required by the longevity insurance seller and the maximum acceptable risk premium by the longevity insurance buyer for various longevity-linked securities. Their pricing method allows for a tighter range of premia and flexibility with securities with different payoff structures.

- A-54 Title: A Study of the Lee-Carter Model with Age-Shifts
 2008 Author(s): Jack C. Yue, Sharon S. Yang, Hong-Chih Huang
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6a-huang.pdf>
 The authors explore analyzing an age-shift model to modify the Lee-Carter model to deal with the issue of non-constancy in parameters.
- A-55 Title: Data Validation and Measurement of Cohort Mortality Among Centenarians in Quebec (Canada) According to Ethnic Origin
 2008 Author(s): Mélissa Beaudry-Godin, Robert Bourbeau, Bertrand Desjardins
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5b-bourbeau.pdf>
 The authors analyze mortality estimates based on ethnic origin in Canada.
- A-56 Title: Inference for Logistic-Type Models for the Force of Mortality
 2008 Author(s): Louis G. Doray, Ph.D., ASA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4a-doray.pdf>
 Using Canadian mortality data, the author finds the parameters for Kannisto's model using a weighted least-squares estimator and for Perks' model parameters by using Taylor series expansion.
- A-57 Title: Is There a Limit to the Compression of Mortality?
 2008 Author(s): Jean-Marie Robine, Siu Lan K. Cheung, Shiro Horiuchi, A. Roger Thatcher
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-03-cheung.pdf>
 The authors examine the subject of mortality compression using historical data from European countries. This paper discusses the notion of a limit for the compression of mortality and examines alternative hypotheses such as the shifting mortality model.
- A-58 Title: Mortality Measurement at Advanced Ages: A Study of the Social Security Administration Death Master File
 2008 Author(s): Leonid A. Gavrilov, Natalia S. Gavrilova
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4b-gavrilov.pdf>
 This paper addresses the three challenges of estimating hazard rates at extremely old ages: (1) the observed mortality deceleration may be at least partially an artifact of mixing different birth cohorts with different mortality (heterogeneity effect), (2) standard assumptions of hazard rate estimates may be invalid when risk of death is extremely high at old ages, and (3) ages of very old people may be exaggerated.
- A-60 Title: On Simulation-Based Approaches to Risk Measurement in Mortality with Specific Reference to Binomial Lee-Carter Modelling
 2008 Author(s): Steve Haberman, Arthur Renshaw
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6a-haberman.pdf>
 This paper develops the binomial version of the Lee-Carter model and provides a comparative study of simulation strategies for assessing risk in mortality rate predictions and associated estimates of life expectancy and annuity values in both period and cohort frameworks.

- A-61 Title: Physical and Socioeconomic Characteristics at Young Age as Predictors of Survival to 100: A Study of a New Historical Data Resource (U.S. WWI Draft Cards)
- 2008 Author(s): Natalia Gavrilova, Leonid A. Gavrilov
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-5b-gavrilov.pdf>
- The authors explore whether people living to 100 and beyond were any different from their peers at their middle age (30 years) in terms of their physical characteristics (height and body build), occupation and marital status.
- A-62 Title: Predictive Modeling for Advanced Age Mortality
- 2008 Author(s): Lijia Guo
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4a-guo.pdf>
- The paper provides both the theoretical frameworks and the application aspects of the predictive modeling process. As the result, a mortality risk score was derived in differentiating the mortality risk for the advanced age population.
- A-63 Title: Typology and Review of Measures of Human Aging, Longevity and Superlongevity, with Applications to U.S. Data and Some Implications for U.S. Public Programs
- 2008 Author(s): Jacob S. Siegel
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-4b-siegel.pdf>
- A multi-way typology of measures of aging, longevity and superlongevity is presented, with measures classified as measures of aging and longevity, direct and indirect measures of aging and longevity, and measures based on population data, death statistics and life table functions. The author postulates that measurement of time to death serves as a new way of looking at aging and longevity, and use of it could provide a degree of control over the fiscal consequences of increasing longevity on public programs.
- A-64 Title: Testing Deterministic Versus Stochastic Trends in the Lee-Carter Mortality Indexes and Its Implications for Projecting Mortality Improvements at Advanced Ages
- 2008 Author(s): Wai-Sum Chan, Siu-Hang Li, Siu-Hung Cheung
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6a-chan.pdf>
- The authors investigate the dynamics of the Lee-Carter mortality index and perform statistical hypothesis tests to examine whether the mortality indexes are best described by stochastic trends or deterministic trends.
- A-65 Title: Economic Sustainability of Retirement Pensions in Mexico: Is There a Link with the Mexican-Origin Population in the United States?
- 2008 Author(s): Roberto Ham-Chande
- URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2a-chande.pdf>
- This author analyzes the relationships between Mexicans and people living in the U.S. of Mexican origin from a demographic and social security perspective. The lower mortality rate, decreasing fertility and migration to the U.S. are contributing to a population aging among Mexicans. The author discusses the challenges and impacts of an aging population, specifically as they relate to social security systems.

- A-66 Title: Evaluation of Approaches to Reducing Women’s Longevity Risks
 2008 Author(s): Beverly J. Orth, JD, FSA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-3b-orth.pdf>
 This article discusses the longevity risk of women in the U.S. Elderly women living alone have some of the highest poverty rates in the U.S. largely because their longevity risk is greater than men. Since existing financial products that can mitigate risk are not very attractive to most people, the author discusses alternative vehicles for pooling longevity risk and compares their effectiveness and viability.
- A-67 Title: Living to 100 and Beyond in Canada with Dignity
 2008 Author(s): Doug Andrews, MBA, FCIA, FSA, CFA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1b-andrews.pdf>
 This author looks at increasing life expectancy of Canadians and suggests that government policy should be focused on allowing the elderly to live with dignity. This paper suggests that the population of 2031 will be very different than it is today. It poses the question: Is living longer a worthwhile goal if it is accompanied by inadequate wealth or loss of mental faculties? This paper outlines the best ways to enhance living with dignity such as replacing the Old Age Security benefit, better integrating retirement communities and legalizing medically assisted suicide.
- A-68 Title: Living to 100—A Woman’s Issue
 2008 Author(s): Anna M. Rappaport, FSA, MAAA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-3b-rappaport.pdf>
 This paper deals with issues facing women at advanced ages. It covers topics such as social security payment issues, working in retirement, need for long-term care and several others broken down by gender. The article also discusses the biggest pitfalls facing women such as divorce, overspending, under-saving and retiring too early. The author stresses that many of these problems do not arise until advanced ages when it is already too late to make the necessary corrections.
- A-69 Title: Micro Pension Plan: Indian Perspective
 2008 Author(s): Prakash Bhattacharya
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1b-bhattacharya.pdf>
 This article discusses the current challenges India faces from a growing economy and an aging population. The author suggests that micro-pension plans are needed to cover the large segment of the population that is not covered under social security. The author feels that even small contributions from each person would generate a vast amount of funds that could be used to grow the economy, develop infrastructure and stabilize the stock market. The best result of this plan would be that it would save a large amount of people from poverty late in their lives without making a significant difference in their current standard of living.

- A-70 Title: Retirement and Retirement Ages in Canada Revisited
 2008 Author(s): Brian L. Burnell, FCIA, FIA, FSA
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1b-burnell.pdf>
 The author discusses the combination of lower birth rates and higher life expectancy in Canada. This change in demographic is projected to cause the senior dependency ratio to almost double from its current 20 percent in the next 20 years. The author examines the effect of gradually increasing the retirement age to stabilize this growing problem. The author concludes major changes are required in the near term and suggests phased retirement programs and a greater degree of flexibility in retirement agreements. The author postulates that the changes must be recognized and acted upon by employees, employers and the Canadian government.
- A-71 Title: Mortality Projections for Social Security Programs in Canada
 2008 Author(s): Michel Montambeault, Jean-Claude Ménard
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-02-menard.pdf>
 This paper examines past mortality trends in Canada and discusses how these trends may change over the next 75 years, thus influencing the growth of the elderly population. In addition, this paper describes the methods and assumptions used to project future mortality rates in Canada, and the results include assumed annual rates of mortality improvement and projected life expectancies. Finally, the stochastic time-series method (ARIMA (0,1,0)) is discussed as a projection model.
- A-72 Title: Mortality Projections for Social Security Programs in the United States
 2008 Author(s): Alice Wade
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-02-wade.pdf>
 This paper examines past mortality trends in the U.S. and discusses how these trends may change over the next 75 years, thus influencing the growth of the elderly population. In addition, this paper describes the methods and assumptions used to project future mortality rates and presents results, including assumed annual rates of mortality reduction and projected life expectancies. This paper also discusses stochastic time-series methods, that help quantify the variability in the mortality rate projections
- A-73 Title: Mortality Projections in the United Kingdom
 2008 Author(s): Adrian Gallop
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-02-gallop.pdf>
 This paper discusses the key forces likely to influence U.K. mortality in the 21st century and describes the methodology and assumptions used in the latest projections of U.K. mortality. The paper also describes recent tables of mortality rates published by the Continuous Mortality Investigation, based on the experience of people taking out insurance contracts and the approaches taken in projecting these.

- A-76 Title: The Biology of Human Longevity, Aging and Age-Associated Diseases
 2008 Author(s): Leonard Hayflick, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-03-hayflick.pdf>
 This article discusses the biology of human longevity. Factors such as genes guide longevity, and processes like natural selection must retain structure and function or the species will vanish. A fundamental problem in the field is the failure to distinguish age changes from a disease that blurs the efforts to understand the biology of aging. The author concludes by asking why more resources are not devoted to understanding aging as the leading cause of death.
- A-77 Title: Putting the Brakes on Aging: Beginning the Pharmaceutical Era
 2011 Author(s): Steven N. Austad
 URL: <https://www.soa.org/files/pd/2011-orlando-living-100-austad-gs1.pdf>
 This presentation discusses the advancements in pharmaceuticals and their effect on aging. Several new agents have shown promise against a variety of late-life diseases although their side effects have not yet been detected. In tests on animals, their life-span has been increased even when beginning the medicine at more advanced ages. The presentation shows that slowing human aging is no longer a pipe dream, but is actually becoming a reality.
- A-78 Title: Is Long-Term Care Social Insurance Affordable in Developed Countries?
 2011 Author(s): Doug Andrews, Ph.D., FIA, FCIA, FSA, CFA
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-andrews.pdf>
 LTC insurance is important for the financial health of elderly populations, but many countries find LTC to be too expensive to fund as a social program. The author looks at whether or not LTC is viable financially as a social program and, if so, whether it should be public or private, and how the definition of LTC changes by country. The impact of future demographic shifts and taxes on affordability is also discussed. The author concludes that LTC is feasible as a social insurance program and is prudent for countries to take on.
- A-79 Title: The Relationship Between Cognitive Impairment and Mortality Rates Among Long-Term Care Insurance Applicants
 2011 Author(s): Marc A. Cohen, Ph.D.; Xiaomei Shi, M.S.; Jessica Miller, M.S.
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-cohen.pdf>
 Using data from LTC insurance applicants, the authors show that a classification of cognitive impairment increases mortality in individuals when holding other factors constant. The results show that an applicant classified as cognitively impaired has a death hazard rate that is 1.52 greater than someone without the impairment. The two cognitive screens used were delayed word recall and enhanced mental skill test.

- A-80 Title: The CLASS Act and the Future of Long-Term Care Financing
 2011 Author(s): Stephen A. Moses
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1a-moses.pdf>
 Medicaid handles the majority of LTC claims, which is putting stress on the financial solvency of the social program. Early policies encouraged the elderly to use Medicaid for LTC coverage; this has had undue consequences on reimbursement rates and quality of care. The Community Living Assistance Services and Support (CLASS) hopes to provide the elderly with more options for in-home care versus nursing home institutionalization.
- A-81 Title: Temporal Evolution of Some Mortality Indicators: Application to Spanish Data
 2011 Author(s): A. Debón, F. Martínez-Ruiz, F. Montes
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1b-debon.pdf>
 This paper looks at Spanish mortality data and the properties of the indicators life expectancy, Lorenz curve, Gini index, modal age at death, standard deviation above modal age and shortest age interval for the 50 percent of deaths. It then discusses the Lee-Carter model and bootstrapping techniques to calculate confidence intervals.
- A-82 Title: Mortality Compression and Longevity Risk
 2011 Author(s): Jack C. Yue
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-1b-yue.pdf>
 Instead of fitting stochastic models for mortality rates, this study explores increasing life expectancy by examining the basic properties of survival curves. The curves are examined to check for mortality compression.
- A-83 Title: Mortality Compression
 2011 Author(s): Leonid Gavrilov, Natalia Gavrilova, Allen Klein, Jack Yue, Jean-Marie Robine; moderator Thomas Edwalds
 URL: <https://www.soa.org/files/pd/2011-orlando-living-100-cheung-1b.pdf>
 Paper authors present research on the following papers: “Temporal Evolution of Some Mortality Indicators: Application to Spanish Data,” “Mortality Compression and Longevity Risk,” and “Patterns of Old-Age Mortality, Emergence of the Centenarians and the Compression of Death above the Mode.”
- A-85 Title: Obesity: Status and Effects
 2011 Author(s): Sam Gutterman
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-gutterman.pdf>
 This article discusses the migration away from using stored fat as an energy source and the resulting negative impact on life expectancy. Discussed are the major contributions and causes of obesity—while U.S. obesity numbers appear to be stabilizing, they are still disturbingly high. Obesity has played a significant role in the increase of U.S. health care costs, and although studies differ as to the magnitude of the increased cost, it has been shown to be anywhere from 5.0 to 16.5 percent. The paper concludes with ideas on how to remedy the problem of obesity.

- A-86 Title: The Impact of Obesity and Diabetes on LTC Disability and Mortality: Population Estimates from the National Long Term Care Survey
- 2011 Author(s): Eric Stallard
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-stallard.pdf>
 This article attempts to estimate the impact of obesity and diabetes on disability and mortality for those over 65. Current obesity was associated with large increases in diabetes, non-significant increases in disability and substantial decreases in mortality among the elderly. Obesity at age 50 and diabetes were both associated with large increases in disability among the elderly. Tests of the interaction between these risk factors did not rule out either additive or multiplicative models.
- A-87 Title: The Role of Social and Health-Related Characteristics in Determining Survivorship Among the U.S. Oldest Old
- 2011 Author(s): Hiram Beltrán-Sánchez, Ph.D.; Jennifer Ailshire, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2a-alishire.pdf>
 This paper addresses the socioeconomic and demographic characteristics, health status and health behaviors associated with oldest-old mortality and survivorship. Data are used from a 1990–1991 mortality study and then followed up on through 2002 to find trends. The study only looks at those who lived beyond age 65 and checks for patterns in their data that can help predict longevity beyond 65. The results of the study indicate that activity limitation and exercise status, when combined with education, play a very important role in surviving from 65 to 85 but have a much smaller effect from 85 and older. The study also notes that numbers for people 90 to 94 were very small, which could lead to unstable results and should be used with caution.
- A-88 Title: Projection of Mortality Rates at Advanced Ages in Canada with a New Lee-Carter Type Model
- 2011 Author(s): Louis G. Doray, Kim O. Tang
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2b-doray.pdf>
 The authors describe how modeling and forecasting of advanced age populations can be improved by combining features of the logistic model for the force of mortality and the Lee-Carter model.
- A-89 Title: Assessing and Extending the Lee-Carter Model for Long-Term Mortality Prediction
- 2011 Author(s): Xiaoming Liu, Hao Yuy
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2b-liu.pdf>
 The authors examine the prediction performance of the Lee-Carter model for forecasting long-term mortality. Two issues are addressed: robustness and drift uncertainty. The authors share suggestions on handling parameter estimation.
- A-90 Title: Coherent Mortality Modeling for a Group of Populations
- 2011 Author(s): Sharon S. Yang, Jack C. Yue, Yu-Yun Yeh
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-2b-yang.pdf>
 The authors address coherent mortality modeling by combining a group of populations with similar period effects. The Lee-Carter model is employed to illustrate the feasibility of coherent mortality modeling using U.S. and Canadian data from the Human Mortality Database.

- A-91 Title: Longevity Risk and Regular Discount Sequence
 2011 Author(s): Hsin Chung Wang, Jack C. Yue
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-3b-wang.pdf>
 The authors adapt the idea of a regular discount sequence in the bandit problem and use it to interpret life expectancy, as well as to develop a model for survival probabilities. They found that many frequently used mortality models, such as the Gompertz law and the Coale-Kisker model, and famous mortality assumptions (uniform distribution of death, constant force and hyperbolic assumption) all satisfy the requirement of regular discount sequence. In addition, they use the Brownian motion stochastic differential equation to model the discount sequence to predict future mortality rates and life expectancy.
- A-92 Title: Simultaneous Prediction Intervals: An Application to Forecasting U.S. and Canadian Mortality
 2011 Author(s): Johnny Siu-Hang Li and Wai-Sum Chan
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-3b-li.pdf>
 The primary objective of this paper is to demonstrate how simultaneous prediction bands can be created for prevalent stochastic models.
- A-93 Title: Age-Related Changes in Factors Associated with Loss of Good Health
 2011 Author(s): Robert L. Brown, Andrew MacKenzie, Steven G. Prus
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g3-brown.pdf>
 This study looks at the factors associated with loss of good health in the age groups 20 to 44, 45 to 64, and 65 and older. The study found that the factors affecting different groups were not the same. Younger and middle-aged individuals were more affected by socioeconomic factors like income and the area they live in, whereas a major factor affecting older people was social involvement. Consuming alcohol and social activity helped to prevent a decline of health in older individuals. This study points out that better understanding the reasons for health decline for various age groups can help develop more effective policies and programs to keep people healthy.
- A-94 Title: The Likelihood and Consequences of “Living to 100”
 2011 Author(s): Leonard Hayflick, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g3-hayflick.pdf>
 This essay discussed the impact on human life if science discovered a way to slow the aging process. The author feels that while it sounds good to have an average life expectancy of 100, the consequences for society and the individual would outweigh the benefits. According to Hayflick, several serious unforeseen complications could arise especially if aging is slowed in children before full development. Another point of emphasis is the burden on an already overpopulated planet. If life were extended, not only would people live longer, but if a woman began treatment pre-menopause, she could reproduce for a longer period of time.

- A-95 Title: Early-Life Predictors of Exceptional Longevity in the United States: Why Centenarians Are Different from Their Shorter-Lived Siblings
- 2011 Author(s): Leonid A. Gavrilov, Natalia S. Gavrilova
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g4-gavrilo.pdf>
- This study explored the effects of early-life factors (birth order, paternal age, maternal age, month of birth) on the likelihood of survival to advanced ages. Centenarians were compared to their shorter-lived siblings using a within-family approach. In contrast to the authors' 2005 study, birth order has no significant effects. However, the paper suggests that the parental age at a person's birth and the month of birth affect survival to age 100.
- A-96 Title: Living to 100 and Liking It—Research of Relevance from the National Institute on Aging
- 2011 Author(s): Marie Bernard
- URL: <https://www.soa.org/files/pd/2011-orlando-living-100-bernard-keynote.pdf>
- This presentation discusses how the aging of the U.S. population can be associated with increased chronic illness and disability. The author asserts that research and neuroscience discoveries can modify health and the human life-span. Behavioral science also plays a major role and could influence people to make better choices for healthy lifestyles. While some of the causes of longevity are genetic, the author feels that, with more research and lifestyle changes, we could have greater control over our longevity.
- A-97 Title: How to Survive Living to 100: Ways to Improve the U.S. Retirement System
- 2011 Author(s): Beverly J. Orth, JD, FSA
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4a-orth.pdf>
- This article discusses ways to improve retirement by addressing the challenges workers face in saving enough money to last for their lifetime. While insurance options are available to protect one's assets, many people will still have trouble with their long-term expenses if they live to be very old or require long-term care. The author concludes that our current retirement system needs incremental changes in social security, annuitization in qualified retirement plans, and the development of more attractive long-term care policies to help retirees meet the financial difficulties of increased longevity.
- A-98 Title: The Impact of the Automatic Balancing Mechanism for the Public Pension in Japan on the Extreme Elderly
- 2011 Author(s): Yosuke Fujisawa
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4a-fujisawa.pdf>
- The author reviews Japanese mortality and life expectancy, emphasizing the growth in the extreme aged, and explains the underlying longevity issues that led to the automatic balancing mechanism used by public pension program. Second, by means of stochastic mortality and fertility modeling, the author analyzes how a mortality decline, particularly at extreme ages, will affect the future of public pensions in Japan. Third, the author demonstrates, on the basis of the stochastic projections, how the automatic balancing mechanism will affect the financial security of people over age 100. The author concludes that significant further research is needed to solve the public pension problem in Japan.

- A-99 Title: Pension Reform in Canada —An Actuarial Perspective
 2011 Author(s): Robert L. Brown
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4a-brown.pdf>
 This paper discusses pension reform in Canada. The author first explains how the existing Canadian income system is structured within the government-sponsored and private sector. The article then integrates a report from the Canadian Institute of Actuaries' Task Force in response to a debate on reform of the Canadian system. The report concludes that amendments to several Income Tax Act rules and in the various Pension Benefit Acts would greatly assist the existing pension system. Further, the fewer restrictions placed on the system, the better the level of participation and the more successful the program.
- A-100 Title: Mortality Improvement in the USA: Analysis, Projections and Extreme Scenarios
 2011 Author(s): Joseph Lu; Wun Wong, Ph.D.
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4b-lu.pdf>
 This paper looks at the mortality improvement trends used in the development of scale AA. The author examines scale AA's historical performance and, using stochastic models, compares the projection of mortality improvement with figures from scale AA.
- A-101 Title: Recent Adult Mortality Trends in Canada, the United States and Other Low Mortality Countries
 2011 Author(s): Nadine Ouellette, Robert Bourbeau
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4b-ouellette.pdf>
 The author examines three populations: U.S. population through a CDC sample, a life settlement population of an independent life settlement underwriter and the population implied by the SOA's 2008 valuation basic table. The author concludes that mortality/survival rates seem to converge after 10 years.
- A-102 Title: Is Raising the Age of Eligibility Fair to All? An Investigation of Socio-Economic Differences in Mortality Using Population Data
 2011 Author(s): Geoff Rashbrooke, FIA
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g5-rashbrooke.pdf>
 This paper draws on New Zealand research that has matched individual death records to census records to derive mortality tables by adapting New Zealand Māori and non-Māori population mortality data to reflect differences in socioeconomic status. This adapted data are used as a basis to explore the implications of differential mortality in assessing the equity of increases in the pension age of eligibility. The paper concludes with suggestions as to how the imperatives for fiscal sustainability might be tempered with actions designed to mitigate the equity shortcomings indicated by the paper's analysis.

- A-103 Title: Patterns of Aging-Related Changes on the Way to 100: An Approach to Studying Aging, Mortality and Longevity from Longitudinal Data
- 2011 Author(s): Anatoliy I. Yashin, Konstantin G. Arbeev, Svetlana V. Ukraintseva, Igor Akushevich, Alexander Kulminski
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g5-yashin.pdf>
- This paper examines the average age trajectories of indices describing physiological states for different groups and their established mortality risk. Indices include BMI, blood pressure, pulse rate, glucose level etc. The data evaluated are from the Framingham Heart Study. The results showed different indices have different age patterns and properties.
- A-104 Title: A Study on Emerging Health Conditions Among the Elderly in India and the Sufficiency of Medical Framework and Health Insurance
- 2011 Author(s): N.V. Subramanyan
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5a-subramanyan.pdf>
- The six decades after independence have been eventful for India, with all-around growth in economic terms, life expectancy and global recognition. There has been change in the social fabric with the number of people older than 60 steadily increasing. The gradual shift from an agrarian base to an industrial economy has had a telling effect. Prevalence of lifestyle diseases such as diabetes and cardiovascular diseases has increased considerably with resultant morbidity severely affecting the quality of life. The inadequacy of health care infrastructure in India further compounds the problem, and absence of a credible social health care policy and health insurance setup makes this a serious issue needing immediate attention. This paper presents the situation, analyzes and estimates the economic impact of changing demographics, and identifies opportunities for insurers.
- A-105 Title: Living to 100: Challenges and Opportunities for Employers
- 2011 Author(s): Mary Nell Billings, Anna M. Rappaport
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5a-billings.pdf>
- This paper deals with challenges facing employers to help their employees plan for old age. Many factors are coming together, such as longer-term talent challenges, the need to work longer and rising health care costs, which make planning for retirement more difficult. While some jobs offer the flexibility of working beyond age 65, jobs that involve manual labor can be difficult even well before the normal retirement age. This paper discusses the issues today's work environment will face in the future and concludes that two very important things are needed: job options and innovation.

- A-106 Title: Risk Management Issues for Individuals with Special Emphasis for Women
 2011 Author(s): Anna M. Rappaport, FSA, MAAA
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5a-rappaport.pdf>
 The author deals with risk management issues primarily affecting women. Women face more difficult challenges because they tend to live longer than men. The author looks at issues regarding long life and managing risk for women while drawing on research done by the SOA. The author concludes that later retirement will be increasingly important in more advanced years, and retirement age will likely increase one to two years per decade. Other points of emphasis are fixing gaps in individuals' knowledge of retirement, like explaining trade-offs and encouraging long-term and balanced planning.
- A-107 Title: Mortality Measurement and Modeling Beyond Age 100
 2011 Author(s): Natalia S. Gavrilova, Leonid A. Gavrilov
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5b-gavrilova.pdf>
 This study uses data from the Social Security Administration Death Master File to show that mortality deceleration in humans observed at advanced ages may be an artifact caused by age exaggeration, data heterogeneity or use of improper estimates of hazard rate. The model comparison using Bayesian information criterion shows that in the age interval 88 to 106 and for data with reasonably good quality, the Gompertz model shows better fitting of hazard rates than the logistic model.
- A-108 Title: Mortality Rates at Oldest Ages
 2011 Author(s): R.C.W. "Bob" Howard, FSA, FCIA
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5b-howard.pdf>
 This paper presents a method for using death records to infer exposure on non-extinguished cohorts, thereby allowing the development of a credible table for high ages. The method uses Whittaker-Henderson graduation in several unusual ways. The paper also validates the method by applying it to stochastically generated sets of death records for which the underlying mortality and improvement tables are known.
- A-109 Title: Making the Most of Experience Data: An Augmented Beta-Binomial Approach
 2011 Author(s): P.J. Sweeting
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-5b-sweeting.pdf>
 Credibility is an important way of combining the results of experience and risk rating. The authors introduce an augmentation to the beta-binomial approach that not only allows for the information contained in ages near to the age under analysis but also for variation in risk types across the different ages.

- A-110 Title: Will There Be Enough Doctors, Nurses and Hospitals for Our Aging Populations?
 2011 Author(s): Douglas Andrews, William Peck, Noreen Siba
 URL: <https://www.soa.org/files/pd/2011-orlando-living-100-andrews-gs6.pdf>
 This presentation discusses the aging population and the capacity to care for them in Canada. The speakers discuss the increasing supply of medical professionals and the extent to which Canadians are engaged in medical tourism; similar issues in the United Kingdom are covered. The presentation also asks the question whether, in an aging society, preventive health care become a necessity.
- A-111 Title: Distinguishing Health Status for Advanced Ages
 2008 Author(s): Craig M. Baldwin, Faye S. Albert, Thomas Ashley, Robert Gleeson, Stephen K. Holland
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-1a-baldwin.pdf>
 This presentation addresses the increasing healthy aging population and how it affects health practitioners. One of the speakers touches on the future use of biomarkers to predict the areas of decline in old age with an eye to prevention. Another speaker discusses the topic of health expectancy by bifurcating the healthy and unhealthy portions of life. A third speaker discusses assessing cognitive function in the elderly. The final speaker discusses long-term care underwriting in the oldest of ages.
- A-112 Title: Implications of Longer Life Spans: What Does This All Mean to Us?
 2008 Author(s): Anna M. Rappaport, Timothy F. Harris, Dawn E. Helwig, Valerie A. Paganelli, David K Sandberg, Steven G. Vernon
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-g1-rappaport.pdf>
 This session discusses the implications of longer life-spans. It deals with the effect on the private sector and the people who actuaries serve. One of the speakers discusses the behavioral challenges that can negatively impact one's health. Another speaker discusses long-term care; the impact of increased longevity and the need for these services. The last speaker discusses the supply and demand of health care as demographics change.
- A-113 Title: Emerging Definitions on Retirement
 2008 Author(s): Anna M. Rappaport, Doug Andrews, Steven Haberman, Valerie A. Paganelli, Steven G. Vernon
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-2b-rappaport.pdf>
 This presentation addresses redefining retirement, in particular, the growing members of the population who consider themselves retired and still working. These people tend to focus more on what they want to do and not how much they can make. The presenters also mention a possible bias since most of their clients are wealthy, they are unsure as to how the poor view retirement. The topic of premature retirement risk is also covered.

- A-114 Title: Social Insurance Follow-up: Methodologies and Implications
 2008 Author(s): Sam Gutterman, Stephen C. Goss, Danita L. Pattemore, Alvin K. Winters
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-3a-gutterman.pdf>
 This presentation deals with a broad variety of actuarial topics dealing with social insurance methodologies and implications of changes in longevity. One topic that is highlighted is the cause of deceleration in mortality by cause of death. The presentation covers a variety of actuarial models that were used to generate mortality rates and includes a comparison of life expectancy at age 65 for people in the U.S., U.K. and Canada broken down by gender.
- A-115 Title: Health Expectancy
 2008 Author(s): Faye S. Albert, John M. Bragg, James C. Brooks, Jr.
 URL: <https://www.soa.org/essays-monographs/2008-living-to-100/mono-li08-6b-albert.pdf>
 This paper looks at a different approach to measuring health expectancy in the elderly population. This new actuarial approach, which incorporates medical impairment profile, is explained along with several illustrations. Medical impairment is broken down into the categories of healthy, needs assisted living and needs skilled care. This paper also discusses mortality results over the age of 90 and the beneficial aspects of health expectancy.
- A-116 Title: Summary of Panel Discussion on Implications of Increasing Life Spans for the Private Sector
 2005 Author(s): Steven C. Siegel
 URL: <https://www.soa.org/essays-monographs/2005-living-to-100/m-li05-1-xxviii.pdf>
 This presentation discusses global issues relating to longevity trends. The idea that governments will need to re-evaluate the programs that are a financial burden was discussed. Social security and other entitlement programs would need restructuring for the current longevity trends. The speaker suggested changing the definition of retirement itself. More and more retirees are working part time or consulting with their former companies, and this trend tends to complicate long-term entitlement solutions.
- A-117 Title: Mortality Experience of Three Senior Populations
 2011 Author(s): Vincent Granieri
 URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-4b-granieri.pdf>
 This paper examines senior mortality in three distinct populations. It looks at the Medicare database from the CDC, the life settlement population of an independent life settlement underwriter, and the SOA's 2008 Valuation Basic Table. While these three populations exhibit varying characteristics with respect to early duration survival, the rates of all three converge within 10 years. A clear effect of wealth is shown on survival as evidenced by survival rates increasing with socioeconomic status.

- A-118 Title: Patterns of Older-Age Mortality, Emergence of the Centenarians and the Compression of Death Above the Mode (Tribute to Roger Thatcher)
- 2011 Author(s): Jean-Marie Robine, Siu Lan Cheung, Shiro Horiuchi
- URL: <http://www.demographic-research.org/volumes/vol22/18/>
- This paper uses the Human Mortality Database to investigate the compression of old-age mortality by combining a simple version of logistic model with Kannisto's analytical tools. The authors present their methodology and show the results of its application to time series of official life tables for England and Wales and life tables for six selected countries in the Human Mortality Database.
- A-119 Title: Health Policy Challenges of Population Aging: Perspectives from the Oxford Institute of Ageing
- 2011 Author(s): Kenneth Howse
- URL: <https://www.soa.org/files/pd/2011-orlando-living-100-howse-keynote.pdf>
- This presentation covers the challenges to health policy caused by an aging population in the United Kingdom. The presentation shows the aging trends and discusses the challenges of protecting and maintaining health. Also discussed is the importance of better management and prevention of chronic disease. One key discussion point is the greatly increased risk of dementia as people live much longer than expected. The presentation concludes with questions like "How should we revise priorities and refine objectives for health care systems under conditions of population ageing?"
- A-120 Title: Comparison of U.S., U.K., and Canadian Annuity Mortality Tables and Studies
- 2011 Author(s): Doug Doll, Nick Dumbreck, Bob Howard, Allen Klein
- URL: <https://www.soa.org/files/pd/2011-orlando-living-100-doll-3a.pdf>
- This presentation compares U.S., U.K. and Canadian mortality tables to address mortality improvement in the U.S. and internationally. The presenters exhibited charts detailing different modeling methods and results. Also shown are causes of decreased mortality including circulatory disease, drastic increases in the treatment of cancer and heart disease.
- A-121 Title: Increasing Genetic Contribution to Exceptional Longevity with Increasing Age
- 2011 Author(s): Tom Perls, Paola Sebastiani
- URL: <https://www.soa.org/essays-monographs/2011-living-to-100/mono-li11-g4-perls.pdf>
- This article looks at the impact of genetics on longevity. Based on twin studies, the heritability of longevity has been noted to be around 20 percent, but many papers have incorrectly extrapolated these results to extreme old age. The authors postulate that the longevity disparity for men and women has not been properly taken into account, skewing the results. Accurate associations are important in that they will reveal genetic associations with some age-related illnesses, which could help develop prevention methods.

- A-122 Title: Social Insurance: Perspectives and Implications
 2011 Author(s): Chresten Dengsoe, Sam Gutterman, Jean-Claude Menard
 URL: <https://www.soa.org/files/pd/2011-orlando-living-100-dengsoe-gs7.pdf>
 This presentation begins with small population mortality projections in Denmark. The conclusion drawn from the first portion of the presentation is that there was a life expectancy gain of 40 years from 1835 to 2006, half of which was from reduction in infant and child mortality. The second portion of the presentation focuses on modeling Canadian mortality. The authors conclude that if mortality rates decrease consistently with the last 15 years, a life expectancy of 100 could be attained in 140 years for males and 120 years for women.
- A-123 Title: Living and Dying Beyond Age 100 in Japan
 2002 Author(s): Jean-Marie Robine; Yasuhiko Saito, Ph.D.; Carol Jagger
 URL: <https://www.soa.org/essays-monographs/2002-living-to-100/mono-2002-m-li-02-1-saito.pdf>
 This paper deals with the increase in the extremely old in Japan. Female life expectancy in Japan is approaching an assumed limit of 85, which is providing valuable information on demographic changes concerning the oldest of the population. Death rates for those between 100 and 105 have been clearly decreasing. A study referenced in this paper suggests that in the winter months environmental interventions could further decrease death rates.
- A-124 Title: Estimating the True Cost of Retirement
 2014 Author(s): David Blanchett
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-blanchett.pdf>
 A common practice of estimating one's required retirement fund is to apply a rate of inflation on the annual amount you expect to begin withdrawing at retirement for a fixed duration. In this paper, the author establishes that this method would provide an overestimated cost of retirement and demonstrates that in order to estimate the true cost of retirement, additional considerations are needed. First, the replacement rate (percentage of earnings needed post-retirement) is likely to vary considerably by retiree household. Second, the author notes that retiree expenditures on average do not increase by inflation but instead vary by total consumption and funding level. When consumption and funding levels are combined and correctly modeled, the true cost of retirement becomes highly personalized.
- A-125 Title: The CBD Mortality Indexes: Modeling and Applications
 2014 Author(s): Wai-Sum Chan, Johnny Siu-Hang Li, Jackie Li
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-chan.pdf>
 This paper discusses using the widely used stochastic mortality model, Cairns-Blake-Dowd, to construct mortality indices. The authors demonstrate in this study that the time-varying model parameters in the CBD model are most suitably used as indices to indicate levels of longevity risk at different time points because they can represent a varying age-pattern of mortality improvement, they are new data invariant and they are interpretable. The authors also illustrate that the cross-correlations between the CBD mortality indices can be captured by a vector autoregressive integrated moving average process. Finally, the authors propose to resolve the uncertainty surrounding the use of

two CBD mortality indices simultaneously with a joint prediction region. It is demonstrated that such a region can be used as a graphical longevity risk metric, which allows practitioners to compare the longevity risk exposures of different portfolios readily.

A-126 Title: Optimal Retirement Tontines for the 21st Century: with Reference to Mortality Derivatives in 1693

2014 Author(s): Moshe A. Milevsky, Thomas S. Salisbury

URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-milevsky.pdf>

This paper discusses tontines, an annuity that offers a lifetime of income that increases as other members of the tontine pool die off and their money is distributed to survivors. Historical tontines have generally been structured to offer fixed cash flows. The authors of this paper conclude that a tontine scheme in which interest payments to the pool are structured to decline over time is the optimal structure. Under this structure, the utility loss is smaller than an actuarially fair life annuity, and the authors conclude that tontines should be reintroduced and allowed to coexist with life annuities. Technical derivations of the optimal tontine structure are also included in the paper.

A-127 Title: Mortality, Health and Marriage: A Study Based on Taiwan's Population Data

2014 Author(s): Hsin Chung Wang, Jack C. Yue

URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1b-wang.pdf>

The article explores the explanatory power of marriage status in determining health and longevity. Taiwan's marital data for the entire population (married, unmarried, divorced/widowed) are used to evaluate whether marital status could be a preferred criteria now and in the future. The authors have modeled mortality improvements under Lee-Carter and age-period-cohort models using both an autoregressive model and an intrinsic estimation method to obtain parameters. The article concludes that, based on Taiwan's marital data, the married have significantly lower mortality rates than the single and, if converting the difference into a life insurance policy, the discount amount is even larger than that for smokers/non-smokers.

A-128 Title: Logistic Regression for Insured Mortality Experience Studies

2014 Author(s): Zhiwei Zhu, Zhi Li

URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-zhu.pdf>

In this paper, the authors discuss using a logistic regression-based model for insured population mortality estimation. They conclude that properly designed logistic modeling processes can more effectively utilize available data to deliver solutions for the following needs: (1) testing mortality drivers' statistical significances in explaining mortality variations; (2) estimating normalized mortality slopes and mortality differentials such as how mortality increases by duration or varies between underwriting classes while product and attained-age distributions are controlled; and (3) addressing analytical challenges such as extrapolating for ultimate mortality, smoothing between select and ultimate estimations, and constructing multidimensional basic experience tables.

- A-129 Title: Predictors of Exceptional Longevity: Effects of Early-Life Childhood Conditions, Midlife Environment and Parental Characteristics
- 2014 Author(s): Leonid A. Gavrilov, Natalia S. Gavrilova
- URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-gavrilov.pdf>
- The authors of this paper studied the simultaneous effects of three factors on longevity: parental characteristics, early-life conditions and midlife environment. Using multivariate logistic regression, the authors found that parental longevity and certain midlife characteristics are significant factors that impact longevity, while the impact of early-life conditions is less critical. The authors also found both general and gender-specific predictors of human longevity. A further comparative study of biological and nonbiological relatives of centenarians is also conducted. The findings demonstrate that shared familial environment and lifestyle play an important role in longevity.
- A-130 Title: Liars, Cheaters and Procrastinators: How They Upset Mortality Studies
- 2014 Author(s): R.C.W. "Bob" Howard
- URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-howard.pdf>
- This paper discusses the impact of bad data on mortality curves. The author examines three specific types of bad data: overstatement of age (liars), failure to report deaths (cheaters) and late reporting of deaths (procrastinators). The author demonstrates that overstatement of age at death causes the negatively sloped mortality rates at the highest ages for U.S. males. However, failure to report deaths does not seem to significantly impact the mortality curve. Finally, the author argues that the impact of late reporting of deaths is not material for ages under 85 but, at higher ages, recommends an adjustment for incurred but not reported.
- A-131 Title: Obesity and Mortality
- 2014 Author(s): Sam Gutterman
- URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-obesity-gutterman.pdf>
- This paper discusses the relationship between obesity and mortality. It provides a background of the obesity epidemic and then explores many issues and reported experiences associated with obesity and mortality. The author also discusses the relationship between obesity and health care costs and disability.
- A-132 Title: Causes-of-Death Mortality: What Do We Know on Their Dependence?
- 2014 Author(s): Séverine Arnold(-Gaille), Michael Sherris
- URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-arnold.pdf>
- This paper discusses modeling the dependency between various causes of death using vector error correction models. In the study, the authors studied the dependency between five causes of death (diseases of the circulatory system, cancer, diseases of the respiratory system, external causes, and infectious and parasitic diseases) among ten countries. Two key conclusions are drawn from the study. Firstly, the authors demonstrate that dependencies do exist between the five competing risks over recent years. Secondly, different countries have different experiences in cause of death mortality trends. Therefore, applying results from one country to another may be misleading.

- A-133 Title: Mortality of Smoking by Gender
 2014 Author(s): Sam Gutterman
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-gutterman.pdf>
 In this paper, the author compares smoking prevalence and cessation by gender and considers its effect on projection of mortality rates. The author observes that the trends in smoking prevalence and consequential mortality by gender are important factors to consider in any long-term mortality projection. He also argues for considering the effect of smoking and smoking cessation in any mortality projection. A few approaches include incorporating a cause-of-death based projection or an adjustment to a statistical technique.
- A-134 Title: Genetically Informed Longevity
 2014 Author(s): Tom Bakos, Marc Klibanow, Nicholas Schork, Ali Torkamani, Ashley Van Zeeland
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-bakos.pdf>
 This paper provides an overview of the role of genetics and how it could change the way practitioners think about longevity. It discusses concepts such as “aging” and “senescence” from a genetic perspective and the use of genetic information to reduce morbidity risks in each individual. The authors also discuss genetic testing, its costs, risk assessments, and data privacy challenges in the U.S.
- A-135 Title: How Genes Modulate Patterns of Aging-Related Changes on the Way to 100: Lessons from Biodemographic Analyses of Longitudinal Data
 2014 Author(s): Anatoliy I. Yashin, Konstantin G. Arbeeve, Deqing Wu, Alexander Kulminski, Liubov Arbeeve, Irina Kulminskaya, Igor Akushevich, Svetlana V. Ukraintseva
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-yashin.pdf>
 This paper reviews various genome-wide association studies to clarify the mechanism of genetic regulation of human aging and longevity. It identifies the inability of such studies to address the problem of how genetic influences are mediated by physiological variables and other biomarkers over the human life-span. The authors use longitudinal genetic data to compare average age trajectories of physiological indices between carriers and non-carriers of selected genetic variants, using stochastic longevity models to investigate the genetic influence on hidden biomarkers of aging. The results demonstrate the benefits of using bio-demographic principles and integrative statistical models of mortality risks in genetic studies of human longevity.
- A-136 Title: Contribution of Familial Longevity to Living to 100
 2014 Author(s): Paola Sebastiani, Stacy L. Andersen, Avery I. McIntosh, Lisa Nussbaum, Meredith D. Stevenson, Leslie Pierce, Samantha Xia, Kelly Salance, Thomas T. Perls
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-sebastiani.pdf>
 In this paper, the authors update estimates of sibling-relative risk of living to extreme ages using data from more than 1,700 sibships (offspring having the same parents) in the New England Centenarian Study (2012). The authors examined the trend for heritability for different birth-year cohorts and built a network model to understand the effects of paternal and maternal longevity on an individual’s chance to live to an extreme age.

- A-137 Title: Coherent Projections of Age, Period and Cohort Dependent Mortality Improvements
 2014 Author(s): Matthias Börger, Marie-Christine Aleksic
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-borger.pdf>
 This paper introduces an age-period-cohort model, including its estimation and application to derive coherent projections for several populations. The authors observe that the incorporation of information on the mortality experience of other populations can significantly impact the projection for another given population. Their proposed methodology is benchmarked to other models and backtested with historical data from Germany. The paper also discusses uncertainties in the proposed projection approach and how to account for them.
- A-138 Title: Measurement of Mortality among Centenarians in Canada
 2014 Author(s): Nadine Ouellette, Robert Bourbeau
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-oulette.pdf>
 This paper replicates centenarian mortality studies using a highly reliable set of data on French-Canadians centenarians to examine the impact of aggregating data for several birth cohorts and of inaccurate data at such old ages. The authors note that, while the aggregation of several birth cohorts is not responsible for the late-life mortality deceleration observed in the studied data, the studied data support the existence of such deceleration.
- A-139 Title: Mortality Trajectories at Extreme Old Ages: A Comparative Study of Different Data Sources on U.S. Old-Age Mortality
 2014 Author(s): Natalia S. Gavrilova, Leonid A. Gavrilov
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-gavrilova.pdf>
 This paper provides analyses of the authors' refutation of mortality deceleration in late ages (i.e., Gompertz law), using independent datasets of the U.S. population and alternative statistical approaches. The authors also analyze an alternative approach for studying mortality patterns at advanced ages based on calculating the age-specific rate of mortality change after age 80. Simulation studies demonstrate that the apparent decline of life table aging rates after age 80 found in earlier studies may be related to biased estimates of mortality rates measured in a wide five-year age interval. The authors also discuss possible reasons for finding apparent mortality deceleration in earlier studies.
- A-140 Title: How Well Have Retirement Systems Adapted to Longer Life?
 2014 Author(s): Anna M. Rappaport
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-rappaport.pdf>
 The article goes through the history of the seemingly ubiquitous "65" retirement age and the effects it has had on labor participation by the old. Following the introduction of social security and pension plans, many people were seen retiring in their late 50s and early 60s. However, in recent years, the labor force participation at older ages has increased and, with limitations on earnings removed from social security, work is becoming accepted as a part of retirement. The author addresses the risk of longevity on retirement and the inadequate link between mortality improvement and retirement age. Sharing longevity risk with participants is an alternative to the actions taken by many of terminating existing defined benefit plans.

- A-141 Title: Mapping the Adequacy of Care and Support for the Elderly in Developed Countries
 2014 Author(s): Doug Andrews
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-andrews.pdf>
 This report looks at six developed countries (Canada, England, France, Germany, Sweden and the U.S.) and assesses the adequacy of their coverage for elders (65+) in social security, health care and long-term care. The study points out similarities and differences between the chosen countries and makes connections to country-specific factors, including social norms, taxation and government responsibility. The author displays aggregate adequacy across the six countries, as well as their current and potential sustainability for the three areas studied. Additionally, he provides actionable recommendations based on the findings from the study.
- A-142 Title: Supporting the Oldest Old: The Role of Social Insurance, Pensions and Financial Products
 2014 Author(s): Jonathan Barry Forman
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-forman.pdf>
 The article goes through a broad spectrum of social programs in place for the old and how they might be enhanced to provide for a population that is surviving to oldest old ages. In particular, the oldest old receive nearly half of their income from social security and only 18.3 percent from pensions and retirement. Many elderly Americans also participate in Medicare. The author explores retirement products, such as pension plans, and financial products, such as lifetime annuities and longevity insurance, and speaks to their abilities to supplement income for the elderly. The article also speaks to potential mechanisms involving these products and social change that may enhance income for the oldest old.
- A-143 Title: A Study of Measuring the Mortality Compression
 2014 Author(s): Jack C. Yue
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-yue.pdf>
 In this paper, the author explores statistical methods for evaluating mortality compression, with explicit consideration of data quality issues. It proposes optimization methods for estimating the standard deviation of age-at-death probability distribution, comparing estimation results with raw and graduated data. The author notes there is not enough evidence to conclude if there is mortality compression based on the proposed nonlinear maximization method.
- A-144 Title: Modal Age at Death: Mortality Trends in England and Wales 1841–2010
 2014 Author(s): Emily Clay
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-clay.pdf>
 This report studies the modal age at death in England and Wales by smoothing mortality rates used to construct period life tables using a p-spline non-parametric method. The author notes that mortality has compressed into a shorter age interval. Mortality above the mode has also compressed, but is now stagnating for females. The report shows that the modal age at death has become more prevalent over time for these two countries, and the author recommends that mode should be used to complement the study of mortality changes in low mortality countries.

- A-145 Title: Compression of Morbidity and Mortality: New Perspectives
 2014 Author(s): Eric Stallard
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-stallard.pdf>
 This paper introduces the concepts of mortality compression and morbidity compression and speaks to their relationship, their role in changes to mortality and morbidity, and their potential implications for the future. The author uses data from the National Long Term Care Survey to formulate his morbidity analysis and data from the Social Security Administration database to formulate his mortality analysis. The author keys in on the components necessary to observe morbidity compression: survival increment (the change in mortality survival) and morbidity decrement (the change in the prevalence of disability). The observed datasets indicate that mortality compression had run its course by the latter half of the 20th century while there was significant morbidity compression. The author indicates that, like other academics, he believes future mortality improvement is likely to take the form of right-shifting survival with limited future rectangularization.
- A-146 Title: Living to 100: Socioeconomic Implications of Increased Longevity
 2014 Author(s): Rick Gorvett
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-gorvett.pdf>
 While mortality in the past has decreased due mainly to improvements in infant mortality, this paper explores categorical implications of late-life mortality changes. It explores positive and negative effects should large decreases in mortality take place, effectively redefining the life cycle paradigm as we know it today. The article goes through multiple aspects of life that may see change, including emphasis on education, multiple careers and increased job expertise, marriage, pensions, and retirement planning.
- A-147 Title: Perspectives on SOA Post-Retirement Risk Research and What It Tells About the Implications of Long Life
 2014 Author(s): Anna Rappaport, FSA, MAAA
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-rappaport.pdf>
 This report serves as an aggregating piece bringing together a wide array of past SOA projects. Specifically, the research this report summarizes includes works concerning the economy, women's issues, retirement planning, working in retirement, longevity and long-term care. Primarily, the reports focus on these issues through a middle-class lens. The author reasons that many low-income Americans depend mostly on public programs, while the economics of retirement planning simply make it more profitable to serve higher income individuals, leaving much of the middle market unserved.

- A-148 Title: Subjective Survival Probabilities and Life Tables: Evidence from Europe
 2014 Author(s): Franco Peracchi, Valeria Perotti
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-peracchi.pdf>
- This article aims to evaluate how subjective probabilities of survival to specific target ages provided by respondents compare with objective data from life tables. As the dataset for the analysis stems from a survey (SHARE—Survey of Health, Ageing, and Retirement in Europe), the author goes through data considerations, including focal values in responses, correlations between attrition and the subjective probabilities, and panel conditioning. Life table counterparts of the subjective survival probabilities are created using period life tables, and the results from the findings detail gender and age differences in the relationships observed between subjective survival probabilities and objective life table probabilities. Additional cohort attributes are studied and observed in relation to the subjective probabilities.
- A-149 Title: Survival Characteristics of Three Senior Populations, with a Focus on Life Settlements
 2014 Author(s): Vincent Granieri and Gregory P. Heck
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-granieri.pdf>
- This report studies three separate populations of aging adults and explores survival experience surrounding early settlements on life insurance policies. The study includes groups of seniors who have considered an early settlement on their insurance policy and accepted a settlement on their policy and an additional group of seniors with a college education (this last group may or may not have an insurance policy). Using these groups, the study attempts to expose a sense of selection among seniors that differs from their underwriting status. Specifically, the report focuses on the survival experience of the two groups that are considering or have elected a settlement option.
- A-150 Title: Modeling Medical Cost Trends for Advancing Age in the Long Run
 2014 Author(s): Thomas E. Getzen
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-getzen.pdf>
- This article observes health expenditures in the U.S. over a varying range of time. Health care is a slow-moving vehicle, and costs tend to lag changes in the macro-environment (such as policy changes and GDP growth). This lag is attributable to cumbersome medical systems and the third-party payment structure ingrained in the U.S. market. To understand the path health care costs have taken over time, a long-term view must be used to see slow-developing trends. Over the past century, costs have formed an S-shaped logistic growth curve (rapid growth occurred from 1950 to 2000 aided by the inception of Medicare and employer-sponsored health plans). Individually, aging presents a natural and unavoidable rise in spending; however, at the national level the ebb and flow of aggregate births and deaths stabilize this value. The cost ratio (distribution of resources between old and young) plays a key role in collectively funding elderly health care. The article states that the largest uncertainties and factors in modeling future health care costs include the rate of growth in GDP, the rate of increase in health costs in excess of GDP, technological advances and the aggregate cost ratio.

- A-151 Title: Sex Differences in Predictors of Health Decline
 2014 Author(s): Steven G. Prus
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-prus.pdf>
 This article discusses the results of a study on gender differences for health decline in adult Canadians over a 16-year self-reported longitudinal survey. The author studies certain key predictors, broadly grouped into socioeconomic status, behavioral and psychological, to understand gender differences arising from the data. The findings show that the factors associated with health decline in males do not necessarily agree with what is observed in females, and vice versa. Instances of this include observations on obesity (BMI) and years since immigration.
- A-152 Title: Cognitive, Psychological and Social Drivers of Longevity
 2014 Author(s): Gordon Woo, Anne Bruce
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-woo.pdf>
 This paper evaluates the cognitive, psychological and social drivers of longevity by reviewing recent longitudinal studies. It analyzes the latest research on brain plasticity, positive psychology and elderly cohort survival, as well as new geriatric psychological theories on successful aging. It also provides a quantitative assessment of the actuarial implications of these drivers in modeling the mortality of elderly annuitants and offers new insights into what factors keep people progressing purposefully into advanced age, beyond avoiding disease.
- A-153 Title: Is Secondary Prevention of Alzheimer’s Disease Possible? A Discussion of Studies in the Alzheimer’s Disease Field
 2014 Author(s): Heather M. Snyder, Dean Hartley, Keith N. Fargo, Maria C. Carrillo
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-snyder.pdf>
 Evidence continues to accumulate suggesting the biological processes associated with Alzheimer’s begin two or three decades prior to clinical manifestation of cognitive and functional symptoms such as challenges with memory. This suggests a window of opportunity for therapeutic intervention to slow or halt disease progression, also known as secondary prevention. There are several secondary prevention efforts for Alzheimer’s disease in different stages of planning or execution; examples include the Dominantly Inherited Alzheimer’s Network (DIAN) Trials Unit (DIAN-TU), the Alzheimer’s Prevention Initiative Autosomal Dominant Alzheimer’s disease Treatment Trial (API), the Anti-Amyloid Treatment in Asymptomatic Alzheimer’s Disease Study (A4) and the TOMMORROW trial. Each trial focuses on volunteers with a potentially increased risk or certainty for developing Alzheimer’s disease. Although each study is distinct, there is cooperation to harmonize protocols and data collection to allow the cross comparison of information between studies. This paper provides an overview of the studies.

- A-154 Title: Mortality Projections for Social Security Programs in Canada
 2014 Author(s): Office of the Chief Actuary
 URL: <https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs4-chief.pdf>
- This report presents an overview of the methodology and assumptions used by the Office of the Chief Actuary in Canada for projecting population mortality for the purpose of actuarial valuations of the Canada Pension Plan and Canada's Old Age Security program. It examines past mortality trends in Canada and discusses how these trends may change over the next 75 years. This paper also discusses mortality by causes of death, provides international mortality comparisons and looks at stochastic time series methods that are used to help quantify the variability in the mortality rate projections.
- A-155 Title: Causal Mortality by Socioeconomic Circumstances: A Model to Assess the Impact of Policy Options on Inequalities in Life Expectancy
 2017 Author(s): Daniel H. Alai, Séverine Arnold, Madhavi Bajekal, Andrés M. Villegas
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-alai-arnold-bajekal-villegas-paper.pdf>
- This paper focuses on creating a model to determine how to most effectively increase life expectancy while decreasing the inequality gap in life expectancy stemming from socioeconomic status. The method is to concentrate on which causes of death have the largest socioeconomic gradient that will maximize life expectancy while decreasing the gap between the highest and lowest quintile. The paper attempts to isolate a few causes of death to recommend for policies to focus on reducing to accomplish the objective.
- A-156 Title: Regional Mortality in the United States at Ages 80 and Older: An Analysis of Direct Estimates over Period 1959-2011
 2017 Author(s): Kirill Andreev, Danan Gu, Matthew Dupre
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-andreev-gu-dupre-paper.pdf>
- The almost-extinct cohort method was used to produce direct mortality estimates for states of the U.S. in the period 1959–2011 and at ages 80 and older. The estimates produced by this method were found unreliable for data for the 1960s, due to heavy age misreporting in the U.S. data on deaths. However, following dramatic improvements in the quality of U.S. data at older ages over the last four decades, mortality estimates for the period 2000–2011 were found to be reasonably good. In 2000–2011, levels of mortality in the U.S. were shown to be very similar to average levels of mortality in Japan (apart from Japanese females) and in 12 European countries with high longevity. Disparities in mortality among U.S. states were also comparable with disparities existing in the 13 high-longevity countries. Overall, mortality was lower in Western and Northeastern U.S. states and higher in Southern U.S. states. Hawaii stood out as a state with exceptionally high survival rates at advanced ages.

- A-157 Title: Health Technology, Health Care Cost, Longevity and Retirement Security: A Dynamic Upward Spiral and Challenge to Future Policy
- 2017 Author(s): Daniel Bailey
- URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-bailey-paper.pdf>
- The squaring of the life curve and the resulting aging of the population have profound ramifications for health care and its increasing overall and per capita cost. Moreover, health security and financial security are integrally related. As people live longer, they need to provide economically for more post-retirement years, including health care costs during this telescoping period; the one intensifies the other. This study will discuss the general global effects of longevity on health care costs, primarily focusing on the system for the finance and delivery of health care in the U.S.
- A-158 Title: Improvement in Late-Life Mortality and Its Impact on the Increase in the Number of Centenarians in Quebec (Canada)
- 2017 Author(s): Mélissa Beaudry-Godin, Robert Bourbeau and Bertrand Desjardins
- URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-beaudry-godin-bourbeau-desjardins-paper.pdf>
- The recent decrease in adult and late-life mortality led to a very rapid increase in the number of centenarians within low-mortality countries. The purpose of this paper is to examine the increase in the number of centenarians in Quebec (Canada) across birth cohorts (1871–1901) and to outline some of the underlying demographic mechanisms involved. It studies the demographic situation of centenarians from Quebec using all aggregated data available since 1871 (census data, vital statistics and population estimations). With demographic indicators such as the centenarian ratio, the survival probabilities and the maximal age at death, this paper tries to demonstrate the remarkable progress realized in old-age mortality. It also analyzes the determinants of the increase in centenarians in Quebec: increase in the number of births, in the probabilities of surviving from birth to age 80, from age 80 to 100. Among the factors identified, the improvement in late-life mortality is the main determinant of the increase of the number of centenarians. This study stresses the importance of monitoring the number as well as the quality of life of this emerging population of centenarians. It also helps us gain greater perspective on what should be expected in the coming years among low-mortality countries such as Canada.
- A-159 Title: Mortality Trajectories at Exceptionally High Ages: A Study of Supercentenarians
- 2017 Author(s): Natalia S. Gavrilova, Leonid A. Gavrilov, Vyacheslav N. Krut'ko
- URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gavrilova-gavrilov-krutko-paper.pdf>
- The current view about mortality beyond age 110 years (supercentenarians) suggests that death rates do not grow with age and are virtually flat. This paper tests this hypothesis and analyzes mortality trajectories at these exceptionally high ages. The results demonstrate that hazard rates after age 110 years do not stay constant and suggest that mortality deceleration at older ages is not a universal phenomenon. Death records of supercentenarians, taken from the International Database on Longevity, are split into two groups: cohorts born before 1885 and cohorts born in 1885 and later. Hazard rates were estimated using the standard procedure available in Stata software.

Mortality in both groups grows with age, although in older cohorts, growth was slower compared with more recent cohorts and not statistically significant. Mortality analysis of the more numerous 1884–1894 birth cohort with the Akaike goodness-of-fit criterion showed better fit for the Gompertz model than for the exponential model (flat mortality). IDL data results are compared with a more contemporary database maintained by the Gerontology Research Group (GRG). Mortality analyses with GRG data produced similar results.

A-160 Title: Historical Evolution of Old-Age Mortality and New Approaches to Mortality Forecasting
2017 Author(s): Leonid A. Gavrilov, Natalia S. Gavrilova, Vyacheslav N. Krut'ko
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gavrilov-gavrilova-krutko-paper.pdf>

The Lee-Carter method, currently used for mortality forecasting, is based on the assumption that the historical evolution of mortality at all age groups is driven by one factor only. This approach cannot capture an additive manner of mortality decline observed before the 1960s. To overcome the limitation of the one-factor model of mortality and to determine the true number of factors underlying mortality changes over time, this paper suggests a new approach to mortality analysis and forecasting based on the method of latent variable analysis. The basic assumption of this approach is that most variation in mortality rates over time is a manifestation of a small number of latent variables, variation in which gives rise to the observed mortality patterns.

A-161 Title: Extreme Value Analysis of Mortality at the Oldest Ages: A Case Study Based on Individual Ages at Death
2017 Author(s): Samuel Gbari, Michel Poulain, Luc Dal, Michel Denuit
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gbari-poulain-dal-denuit-paper.pdf>

This paper studies the force of mortality at the oldest ages using the statistical tools from extreme value theory. A unique database recording all individual ages at death above 95 for extinct cohorts born in Belgium between 1886 and 1904 is used to illustrate the relevance of the proposed approach. No leveling off in the force of mortality at the oldest ages is found, and the analysis supports the existence of an upper limit to human lifetime for these cohorts. Therefore, assuming that the force of mortality becomes ultimately constant—that is, that the remaining lifetime tends to the negative exponential distribution as the attained age grows—is a conservative strategy for managing life annuities.

A-162 Title: A Comprehensive Analysis of the Patterns of Worldwide Mortality Evolution
2017 Author(s): Martin Genz
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-genz-paper.pdf>

Various sources deal with the question how the age distribution of deaths develops over time. In Börger et al (2016), a classification framework was developed that allows for a unique classification of mortality evolution patterns. In particular, the framework assigns a unique scenario to any possible mortality evolution. In contrast to many other classification approaches, this approach allows for so-called mixed scenarios, such as a combination of elements of compression and shifting mortality. Thus, it provides a more comprehensive picture of historical and potential future mortality evolution patterns.

Genz's paper summarizes this classification framework and discusses issues in its practical application. Then it applies the framework to mortality data for different countries all over the world, which yields a complete picture of historical mortality evolution patterns in those countries. The paper then discusses similarities and differences in the historical mortality evolution patterns between different populations.

A-163 Title: Mortality Inequality: Impact of Socioeconomic Factors

2017 Author(s): Sam Gutterman

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gutterman-paper.pdf>

Human behavior plays a significant role in shaping mortality experience. Two primary behavioral drivers of mortality assessed in this paper are smoking and obesity. The smoking epidemic has been on the wane for several decades in the U.S., but its adverse consequences on mortality will continue to be felt for quite some time. In the U.S., obesity is still on a 40-year rise, with its most significant effects on mortality expected in the future.

A-164 Title: Mortality Improvement Rates: Modeling and Parameter Uncertainty

2017 Author(s): Andrew Hunt, Andrés M. Villegas

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-hunt-villegas-paper.pdf>

Mortality improvement rates are difficult to estimate robustly, and models of them are subject to high levels of parameter uncertainty, since they are derived by dividing one uncertain quantity by another. Despite this, mortality improvement rate studies to date have not investigated parameter uncertainty due to the ad hoc methods used to fit the models to historical data. This paper adapts the Poisson model for the numbers of deaths at each age and year to model mortality improvement rates. This enables models of improvement rates to be fitted using standard maximum likelihood techniques and allows parameter uncertainty to be investigated using a standard bootstrapping approach. This paper illustrates the proposed modeling approach using data for populations in the U.S. and in England and Wales.

A-165 Title: Compiling a Very Large Sample of Centenarian Pedigrees to Ascertain Patterns of Inheritance and a Familial Propensity for Longevity Score

2017 Author(s): Lisa Nussbaum, Giacomo Nebbia, Annie Helmkamp, Stacy Andersen, Thomas Perls, Paola Sebastiani

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-nussbaum-nebbia-helmkamp-andersen-perls-sebastiani-paper.pdf>

This paper hypothesizes that determining common patterns of longevity (e.g., paternal, maternal, skipping generations) and level of risk according to which of one's relatives were long-lived can help inform actuaries about longevity risk. To explore this hypothesis, it proposes to perform network analyses of thousands of pedigrees that provide vital information for each family member. An important step of this work is to compile the largest possible samples of pedigrees with and without long-lived family members. It describes the process of hand curation of centenarian pedigrees and the software developed for the automated construction of such pedigrees.

- A-166 Title: Financial Shocks, Unexpected Expenses and Financial Experiences of Older Americans
 2017 Author(s): Anna M. Rappaport
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-rappaport-paper.pdf>
- This paper synthesizes the work on shocks from various studies and additional research to further understand the financial experiences of older Americans. It also offers perspectives on financial management and planning for middle market segment Americans as well as some suggestions for further research and responses to the findings.
- A-167 Title: Where is the Level of the Mortality Plateau?
 2017 Author(s): Roland Rau, Marcus Ebeling, Frederik Peters, Christina Bohk-Ewald, Trifon I. Missov
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-rau-ebeling-peters-bohnik-ewald-missov-paper.pdf>
- The goal of the analysis was to test whether there is support for a plateau of the population hazard at a level of 0.7 as estimated by Gampe (2010) with a nonparametric approach. The gamma-Gompertz models are used for the analysis. The gamma-Gompertz models are calibrated with data from the Human Mortality Database. The analysis shows that there is, indeed, support for a mortality plateau for women. At 0.8, it is slightly higher than suggested by Gampe (2010). If a mortality plateau exists for males, it is higher than for females, but the estimates were not convincing. For males, more data of centenarians and semi-supercentenarians are necessary to have more robust estimates.
- A-168 Title: Grouped Multivariate and Functional Time Series Forecasting: An Application to Annuity Pricing
 2017 Author(s): Han Lin Shang, Steven Haberman
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-shang-haberman-paper.pdf>
- Age-specific mortality rates are often disaggregated by different attributes, such as sex, state, ethnic group and socioeconomic status. In making social policies and pricing annuities at national and subnational levels, not only is it important to forecast mortality accurately, but forecasts at subnational levels should add up to the forecasts at the national level. This motivates recent developments of grouped functional time series methods to reconcile age-specific mortality forecasts. This paper extends these grouped functional time series forecasting methods to multivariate time series and applies them to produce point forecasts of mortality rates at older ages, from which fixed-term annuities for different ages and maturities can be priced. The grouped forecasting methods are shown not only to be useful for reconciling forecasts of age-specific mortality rates at national and subnational levels, but also to enjoy improved forecast accuracy. The improved forecast accuracy of mortality rates would be of great interest to the insurance and pension industries for estimating annuity prices, in particular at the level of population subgroups defined by key factors such as gender, region and socioeconomic grouping.

A-169 Title: Using Life Table Techniques to Model Mortality Rates for Small Populations
2017 Author(s): Jack C. Yue, Hsin Chung Wang
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-yue-wang-paper.pdf>

The study of human longevity has been a popular research topic due to the prolonging of life. However, the limited availability and poor quality of elderly data increase the difficulty of mortality modeling. It is particularly challenging if the size of the target population is small, and the parameter estimation of stochastic mortality models can be distorted. For example, the famous Lee-Carter model (Lee and Carter 1992) would have biased estimates for age-related parameters in the case of small populations. This study aims to provide a possible solution to deal with the parameter estimation of mortality models when the population size is small. This paper proposes graduation methods to modify the parameters' estimates of mortality models, similar to the process of constructing life tables where mortality rates are smoothed to remove the irregularity of some observed values. The graduation methods, including Whittaker graduation and partial standard mortality ratio, are applied to the Lee-Carter model to smooth the parameters' estimates and compared to the coherent Lee-Carter model (Li and Lee 2005). Computer simulation is used to evaluate the proposed approach, and findings are that the method does have smaller fitting errors when the population size is small.

A-170 Title: Longevity Greeks: What Should Insurers and Capital Market Investors Know About?
2017 Author(s): Kenneth Q. Zhou and Johnny S.-H. Li
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-zhou-li-paper.pdf>

Recently, it has been argued that capital markets may share some of the overwhelming longevity risk exposures borne by the pension and life insurance industries. The transfer of risk can be accomplished by trading standardized derivatives such as q-forwards that are linked to published mortality indexes. To strategize such trades, one may utilize "longevity Greeks," which are analogous to equity Greeks that have been used extensively in managing stock price risk. This paper first derives three important longevity Greeks—delta, gamma and vega—on the basis of an extended version of the Lee-Carter model that incorporates stochastic volatility. It then studies the properties of each longevity Greek and estimates the levels of effectiveness that different longevity Greek hedges can possibly achieve. The results reveal several interesting facts; for example, in a delta-vega hedge formed by q-forwards, the choice of reference ages does not materially affect hedge effectiveness, but the choice of times to maturity does. These facts may help insurers to better formulate their hedge portfolios, and issuers of mortality-linked securities to determine what security structures are more likely to attract liquidity.

- A-171 Title: Accuracy of Official High-Age Population Estimates, In England and Wales: An Evaluation
 2017 Author(s): Office for National Statistics
 URL: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/aging/methodologies/accuracyofofficialhighagepopulationestimatesinenglandandwalesanevaluation>
 This paper assesses the quality of the component input data for official midyear population estimates for ages 80 and over (deaths registrations, census estimates and migration estimates). The method used to distribute the official age 90 and over midyear estimate to single years of age above age 90 (the Kannisto-Thatcher method) is also assessed.
- A-172 Title: Mortality Projections from a Social Security Panel
 2017 Author(s): Mark Bye, Stephen Goss, Adrian Gallop, Jean-Claude Menard, Annie St-Jacques
 URL: <https://www.youtube.com/watch?v=CmnO5kPber8&t=2s>
 Representatives from three countries—the U.S., Canada and the U.K.—present their mortality projections for the years to come. They analyze contributors to mortality improvement as well as predictions regarding how likely it is to live to older ages 80, 90 and 100. Furthermore, they discuss some of the implications mortality projections have on social programs.
- A-173 Title: How to Die Young at a Very Old Age
 2017 Author(s): Dr. Nir Barzilai
 URL: <https://youtu.be/pOJqXXFWCzQ>
 Dr. Barzilai discusses his research into the genetics of human longevity. His focus is on how to extend a healthy life-span, not necessarily living a longer life. He goes through various topics on trying to determine what in the human genome or what in general can delay the process of aging. He ends by going over his own research on TAME and how metformin can increase a person's healthy life-span.
- A-174 Title: Suppressing Aging and Extending Longevity: Will the Twain Meet?
 2017 Author(s): Dr. Judith Campisi
 URL: <https://www.youtube.com/watch?v=Beax-wE4gsA&feature=youtu.be>
 In this talk Dr. Campisi goes over her recent research in attempting to understand the biological component behind aging. She discusses the various hypotheses her team went through and their logic behind their final conclusion regarding how cancer and aging are related and again delving deeper into what biological processes contribute to aging.

A-175 Title: On the heterogeneity of human populations as reflected by mortality dynamics

2017 Author(s): Demetris Avraam, Séverine Arnold, Olga Vasieva, Bakhtier Vasiev

URL: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5191885/>

The heterogeneity of populations is used to explain the variability of mortality rates across the life-span and their deviations from an exponential growth at young and very old ages. A mathematical model that combines the heterogeneity with the assumption that the mortality of each constituent subpopulation increases exponentially with age has been shown to successfully reproduce the entire mortality pattern across the life-span and its evolution over time. In this work the authors aim to show that the heterogeneity is not only a convenient consideration for fitting mortality data but is indeed the actual structure of the population as reflected by the mortality dynamics over age and time. In particular, they show that the model of heterogeneous population fits mortality data better than other commonly used mortality models. This was demonstrated using cohort data taken for the entire life-span as well as for only old ages. Also, it is shown that the model can reproduce seemingly contradicting observations in late-life mortality dynamics. Finally, they show that the homogenization of a population, observed by fitting the model to actual data of consecutive periods, can be associated with the evolution of allele frequencies if the heterogeneity is assumed to reflect the genetic variations within the population.

Appendix B: Census of Discussions

B-1	Title:	Summary of Panel Discussion on the Advancing Frontier of Human Survival
2014	Discussant(s):	James Vaupel
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1-soa-informal-discussant.pdf
		This presentation focuses on mortality evidence suggesting senescence is being postponed on a global basis over the last three centuries. As well, linear extrapolation is discussed as a possible extrapolation technique for future life expectancy and validated by being the only projection method able to pass the historical forecasting test. Future biomedical and technological possibilities that might lead to additional mortality improvements are also mentioned.
B-2	Title:	Summary of Panel Discussion on Perspectives and Implications to Stakeholders of Increasing Longevity
2014	Discussant(s):	Robert L. Brown, Jennifer A. Haid, Sally Hass, Sandy Timmermann
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1c-soa-informal-discussion.pdf
		This presentation covers implications of longevity to the general population. In particular, modifications to the traditional retirement structure are discussed, as well as the need for both private and governmental entities to step in and tend to the needs of a growing elderly population. Restrictive federal regulations and lack of public education are identified as recurring themes in hindering society's adaptation to an aging population.
B-3	Title:	Summary of Panel Discussion on Developing a Winning Strategy to Address the Good, the Bad and the Wrinkled of Our Aging Workforce
2014	Discussant(s):	Zhiwei Zhu, Leonid A. Gavrilov
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2c-soa-informal-discussion.pdf
		This presentation focuses on the roles employers will play in adjusting to an elderly population and, in particular, a more senior workforce. New retirement structures, including phased retirement, are discussed, as well as barriers to desirable solutions of employment for the aging baby boomers. The presenters also identify what type of employers will be more willing to adapt for an aging workforce than others.
B-4	Title:	Summary of Panel Discussion on Innovative Business Solutions to Respond to the Aging Society
2014	Discussant(s):	Tim Driver, Nigel W. Nunoo, Cindy Hounsell
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2-soa-informal-discussant.pdf
		This presentation focuses on how the aging society affects businesses and creates opportunities. The presenters identify challenges senior workers will face in seeking employment and how employers should be made aware of the benefits in having a more senior workforce. New opportunities for the financial industry services are identified, as well as the evolving issues and challenges of housing for seniors.

B-5	Title:	Summary of Panel Discussion on Data Sources and Projection Methods for Successfully Supporting the Needs of the Senior Market
2014	Discussant(s):	Louis Adam, Ward Kingkade, Jean-Marie Robine
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3c-discussion.pdf
		This presentation discusses challenges in retrieving data of good quality, as well as how to overcome those challenges. The presenters also identify trends in past mortality improvements, as well as considerations to take when applying projection techniques.
B-6	Title:	Summary of Panel Discussion on Proactive Strategies for Managing Long-Term Care Needs in Retirement
2014	Discussant(s):	John Cutler, Steve Schoonveld, Sandra Timmermann
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4c-soa-informal-discussion.pdf
		This presentation focuses on incoming long-term care needs from the aging baby boomers. Challenges associated with long-term care plans are identified, as well as their importance in ensuring the financial security of seniors. Solutions for addressing the long-term care crisis are discussed.
B-7	Title:	Summary of Panel Discussion on Could Moses Live to Be 120?
2014	Discussant(s):	Timothy F. Harris
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4-soa-informal-discussant.pdf
		This presentation focuses on aging and its close connections with longevity. The presenter identifies aging as the underlying factor of all age-related diseases and how its postponement would have higher mortality improvements than cures for other age-related diseases. Challenges in studying aging are identified, with the most prominent being how to measure aging. The session also discusses the role of genetics in longevity, as well as factors that have been shown to elongate life-spans.
B-8	Title:	Summary of Panel Discussion on Mortality Projections from a Social Security Perspective
2014	Discussant(s):	Stephen C. Goss, Adrian Gallop, Jean-Claude Menard
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5-dicussion.pdf
		Prominent actuaries from the U.S. Social Security Administration, Canada's Office of the Superintendent of Financial Institutions, and the U.K. Government Actuary's Department discussed key factors and issues associated with mortality projections on a global scale. The shifting age structure, which refers to the increasing ratio of elderly to non-elderly, is identified as a major issue that has not been studied as thoroughly yet.
B-9	Title:	Summary of Panel Discussion on Leaving Worries Behind: Risk Management Strategies for Individuals to Address the Economic Issues Related to Increased Longevity
2014	Discussant(s):	Gordon Woo, Heather Snyder
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5c-discussion.pdf
		This presentation focuses on risk management strategies to deal with arising longevity issues. Proposed financial products and services include deeply deferred annuities, longevity insurance and riders that allow for desirable flexibility, as well as continuing

care communities. Challenges associated with these strategies include restrictive legislations, misalignment of incentives for brokers within annuity space, and lack of education of public when it comes to retirement.

B-10	Title:	Discussant Comments for Session on Innovative Retirement Products
2014	Discussant(s):	Kai Kaufhold
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1a-kaufhold-discussant.pdf
B-11	Title:	Discussant Comments for Session on Happily Ever After, Marriage and Old Age Mortality
2014	Discussant(s):	Jean-Marc Fix
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-1b-fix-discussion.pdf
B-12	Title:	Discussant Comments for Session on From Population to Insured Lives, Finding Longevity Drivers
2014	Discussant(s):	Tom Edwalds
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2a-edwalds-discussant-comments.pdf
B-13	Title:	Discussant Comments for Session on Behavior and Causes of Death: Impact on Mortality and Mortality Modeling
2014	Discussant(s):	S. Jay Olshansky
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-2b-olshansky-discussant-comments.pdf
B-14	Title:	Discussant Comments for Session on Learning from Genetics
2014	Discussant(s):	Leonard Hayflick
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-hayflick.pdf
B-15	Title:	Discussant Comments for Session on Learning from Genetics
2014	Discussant(s):	Tom Bakos (reply to Leonard Hayflick from B-14)
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-gs3-bakos-reply.pdf
B-16	Title:	Discussant Comments for Session on Mortality Age Patterns: Trends and Projections
2014	Discussant(s):	Johnny Li
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3a-li-discussant-comments.pdf
B-17	Title:	Discussant Comments for Session on Societal Changes and Adaptations as a Result of Longer Life Spans
2014	Discussant(s):	Robert Brown
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-3b-brown-discussant-comments.pdf
B-18	Title:	Discussant Comments for Session on the Changing Age Distribution of Deaths
2014	Discussant(s):	Jean-Marie Robine
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4a-robine-discussant-comments.pdf

B-19	Title:	Discussant Comments for Session on Longevity and Lifestyle
2014	Discussant(s):	Arnold Dicke
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-4b-dicke-discussant-comments.pdf
B-20	Title:	Discussant Comments for Session on Aging and Changes in Health Status
2014	Discussant(s):	Eric Stallard
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5a-stallard.pdf
B-21	Title:	Discussant Comments for Session on Longevity and Cognitive Impairment
2014	Discussant(s):	S. Jay Olshansky
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-olshansky-discussant-comments.pdf
B-22	Title:	Discussant Comments for Session on Longevity and Cognitive Impairment
2014	Discussant(s):	Robert Pokorski
	URL:	https://www.soa.org/essays-monographs/2014-living-to-100/mono-li14-5b-pokorski.pdf
B-23	Title:	Session 1A Informal Discussion Transcript
2017	Discussant(s):	N/A
	URL:	https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1a-transcript.pdf
		When data are broken down by region, state or county, the data get smaller and therefore less reliable. However, Dr. Andreev indicates that his findings using state-by-state data relatively match a study from the University of Washington that broke data down by county to show trends in life expectancy. As observed by Larry Pinzur, mortality was the highest in the Deep South and lowest on the coasts. There is more validation work to be done if this method is used to make more accurate predictions, but this is a positive first step toward validation of this approach.
B-24	Title:	Session 1B Informal Discussion Transcript
2017	Discussant(s):	N/A
	URL:	https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1b-transcript.pdf
		This transcript includes a question and answer session with authors presenting their papers. It includes a discussion on the application of the Gompertz law depending on period effect. There is also an explanation of the differing levels of plateaus for different countries from Roland Rau. Additionally, there are comments about the reliability of U.S. data and the fact that there isn't a consistent method applied to adjust U.S. data at advanced ages.
B-25	Title:	Panel Discussion on Biggest Current Policy Challenges from the UK/US/Canada as a Result of Aging
2017	Discussant(s):	Robert Brow, John Cutler, David Sinclair
	URL:	https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-1c-transcript.pdf
		In this discussion, panelists discuss various topics such as arising issues and possible solutions to a growing elderly workforce as well as a crisis seen across many countries of people not saving enough for retirement. They delve into what they believe to be

problematic about the current environment surrounding long-term care and present ways in which the private industry can help alleviate some of these issues.

B-26 Title: Session 2A Panel: Drivers of Future Mortality

2017 Discussant(s): Allen M. Klein, Phillip Smalley, Laurie M. Orlov

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2a-transcript.pdf>

This panel explores future drivers of mortality improvements. The discussion includes identifying the key drivers of mortality and the positives and negatives of the changes that are occurring for each driver. It also includes an overview of how innovative technology will help the older population live longer and more comfortably from their home. Finally, the discussion takes a deep dive into genetic testing and how precision medicine could impact future mortality.

B-27 Title: Session 2B Informal Discussion Transcript

2017 Discussant(s):

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2b-transcript.pdf>

This monograph is a question and answer session surrounding some of the data and methodology used to develop models for the populations attaining the oldest ages. There is a discussion about accuracy of census data compared to administrative data. There is conversation around the drivers of the increase in prominence of the population at the oldest ages both in reaching 100 and in the ability to reach close to a potential maximum in age.

B-28 Title: Panel Discussion on What Can Individuals and the Private Sector Do to Address the Challenges Resulting from Aging?

2017 Discussant(s): Susana Harding, Cindy Hounsell, David Sinclair

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-2c-transcript.pdf>

This discussion focuses mainly on the issue of lack of savings. Representatives consider extensively how, in the U.K., Singapore and the U.S., people are simply not saving enough for retirement and are not aware of how much their expenses will be as a retiree. With longer life-spans and people underestimating how long they will live, this problem is perpetuated. Each panelist provides various approaches she or he feels will help address this issue. In general, this panel covers how people are not saving enough, why it's important to save and how to save enough for retirement.

B-29 Title: Session 3A Informal Discussion Transcript

2017 Discussant(s):

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3a-transcript.pdf>

There are many ways to apply data, including socioeconomic classes, causes of death and age. One of the ways studied by Alai et al is gap in life expectancies in U.K., but that could be complemented by other models and studies.

- B-30 Title: Session 3B Informal Discussion Transcript
 2017 Discussant(s):
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3b-transcript.pdf>
 This transcript is a question and answer session where the authors from the section have the opportunity to address the comments made by Kaufhold in the session discussion. Additional questions concern application of the methods presented in the papers.
- B-31 Title: Panel Discussion on Challenges and Strategies for Financing the Increasingly Long Life
 2017 Discussant(s): Vickie Bajtelsmit, Ben Miclette, Vekevia Tillman-Jones
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-3c-transcript.pdf>
 This panel begins with Vickie Bajtelsmit running through a high-level overview of a study she recently conducted analyzing retirement savings. The results of this study demonstrate what people can do to facilitate that they have enough saved for retirement, given increased life expectancy. A majority of the remainder of this discussion focuses on long-term care, the challenges it faces and some possible solutions.
- B-32 Title: Panel Discussion on Longevity in the Public Eye
 2017 Discussant(s): Sam Gutterman, Anna Rappaport
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4a-transcript.pdf>
 This discussion starts by covering Anna Rappaport’s article and clarifying aspects of each focus group as well as some limitations of the surveys and research used in the article. The remainder of the discussion focuses on the U.S. health care system and its struggle with high health care costs.
- B-33 Title: Session 4B Informal Discussion Transcript
 2017 Discussant(s):
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4b-transcript.pdf>
 This transcript covers a question and answer section for the presentations and papers from session 4b from the 2017 symposium. Arnold defends the use of cross-sectional life tables for the heterogeneity model used. Villegas clarifies the confidence intervals in the research surrounding mortality predictions at older ages.
- B-34 Title: Panel Discussion on Innovative Business Solutions to Respond to an Aging Society
 2017 Discussant(s): Dr. Lisa D’ Ambrosio, Timothy Harris, Jodi Olshevski
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-4c-transcript.pdf>
 This discussion addresses various solutions already introduced in the private industry to help people adapt to living longer as well as pushing people to start thinking about life at an older age sooner. Much of the focus was on how technology can play a role in assisting the elderly population along with the issues that arise with increased use of technology.

- B-35 Title: Panel Discussion on Mortality and Longevity Research
 2017 Discussant(s): Dale Hall, Cindy MacDonald, Andy Peterson
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-5a-transcript.pdf>
 Panelists cover different research and papers the SOA has been involved with and how various resources have developed over time. Tips are provided regarding various databases, and takeaways from some of the research are discussed.
- B-36 Title: Discussant Comments for Session on What is Different Today for Post-Retirement Financial Planning?
 2017 Discussant(s): Tamara Burden
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-5b-transcript.pdf>
 Rather than a panel, Tamara Burden speaks of the challenges facing seniors as they retire and why it is different today saving for retirement than for previous generations. She offers ways in which both individuals can adapt to succeed in retirement as well as ways the industry can aid them in doing so.
- B-37 Title: Session 6A: Mortality Improvement Approaches
 Discussant(s): Laurence Pinzur
 2017 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6a-transcript.pdf>
 In this discussion, Pinzur explains the process of modeling mortality improvement and some of the challenges that one faces when attempting to do so. He walks through the process and details behind updating mortality tables from one-dimensional to two-dimensional tables. A review of the particular assumptions and inputs is explained in the discussion, including setting near-term rates, long-term rates and the smoothing process between them. The argument is made for consolidating tables currently used for different actuarial purposes into one comprehensive table.
- B-38 Title: Discussant Comments for Session on The Changing Face of Elder Care
 2017 Discussant(s): Phyllis Mitzen
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-6b-transcript.pdf>
 This discussion goes over Medicaid, Medicare and Social Security, explaining their origins and how they contributed to what the U.S. has today, the Affordable Care Act. It then delves deeper into various forms of community living for elders and how they can make living in old age easier.
- B-39 Title: Panel Discussion on Insights into Successful Aging
 2017 Discussant(s): Cynthia Hutchins, Vekevia Jones, Jim Toole
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsii-transcript.pdf>
 This panel goes over ways to be successful in retirement in financial planning, healthy living and remaining sociable. It discusses two different studies on what people are worried about most in retirement and how to address those fears.

- B-40 Title: Senior Citizen in 2050
 2017 Discussant(s): Robert Bourbeau, Neil Charness, Thomas Getzen, S. Jay Olshansky, Dr. Philip Smalley
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsvi-transcript.pdf>
 This session of the symposium starts by each panelist giving their dystopian view of what life will be like in 2050, specifically for the older population. Panelists discuss the potential implications of today's issues projected into 2050 and what they believe we can do to have a brighter future for retirees.
- B-41 Title: The Nitty Gritty of Human Mortality Database
 2017 Discussant(s): Magali Barbieri
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-gsv-transcript.pdf>
 This discussion gives an overview of the Human Mortality Database and the process of how it has been developed. Magali Barbieri describes the goals of the HMD, which are to provide data where life tables can be developed across multiple countries that are comparable, accessible, flexible in format, reproducible and having sound quality. The process of building the life tables is explained, which uses a combination of methods to develop rates for different age groups.
- B-42 Title: Discussant Comments for Session on Comparing Mortality of Different Groups
 2017 Discussant(s): Kai Kaufhold
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-kaufhold-discussant-comments.pdf>
 In this discussion, Kai Kaufhold comments and explains the papers from the corresponding session. He indicates that simple models are preferable when they can accurately predict results. He also challenges authors of the reports to try testing other models with similar methodologies to see if similar conclusions can be drawn.
- B-43 Title: Discussant Comments for Session on Mortality Projections
 2017 Discussant(s): W. Ward Kingkade
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-kingkade-discussant-comments.pdf>
 This discussion reviews some of the presented concepts that are being used to enhance mortality extrapolation models. Suggestions are made for more rigorous model testing to confirm that the proposed methods are creating significantly better projections. Additionally, comments are made on using frailty as an explanation of trends observed between different types of populations. Turning to frailty as an explanation is difficult to prove or disprove because a possible explanation including frailty will always exist.
- B-44 Title: Discussant Comments for Session on Mortality Inequality: Impact of Socioeconomic Factors
 2017 Discussant(s): S. Jay Olshansky
 URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-olshansky-discussant-comments.pdf>
 This discussion challenges the idea that eliminating diseases or risk factors will create large increases in life expectancy. The underlying factor that will ultimately limit life-span

is genetics, and as the body ages it deteriorates because it isn't built for long-term use. Additionally, the examination discusses that health inequalities are ubiquitous and have persisted over time, and they will continue to persist. Eliminating one cause of death that impacts the lower socioeconomic classes disproportionately will likely shift those inequalities to other risk factors. This problem is difficult to solve with public policy or medicine.

B-45 Title: Discussant Comments for Session on Older-Age Mortality Trends

2017 Discussant(s): Jean-Marc Fix

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-2b-discussant-comments.pdf>

Jean-Marc Fix discusses papers from the session and their impact on understanding the prominence of centenarians. Fix indicates that centenarians are difficult and interesting to study because they are rare and that represents a potentially large impact on our society. It is crucial to verify and clean the data being used at these extremely old ages to confirm that the data are reliable and helping to produce accurate models. Understanding the trends at extreme old ages could give insight into the potential social impact that the growing prominence of centenarians will have on society.

B-46 Title: Discussant Comments for Session on Longevity in the Public Eye

2017 Discussant(s): Sam Gutterman

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-4a-discussant-comments.pdf>

In this section Gutterman discusses two separate papers. One analyzes domestic and international health care as well as the retirement system. The other gathers information from various studies about financial shocks, focusing on the impact on retirees while offering some insight as what the results of these studies demonstrate. Mr. Gutterman offers his takeaways from each study as well as ways for improvement for each.

B-47 Title: Discussant Comments for Session on Data Sources and Analysis

2017 Discussant(s): Thomas Edwalds

URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-edwalds-discussant-comments.pdf>

One of the crucial steps to accurately predicting future longevity is to understand and feel confident in the data being used. Edwalds claims that the Human Mortality Database is the gold standard of data for these studies because it includes records and statistics that are very useful. Building out pedigrees around centenarians to gain more data elements could be a useful way to analyze more potential predictors of future mortality.

B-48 Title: Discussant Comments for Session on Late-Life Mortality Curves
2017 Discussant(s): Jean-Marie Robine
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-monograph-session-robine-discussant-comments.pdf>

In this transcript, Robine discusses three papers addressing the idea of late life mortality curves. There is tension between papers that disagree over the trajectory of mortality past age 110. Mr. Robine remarks on the applicability of the Gompertz model to assume continue linear trends to the oldest age. There is a review of the adult longevity revolution and discussion on its applicability to all populations across all ages. The author also challenges researchers to better understand the shape of the distribution of frailty to better understand future trends in mortality.

B-49 Title: Foreword
2017 Discussant(s): Timothy F. Harris, Jean-Marc Fix
URL: <https://www.soa.org/essays-monographs/2017-living-to-100/2017-living-100-foreword.pdf>

Appendix C: Categorization of Articles by Practice Area and Analytical Phase

To help the reader better understand the breadth and coverage of the symposia material, we have developed a heat map to organize the material by practice area—retirement, health, life, and other—and by analytical phase.

This heat map helps illustrate areas for which there is broad coverage and areas where future research is required.

Practice Area / Focus		Analytical Phase							
		Data	Development of Raw Rates		Projection of Future Rates		Implications and Opportunities		Other
		Sources and Due Diligence	Best Estimates	Enhancements - Older Ages	Numerical Extrapolations	Driver-Based Approaches	Business	Policy	
General Population		2, 3, 4, 11, 21, 27, 29, 30, 33, 61, 127, 129, 130, 138, 139, 148, 158, 162, 165, 171	2, 3, 11, 29, 33, 55, 61, 71, 72, 73, 127, 136, 138, 139, 144	2, 3, 11, 27, 30, 33, 51, 55, 71, 72, 136, 138, 139, 158	1, 11, 33, 40, 41, 55, 71, 72, 73, 122, 158, 159, 160, 167, 171	9, 33, 40, 41, 55, 73, 127, 129, 152, 160	33	33	146, 148, 162, 165
Retirement, Annuity	Government	36, 70, 102, 154	36, 63, 82, 102, 114, 154	45, 54, 82, 91, 114	42, 54, 67, 82, 90, 91, 98, 100, 154	114, 154	70, 116, 126, 142	32, 37, 42, 65, 67, 69, 70, 98, 102, 116, 140, 141, 147	
	Corporate						20, 31, 34, 66, 68, 82, 97, 105, 113, 140	20, 31, 34, 68, 97, 99, 105, 106, 113, 140, 147	
	Individual Annuity	35, 36	35, 36, 82, 168	35, 54, 82, 91, 161	35, 43, 54, 82, 90, 91, 100, 161, 168	35, 151	43, 52, 82, 126, 142, 147		124, 147
General Health		47, 50, 87, 101, 117, 131, 155, 163	47, 50, 103, 131, 155, 163	121, 123	48, 77, 120	48, 50, 87, 93, 95, 101, 103, 117, 120, 121, 123, 151, 163		47, 93, 94, 121, 155	76
Health Insurance	Government (Medicare/Medicaid/LTC)	46, 49	46, 63, 172?		172	86, 96, 119	34, 104, 147, 150	34, 78, 80, 85, 96, 104, 110, 119, 157, 174	150, 157, 166
	Private (LTC/Major Medical)	38, 46, 49	46, 115	115	38, 111	79, 86, 111, 112	97, 111, 112, 150	78, 97, 110, 173	150
Life Insurance	Life (Group/Individual)	36, 149	6, 36, 82, 149	6, 54, 82, 91	6, 54, 82, 90, 91, 100, 111	6, 7, 62, 111	52, 82, 111, 149	149	
Other	Reinsurance *								
	Banking/Capital Markets	36	36, 82	54, 82	54, 82		53, 82, 125, 170		170
Theoretical (has the potential to be applied across all practice areas)		5, 12, 13, 14, 28, 39, 58, 107, 108, 109, 123, 132, 133, 156, 161, 168	5, 16, 22, 23, 24, 26, 28, 39, 44, 56, 58, 107, 109, 118, 128, 133, 145, 164	5, 10, 12, 13, 14, 15, 16, 22, 23, 24, 25, 26, 39, 44, 56, 57, 58, 60, 64, 88, 107, 108, 118, 143, 145, 156, 161, 171	5, 12, 13, 14, 15, 16, 17, 22, 23, 24, 25, 26, 44, 56, 57, 58, 60, 64, 81, 88, 89, 92, 108, 118, 128, 137, 143, 145, 164, 169	5, 8, 17, 39, 132, 133			18, 19, 134, 135, 147, 164, 169

green:	good coverage
yellow:	some coverage
red:	little or no coverage
white:	other

* Reinsurance practitioners are active in research and writing, but it is generally in a consulting role to life and other industries rather than about applications specific to reinsurance itself.

Appendix D: Summary of Mortality Models

Table 01 overleaf below summarizes parametric models that were referenced in the symposia conference presentations. They range from older models (e.g., Gompertz from 1825) to more contemporary ones (e.g., Heligman and Pollard from 1980). Note that this table is not intended to be a complete list of all mortality curves which may be used by practitioners, but is presented as a summary of approaches discussed at prior Living to 100 symposia.

Table 02 summarizes non-parametric models that were discussed in the 2017 symposium. The models are non-parametric in the sense that the mortality rate is not parametrized with a small number of parameters like those models in Table 01. Those non-parametric models are based on the concepts of existing models, such as parametric models in Table 01 and Lee-Carter models, but they are expanded to have more explanatory variables and more factors considered, to be more dynamic and to fit the data better.

One of the non-parametric models in Table 02 is the extension of the Lee-Carter model by Zhou and Li.^[A-170] The model introduced the stochastic volatility for mortality rates. More detail on the model and its theoretical application to mortality hedging is provided at end of this appendix.

Table 01: Summary of Parametric Models Referenced in Symposia Conference Presentations

Exponential Class	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Gompertz	1825	$\mu_x = \alpha e^{-\beta x}$	μ_x = force of mortality α = baseline mortality, shape β = aging component	Exponential increase of death rates with age. The growth is very slow at the beginning.	Questionable fit at older ages due to 'late-life mortality deceleration'. Good fit between age 30 to 90	Continued acceleration at all ages, unbounded and tends to 1. There is an asymptote for the Gompertz function, however, in the mortality modeling case, the rate will not reach its asymptote.	Least squared errors	1. 1941 Standard Ordinary Mortality Table 2. 1958 Standard Ordinary Mortality Table 3. K-tables for life insurance valuation. Cannot capture convexity, e.g. not used in 1958 CSO Mortality table. It holds for United States population data.
Makeham	1860	$\mu_x = \alpha e^{-\beta x} + \gamma$	μ_x = force of mortality α = baseline mortality, shape β = aging component γ = non-aging component (e.g. accidents)	Gompertz model with an age-independent parameter for accidental death	Questionable fit at older ages due to 'late-life mortality deceleration'	Continued acceleration at all ages, unbounded and tends to 1	Least squared errors	Used by CIA9704 mortality table for older age. 1941 CSO table. Almost any 30 year range of ages in arbitrary mortality table can be successfully regressed using a Makeham formula
Heligman and Pollard (HP)	1980	$\frac{q_x}{1 - q_x} = A^{(x+B)^C} + D e^{-E(\frac{x}{\theta})^F} + GH^x$	qx = mortality rate There are three components: A, B, C = mortality from birth to first year of life (A and B), then decrease in mortality rates through childhood (C) D, E, F = Mortality from ages 10-40 (captures the "accident hump") G, H = mortality levels and changes in the older population	The third term (older ages) can be interpreted as a version of Gompertz law of mortality. There are additional parameters to better fit childhood and younger ages (10-40) where accident years affect the mortality. For age above 50, the first two terms can be neglected.	May be difficult to fit with the large number of parameters. Parameters are highly correlated which may impede one's ability to isolate them.	Follows Gompertz's law of mortality, depending on one's view of old-age mortality this may not be appropriate	CDC: Least squared errors (non-linear weighted). Iterative procedure requires starting points which were taken from existing papers/fits. Fitting was done piece-wise on first, second and third components, smoothing methods applied to ensure smooth transition between pieces.	Used by CDC for smoothing and extrapolation for ages 66-109. Supported with empirical evidence.
Logistic Class of Parametric Models	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Perks	1932	$\mu_x = \frac{\alpha e^{-\beta x} + \gamma}{\theta e^{-\beta x} + 1}$	μ_x = force of mortality α, θ = baseline mortality β = aging component γ = level component	Plus one additional parameter from Makeham, and logistic. Beard (1971) showed that logistic function can arise from heterogenous populations where each member has a Makeham distribution. It has better adjustment to older ages in industrialized countries. Force of mortality tends to a constant as x increases	Actuaries do not use this for pricing annuities. Limitation hard to estimate parameters and variance covariance matrix. (ref. Inference for Logistic-type Models for the Force of Mortality, Louis G. Doray, PH.D, ASA, January 7-9, 2008). Difficult to estimate parameters by MLE	Force of mortality reaches an asymptote as age increases to α/θ . Plateaus at a certain level, $1 - e^{-\beta/C}$	Least squared errors. It can be difficult to perform maximum likelihood estimation.	
Beard	1971	$\mu_x = \frac{\alpha e^{-\beta x}}{\theta e^{-\beta x} + 1}$	μ_x = force of mortality α, θ = baseline mortality β = aging component	Same as perks but sets gamma term to zero. Force of mortality tends to a constant as x increases.	Difficult to estimate parameters by MLE	Force of mortality reaches an asymptote as age increases to α/θ . Plateaus at a certain level	Least squared errors	
Kannisto	1997	$\mu_x = \frac{\alpha e^{-\beta x}}{\alpha e^{-\beta x} + 1}$ or $\frac{\mu_x}{1 - \mu_x} = \alpha e^{-\beta x}$	μ_x = force of mortality α = baseline mortality β = aging component	- Similar to Beard, but down to two parameters - Also similar to Gompertz, but fitted to a logistic function. Force of mortality tends to a constant as x increases	Difficult to estimate parameters by MLE	Plateaus at a certain level: $1 - e^{-\beta}$, or about 0.632.	Least squared errors. It can be difficult to perform maximum likelihood estimation.	Fits and approximates old-age mortality better than Gompertz, Weibull, and Heligman and Pollard

Table 01: Summary of Parametric Models Referenced in Symposia Conference Presentations (*continued*)

Weibull Models	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Weibull	1951	$\mu(t) = -\frac{1}{S(t)} \frac{dS(t)}{dt}$ $= \frac{m}{t_0} \left(\frac{t - \gamma}{t_0} \right)^{m-1}$	μ = force of mortality γ = position parameter t_0 = scale parameter m = shape parameter	$m < 1$: the mortality rate should be decreasing over time. $m=1$: constant death rate over time. $m > 1$: death rate increases with time. This is one of the limiting forms of the distribution of the lowest observed value in a large sample.	This model considerably overestimates the ascent of mortality with advancing age, the discrepancy with observed data widening progressively. This tendency appears earlier and is stronger among the females.		Least squared errors	Japanese Mortality Table JLT15 (1980), JLT17 (1990) and JLT19 (2000)
Mixed Weibull		$S(t) = \sum_{i=1}^m p_i \exp \left[- \left(\frac{\text{Max}(t - \gamma_i, 0)}{t_{0i}} \right)^{m_i} \right]$ where $\sum_{i=1}^m p_i = 1$ ($p_i > 0$) mix ratio	μ = force of mortality γ = position parameter t_0 = scale parameter p = mixed ratio, m = shape parameter	A Mixed Weibull Model consists of two or more Weibull components combined in some fixed proportion.	Parameters are hard to estimate.		Least squared errors	Japanese Mortality Table JLT15 (1980), JLT17 (1990) and JLT19 (2000)
The Quadratic Model	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
The Quadratic model		$\ln(\mu_x) = a + bx + cx^2$	a, b, c = model coefficients	The log of force of mortality can be fitted by a quadratic function.		Limited range of ages was used by Coale & Kisker (1990) for the purpose of interpolating the force of mortality in the range of ages from 85 to 110, between data up to age 85 and an assumed value at age 110.	Least squared errors	
Older Age Specific Methods	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Coale Kisker (CK)	1990	$k(x) = k(x-1) - R, \quad x \geq \text{last credible age}$ where $k(x) = \ln \left(\frac{m_x}{m_{x-1}} \right)$ $R \text{ is a constant}$	m_x = central rate of death R = constant solved by assuming a maximum age	- Assumes that mortality rates increase at a varying rate (in contrast to Gompertz which increases at a constant rate)	- Assumes a maximum age where the central rate of death (m_x) is 1.0	Assumes a maximum age where the central rate of death (m_x) is 1.0 Possible for a crossover of male and female mortality. Some practitioners may choose to cap the female mortality rates at the male rates. Coale and Kisker (1990) assumed that the terminal central rate of death for females was 0.8 rather than 1.0 to avoid a crossover.	Straightforward once a maximum age (and associated central death rate) is set, the constant R can be solved for directly and the mortality rates can be determined through an iterative procedure.	
Himes Preston Condran (HPC)	1994	Fitting of "standard": $\text{logit}(m_x^s) = \alpha + \beta x$ Relational fitting to the standard: $\text{logit}(m_x) = \delta + \gamma \text{logit}(m_x^s)$	m_x^s = central rate of death for the standard m_x = central rate of death for the table intended for extrapolation $\alpha, \beta, \delta, \gamma$ = regression coefficients	Essentially extrapolation of a straight line fit to the logit mortality rates. A "standard" set of mortality rates is set by calibrating to a large number of mortality rates across different countries. Logit function fitted through age 80-99. Extrapolated for ages 100 and beyond. Other life tables can then be related to the "standard" schedule through a logit regression. This model represents the typical mortality pattern at advanced ages based on the patterns observed in a variety of countries and periods				Adopted by UN for table closing across nations

Table 02: Summary of Non-Parametric Models Referenced in 2017 Symposium

Factor Analysis Models	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Gavrilov, Gavrilova and Krutko	2017	$\mu(x, t) = a_0(x) + a_1(x)F_1(t) + a_2(x)F_2(t)$	$\mu(x,t)$ = the force of mortality at age x time t. α = three sets of parameters depending on age x only F = two sets of parameters depending on time t only	Factor analysis is used to determine true number of factors underlying mortality changes over time. Two factors are capable of explaining high 90's percent of the variance.		Factor analysis for oldest-old ages (65-100 years) found two factors explaining variation of mortality at extremely old ages in the US.	P-technique of factor analysis, promax rotation method	
Mortality Improvement Models	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Hunt and Villegas	2017	$-\ln\left(\frac{m_{x,t}}{m_{x,t-1}}\right) = -\Delta m_{x,t} = \eta_{x,t},$ $\eta_{x,t} = \alpha_x + \sum_{i=1}^N \beta_x^{(i)} \kappa_t^{(i)} + \gamma_{t-x}$	m = the central mortality rate at age x in year t. η = the rate of change of m . α, κ, β = parameters in the predictor structure using age/period/cohort for η	Directly model mortality improvements with a more robust mathematical approach to parameter estimation	Inclusion of the α term is subjective and depends on model user's preference. The term gives a constant component to the rate of improvement which might violate biological reasonableness, but it does fit trends.		Maximum likelihood techniques can be used to estimate parameters which allows for parameter uncertainty to be investigated	
Lee-Carter Model with Stochastic Volatility	Publish Date	Model Formula	Parameters	Interpretation	Limitations	Older Age Implications	Fitting Procedure	Mortality Tables and Other Notes
Zhou and Li	2017	$\ln(m_{x,t}) = \alpha_x + \beta_x \kappa_t,$ $\begin{cases} \kappa_t = \kappa_{t-1} + \theta + \epsilon_t \\ \epsilon_t = \sqrt{h_t} \eta_t \\ h_t = \omega + a\epsilon_{t-1}^2 + bh_{t-1} \end{cases}$	m = central death rate α = mortality at age x κ = overall level of mortality in year t, follows a random walk β = sensitivity of mortality at age x to changes in κ θ = draft of κ ϵ = innovation of κ h = conditional variance of ϵ η = standard random variable w, a, b = parameters in the GARCH(1,1) process of h	Based on the LEE-Carter model, the model introduces stochastic process to the overall level of mortality in year t.	The model is complex.		Poisson maximum likelihood method	

Visualization of the parametric models

In the next few pages, each model from the Table 01 overleaf is graphed with U.S. population data from the U.S. Social Security Administration (SSA) to give readers a visual representation of the various methodologies. In the figures below, there are two plots: one yellow and one gray. Through age 95, approximately the last age at which the SSA data is credible, both the yellow and the gray follow the model of interest. After age 95, the yellow plot continues along the model of interest, projecting post-95 mortality with the pre-95 data. The gray plot follows a different course. From ages 95 to 100, it uses a graduation formula, and past age 100, mortality rates are extended at a rate of 5 percent per year for males and 6 percent per year for females (the percentages are derived from an analysis of Social Security Charter Old-Age and Survivors Insurance Trust Fund beneficiaries).

The first three charts—Figure D-01, Figure D-02 and Figure D-03—show the plots for exponential parametric models. As is apparent in the graphs, the exponential parametric models output steeper mortality increases than the SSA assumptions for ages over 95.

Figure D-01: Parametric Models
Makeham (fitted through age 95)

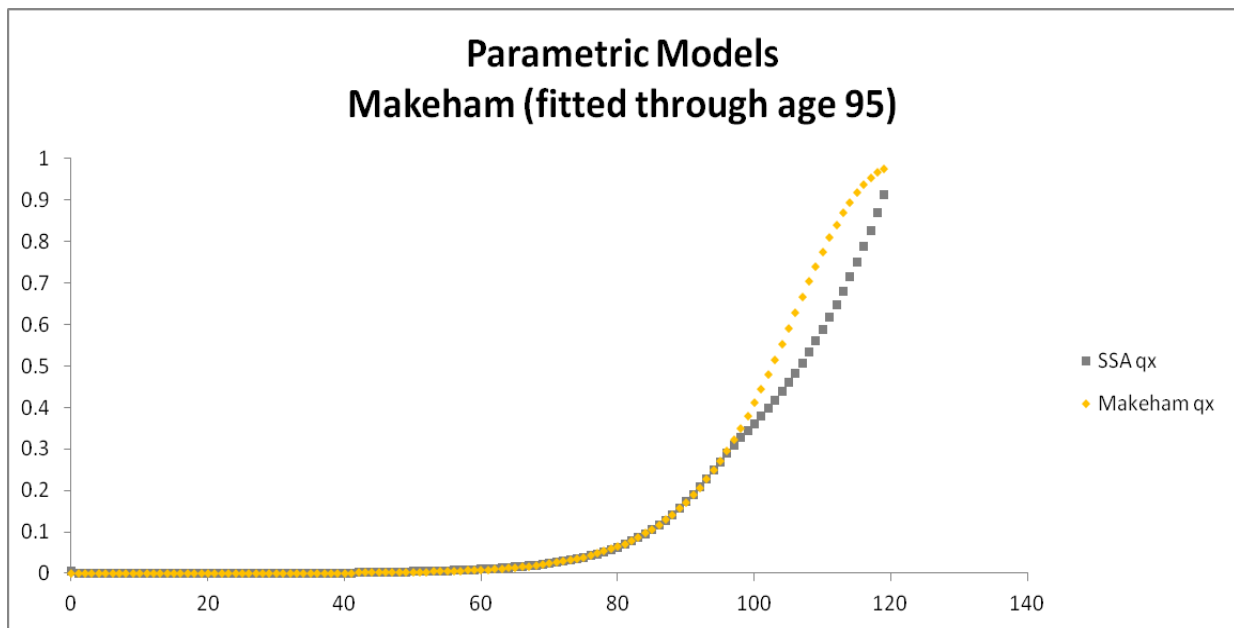


Figure D-02: Parametric Models
Gompertz (fitted through age 95)

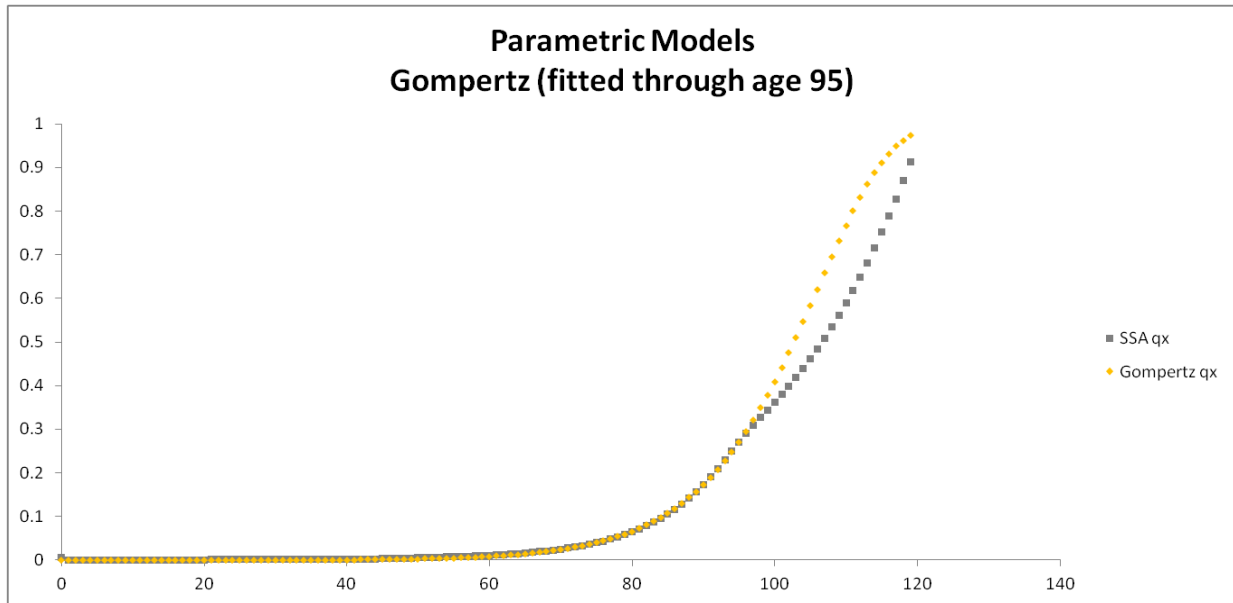
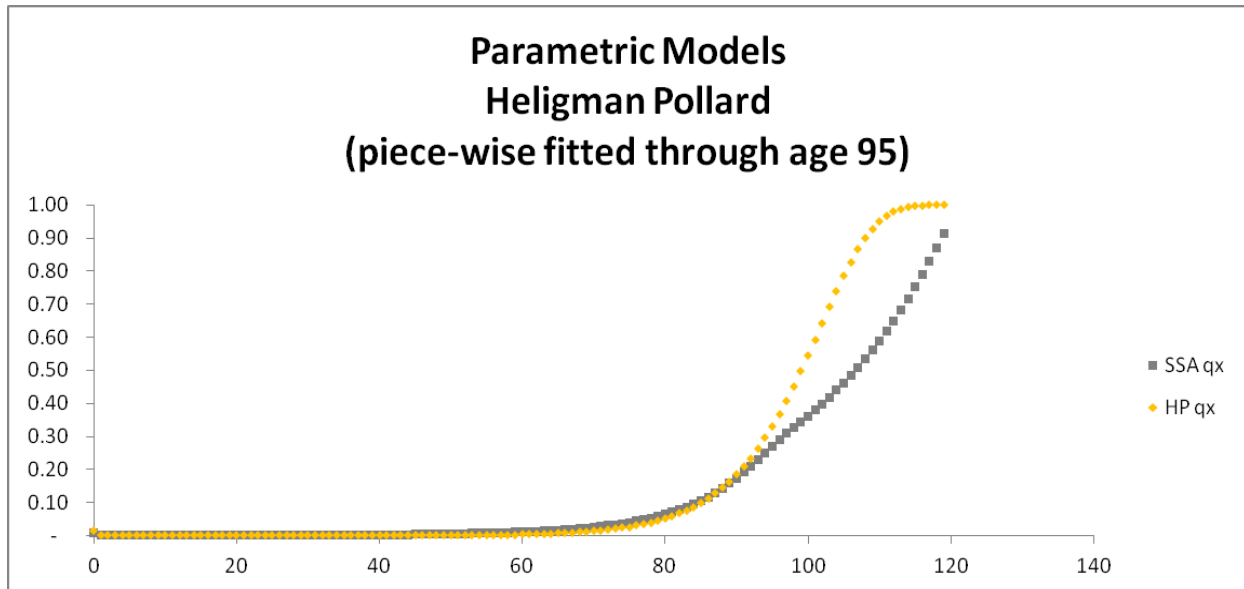


Figure D-03: Parametric Models
Heligman Pollard
(piece-wise fitted through age 95)



The next series of charts—Figures D-04, D-05, D-06, D-07 and D-08—show the plots for logistic parametric models. Logistic parametric models follow the “mortality deceleration” trend at advanced ages, so unlike the exponential models, the logistic models level off after the age of 95. As a result, SSA assumption records a steeper rate of mortality than logistic models after the age of 95.

Figure D-04: Logistic Class of Parametric Models
Perks (fitted through age 95)

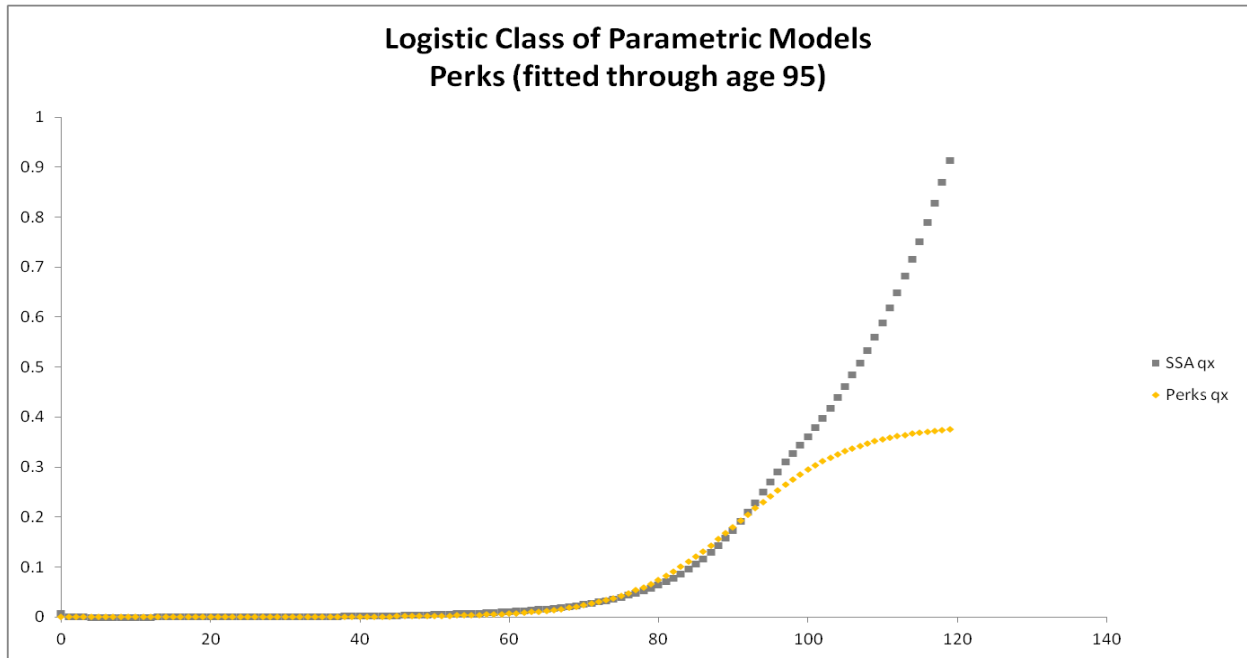


Figure D-05: Logistic Class of Parametric Models
Beard (fitted through age 95)

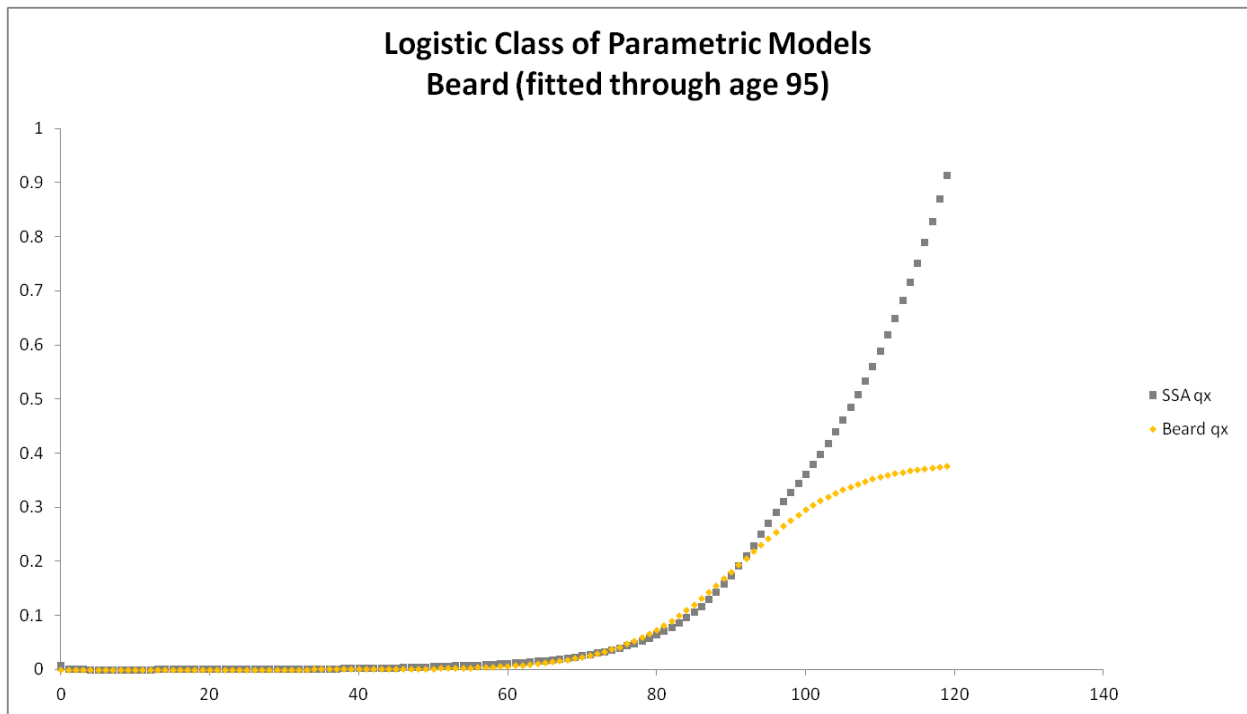


Figure D-06: Logistic Class of Parametric Models
Kannisto (fitted through age 95)

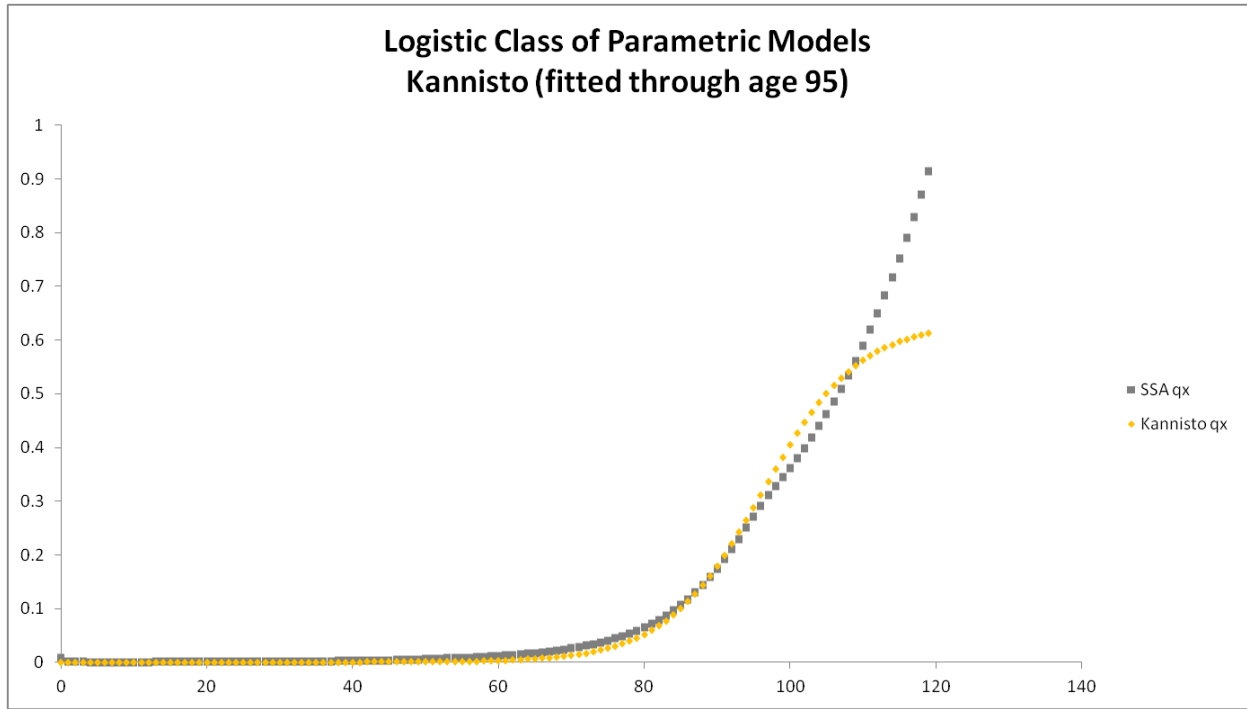


Figure D-07: Weibull Models
Weibull (fitted through age 95)

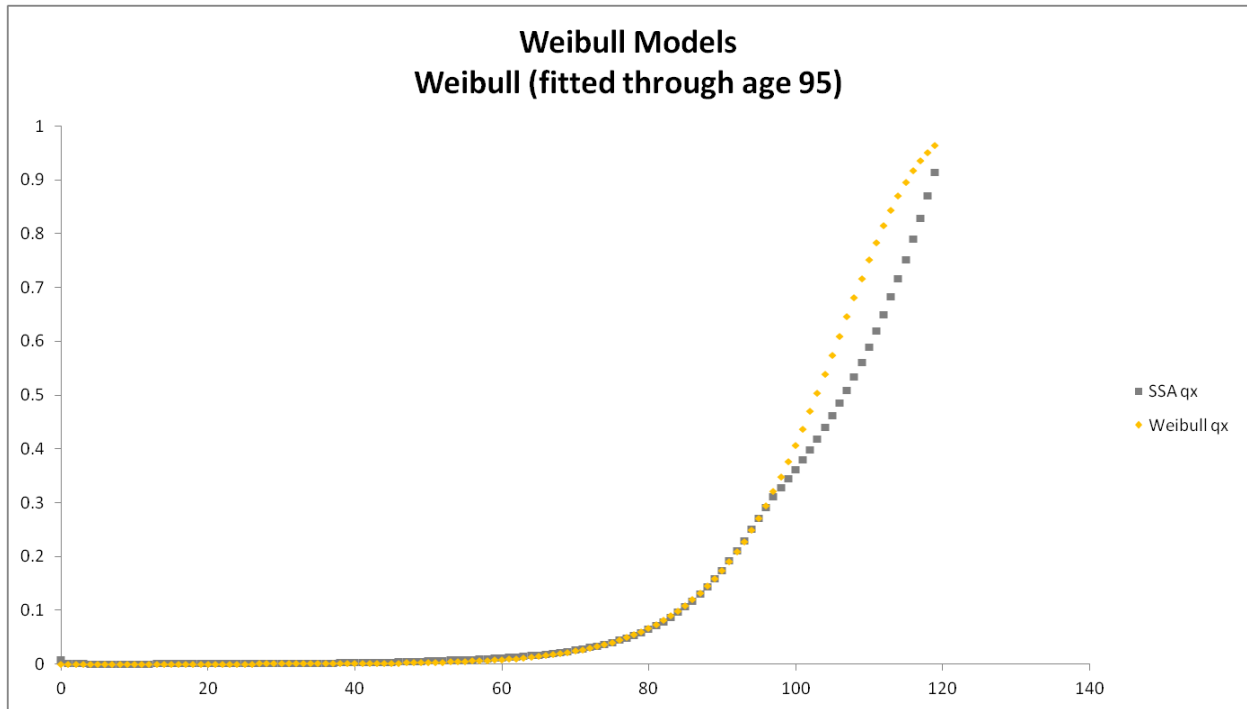
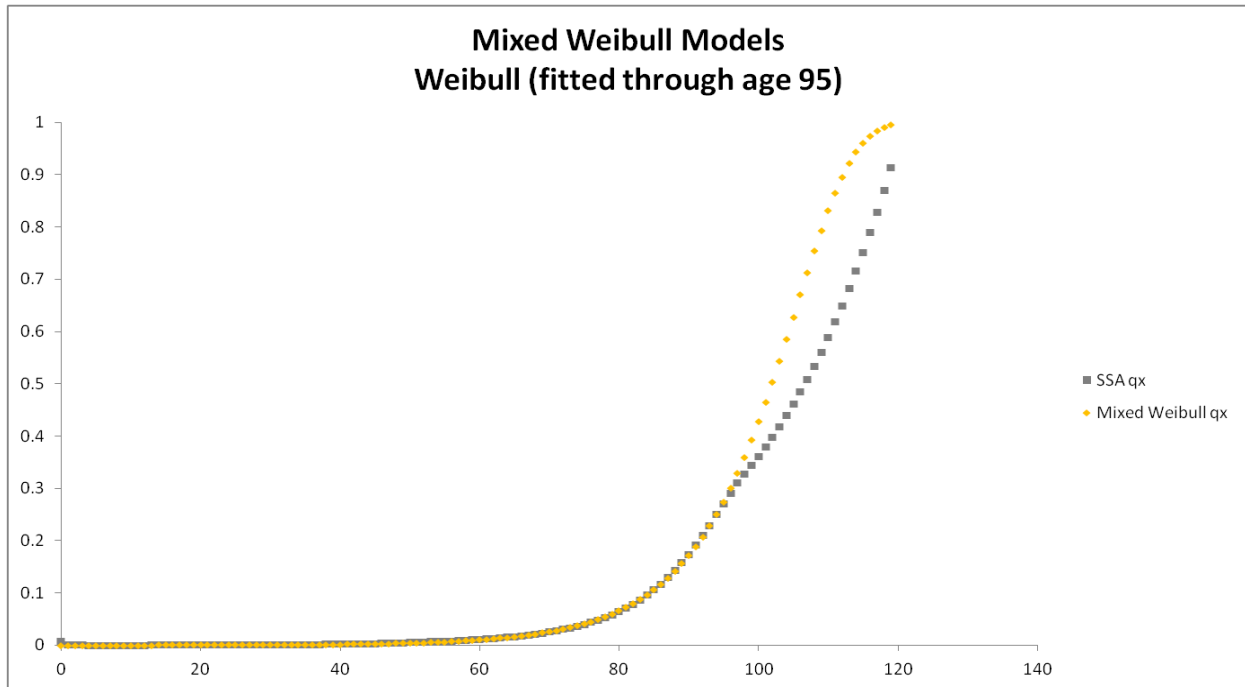


Figure D-08: Mixed Weibull Models
Weibull (fitted through age 95)



Mortality Greeks and q-forwards

The rest of this appendix will focus on the stochastic volatility model proposed by Zhou and Li. As an application of the model, Zhou and Li studied the model-based hedging of mortality risks. Capital market investors may be interested in taking longevity risk in exchange for a risk premium. Such transactions could be of interest for actuaries to hedge longevity risk experienced by many insurance products. One proposed product to carry out such a hedging strategy is a q-forward. The capital market participation in the mortality market has a huge potential impact on how aging is financed and risk managed, but currently it is only at the stage of theoretical and conceptual formulation. Zhou and Li explored the theory of the mortality Greeks and hedging with q-forwards.

A q-forward is a zero-coupon swap with the floating leg proportional to the realized death rate at a given age (reference age) in a certain year (time to maturity) and its fixed leg proportional to the corresponding predetermined forward mortality rate. Using the Lee-Carter model, Zhou and Li derive longevity Greeks, which are augmented by a generalized autoregressive conditional heteroscedasticity (GARCH) model to capture stochastic volatility of mortality over time. The specific longevity Greeks derived in this paper are delta, the first-order sensitivity to the time-0 value of the period effect; gamma, the second-order sensitivity to the time-0 period effect; and vega, the first-order sensitivity to changes in the time-0 value of the conditional volatility.^[A-170]

Each of the Greeks has a general range of support for most mortality datasets. Delta is always negative, which means the expected probability of survival to a certain age is negatively related to the time-0 period effect. Gamma is the first-order sensitivity of the longevity delta, meaning if gamma is negative, the probability of survival to a given age is a concave function, and if gamma is positive, it is a convex function. Longevity vega depends critically on the parameter b, which measures the extent of the GARCH effect. If b equals 0, the longevity vega is always zero. This means the expected probability of survival to a given age is no longer sensitive to the time-0 value of the conditional volatility.^[A-170]

Zhou and Li derived the longevity Greeks for both annuity liabilities and q-forward. They then analyzed the longevity Greeks of the q-forwards. The derivation indicates that the graph of $\exp(-\exp(Y_{x,t}(1)))$ against $Y_{x,t}(1)$ has large implications for the expected present value of the q-forward. The curve has three main properties. First, for all real values of $Y_{x,t}(1)$, the curve is downward sloping. Second, for all $Y_{x,t}(1) < 0$, the curve is concave. Third, for $Y_{x,t}(1) < -1$, the curve becomes increasingly concave as $Y_{x,t}(1)$ increases. The portion of the curve that is of interest to actuaries using these Greeks is covered by the three stated rules.^[A-170]

As mentioned longevity deltas are always negative, which makes sense because of the curve described above being downward sloping. The longevity delta increases, approaching zero, when the time to maturity of a q-forward lengthens, but it decreases when the reference age increases.^[A-170]

Analysis of the longevity gamma of q-forwards uncovers multiple important observations. Due to the curve concavity, gamma is negative for the relevant datasets analyzed. As time to maturity increases, gamma becomes less negative due to decreased concavity. Gamma's relationship to the reference age is more complicated because curve concavity and the beta variable of the Lee-Carter model act in opposite directions. For reference ages below 85, gamma will become more negative, but for reference ages above 85, gamma will increase. This relationship between gamma and reference age is jagged because the beta parameter effects are not smooth across all ages.^[A-170]

The longevity vega of a q-forward is negative over the reference ages (60–89) and times to maturity (1–30) analyzed in the Zhou and Li paper. This can be interpreted to mean the expected present value of a q-forward decreases as the conditional volatility of the current period effect increases. Vega's response to reference age also depends on the age selected. For ages under 85, vega becomes more negative as reference age increases. At approximately age 85, vega begins increasing again as reference age increases. Likewise, as time to maturity increases, vega decreases until about 12 years and then begins to increase again.^[A-170]

Effective Hedging

Hedging can be done with only one q-forward to match one longevity Greek at a time or with multiple q-forwards to match multiple longevity Greeks. Zhou and Li first analyzed one q-forward to match each delta and vega one at a time. The study indicates it is inappropriate to gamma hedge if it isn't simultaneously delta hedging. For both Greeks, the hedge effectiveness is insensitive to the choice of a reference age. Delta hedging is almost equally effective as the optimal hedge when the time to maturity is under 15 years but very ineffective for longer times to maturity. Vega hedging approaches the optimal hedge when the time to maturity is longer. This is associated with the moments of the period effect under the GARCH process.^[A-170]

As mentioned, hedging can also be done with two q-forwards to match two longevity Greeks. Since the study doesn't consider gamma independently of delta, the two options are to match delta and gamma or delta and vega. Another necessary condition of this process when the q-forwards have different times to maturity is for the notional amounts of both q-forwards to be positive. That means the hedger must be the fixed leg receiver in both q-forwards to ensure decrease in risk. The ratio of the two matched longevity Greeks for the liability being matched must be strictly between the ratios of the two q-forwards. Below are the observations of the impact of reference age and time to maturity for each combination of hedges:^[A-170]

- ▶ Delta-gamma hedges
Most reference age combinations yield very low or negative hedge effectiveness. Reduction in risk occurs only when one age is above 86 and the other is not. When analyzing the impact of time-to-maturity combinations, delta-gamma hedges are almost as effective as optimal hedges for all combinations except when both times to maturity are high.
- ▶ Delta-vega hedges
Hedge effectiveness is close to optimal regardless of reference ages selected. However, delta-vega hedges perform well only for some combinations of time to maturity. For example, if reference ages are set to be

80 and 89, this hedge will perform well only when the reference age 80 has time to maturity less than 10 and the reference age 89 has time to maturity greater than 15 years, or the reference age 89 is paired with a time to maturity of less than 15 years and the reference age 80 is greater than 10 years to maturity.

Discussion on Model-Based Hedging

A validation process for these hedges is to remove the assumptions of the model and instead bootstrap mortality rates from the population rates. The result indicated by Zhou and Li is that effectiveness of all hedges is decreased as would be expected. However, delta and vega hedges can still have comparable success when the right times to maturity are selected. Key conclusions of sensitivities to reference age and age to maturity for each combination of hedged Greeks made in the section above hold true in the bootstrapping validation.^[A-170]

A few notable caveats from Zhou and Li are that stochastic volatility is data dependent, and if it doesn't exist, it makes the longevity vega irrelevant. Additionally, the authors ignored population basis risk and small sample risk.^[A-170]

Kaufhold indicates that the crucial takeaway of this hedging analysis is that the optimal strategy depends on the composition of the portfolio's age and time to maturity. Kaufhold also challenges this model-based hedging due to the difficulty in applying to different types of mortality modeling processes.^[B-42]

Zhou indicates in his remarks that using a model-based hedging approach allows for a simplified and realistic hedging approach because it can be done with a single q-forward instead of a larger portfolio of q-forwards. He indicates that this approach could be applied to other models like the CBD as long as they have a period effect. Zhou also notes this hedging process is a static hedge, which means that the q-forward is purchased at time zero to hedge the position based on one longevity Greek or a combination. Under this approach the hedger then would not continue to trade the q-forwards.^[B-30]