

# Literature Review and Assessment of Mortality Improvement Rates in the U.S. Population: Past Experience and Future Long-Term Trends

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## I. Executive summary

The purpose of this report is to provide pension actuaries and the Retirement Plans Experience Committee (RPEC) with a literature review and an assessment of mortality improvement rates in the United States population. The report addresses the following topics, which were of particular interest to the RPEC:

- An overview of common mortality improvement projection models (section IV) and a more detailed analysis of the U.K. Continuous Mortality Investigation (CMI) model (section V)
- A range of professional opinions regarding a long-term estimate of mortality improvement in the United States (section VI)
- The extent and interaction of age, period and year-of-birth cohort effects in U.S. mortality improvement (section VII)
- External factors that might be correlated with variations in mortality improvement, such as socioeconomic status and lifestyle (section VIII)

### **CMI model**

The CMI uses a sophisticated framework that incorporates current rates using an interpolation mechanism, a user-selected long-term mortality improvement rate, and a formula allowing flexibility in convergence periods. We did not find any specific reason this approach would not be appropriate for the United States population.

### **Long-term rate of mortality improvement in the United States**

Among the wide range of opinions among academic researchers, all sources we studied agree historical data shows some degree of continuous mortality improvement in the aggregate U.S. population over the last century. However, we found researchers tend to fall into the extremes — assuming either a maximum age to human longevity or future lifespans with no predetermined biological limit — with very little middle ground.

One of the few opinions that appears to have been developed in a balanced manner is the Social Security Administration's 2011 Technical Panel on Assumptions and Methods, which provides an implied improvement rate of 1.26 percent<sup>1</sup>. We believe the long-term intermediate-cost assumption in the Social Security Administration's 2012 Trustees report — 0.73 percent<sup>2</sup> —

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<sup>1</sup> The 2011 Technical Panel on Assumptions and Methods recommended a target life expectancy at birth of 88.7 in 2085. According to the Office of the Chief Actuary 2012, this can be achieved by assuming a 1.26 percent reduction in annual death rates for all ages and both sexes combined. A new Technical Panel is appointed every four years by the Social Security Advisory Board, an independent, bipartisan board created to advise the President, Congress, and the Commissioner of Social Security on matters related to Social Security programs.

<sup>2</sup> Long-term assumption for years 2036-2086, all ages and both sexes combined.

provides a lower bound for mortality improvement in the United States. Our literature search was unable to find any reliable estimates of an upper bound.

### **Extent and interaction of age, period and cohort effects in U.S. mortality improvement**

Recent approaches to modeling mortality improvements, including the CMI methodology, are based on projections by age, period and cohort (APC). Note that there is some lack of precision in how the term “cohort effect” is used in longevity research. This report uses cohort effect as proposed by Yang (2008).

Cohort effects represent variations in mortality across groups of individuals born in the same year or years. Cohort effects may arise when each succeeding cohort carries with it the imprint of physical and social exposures from gestation to old age that bear upon its morbidity and mortality risk in a specific way.

Evidence suggests that APC effects exist in the United States. However, there is a lack of consensus regarding whether a cohort or period effect has been dominant in particular causes of death. Research indicates that a period or cohort effect is generally modest when the other effects are simultaneously controlled. In section V of this report, we discuss further how the CMI model incorporates APC effects.

### **Other factors that affect mortality improvement patterns in the United States**

While we were able to find considerable research into U.S. base mortality rates by race and socioeconomic factors, we found very little on their effect on U.S. mortality improvement rates.

Socioeconomic factors. Research indicates that wealth, income, and education impact baseline mortality and mortality improvement. Individuals in higher socioeconomic groups (identified by level of education achieved) may experience aggregate mortality improvements between 0.5 and 1 percent per year greater than the general population. There was no indication as to how long this effect might persist.

Smoking. Studies continue to show that smoking has a significant effect on mortality in the United States. While literature on U.S. population mortality improvement already accounts for a reduced percentage of smokers, research supports that mortality improvement levels for nonsmokers are significantly greater than improvement levels for smokers. Moreover, future cohort effects are expected to appear as a result of changes in smoking behavior.

Obesity. Lack of reliable data makes it difficult to quantify the long-term impact of increasing levels of obesity within the U.S. population on mortality improvement. Nevertheless, studies suggest that period effects will appear as a result of health campaigns impacting obesity levels at all ages in the next decades.

## II. Reliances and limitations

### II.A. Use of the term “review”

The services we performed throughout this engagement were advisory in nature; therefore, this report does not represent an assurance report or opinion, nor does it constitute an audit, review, examination or other form of attestation as those terms are defined by the American Institute of Certified Public Accountants (AICPA). Any use of the term “review” within this report should be interpreted in the common use of that term and not in the definition of review promulgated by the AICPA. Also, this report does not constitute advice or a legal opinion.

### II.B. Data and qualitative information

In preparing our analysis, we relied on data and qualitative information collected from available literature. Any inaccuracies or inconsistencies in the data could have a significant effect on our results.

We did not review the data provided to us because such a review was outside the scope of our engagement.

### II.C. Responsible party for methods and assumptions

Bruce Rosner, FSA, MAAA; Chris Raham, FSA, MAAA; Francisco Orduna, FSA, MAAA; Michael Chan, FSA, MAAA; and Lynn Xue, FSA, MAAA, are responsible for this report. We meet the U.S. Qualification Standards of the American Academy of Actuaries to perform this engagement and provide the findings contained herein. Comments or questions regarding this report should be directed to Bruce Rosner (212.773.1190) or Chris Raham (212.773.9064), who are also available to provide supplemental information and/or explanations as requested.

### III. Introduction

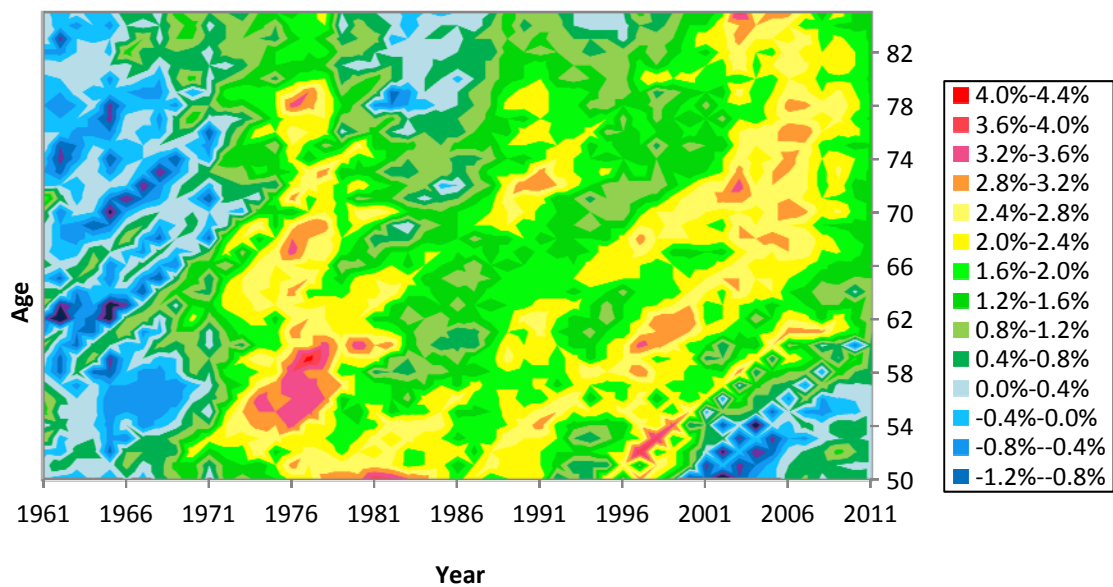
The purpose of this report is to provide actuaries and the Retirement Plans Experience Committee (RPEC) with background information they can use to develop future mortality improvement assumptions.

Mortality improvement is the measure of how mortality rates change over time. In other words, a flat mortality improvement rate assumption of 1 percent means that mortality rates during 2013 are expected to be 1 percent lower than 2012 mortality rates for the corresponding ages.

Figure 1 and Figure 2 below illustrate historical mortality improvement rates in the United States using a heat map. In these graphs, red represents a reduction in mortality of about 4 percent, whereas the blue areas represent an increase in mortality of about 0.4 percent or more.

**Figure 1. United States mortality improvement for males, ages 50–85**

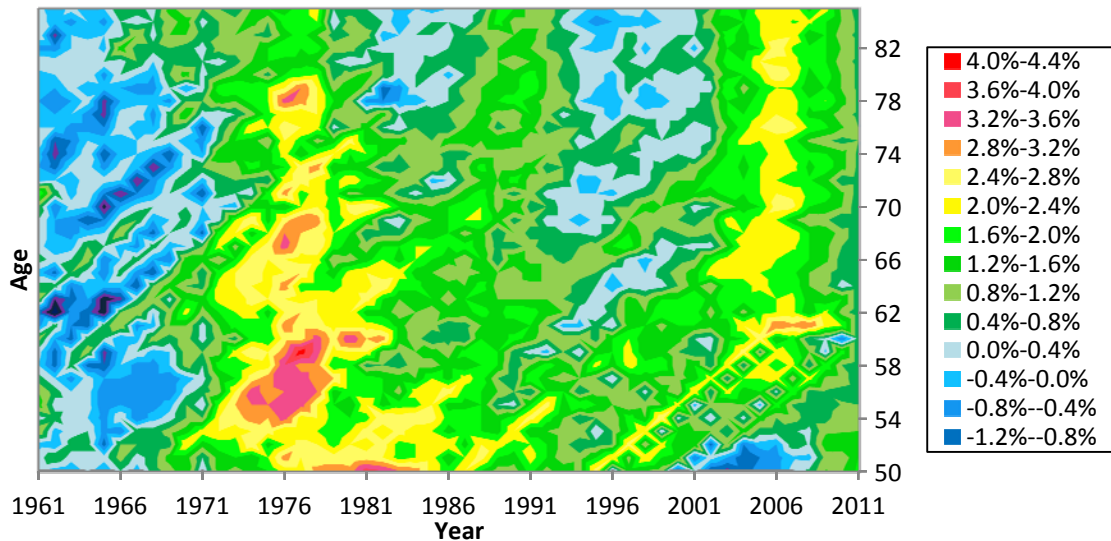
**Source: Data from Human Mortality Database, converted by Ernst & Young LLP**





**Figure 2. United States mortality improvement for females, ages 50–85**

Source: Data from Human Mortality Database, converted by Ernst & Young LLP



Literature typically specifies future mortality improvement assumptions against a number of dimensions.

- Gender. Male and female mortality rates do not change at the same rate.
- Age. During different historical periods, the various factors that underlie mortality improvement have not affected all ages equally. For example, better medical procedures to treat heart disease will tend to improve mortality at older ages more than at younger ages.
- Period. Changes to the mortality improvement levels occur over a short-term or long-term period across all age groups. For example, short-term period assumptions can include delayed effects from previous medical advances, whereas long-term period assumptions may be based on long-term historical trends or long-term estimates of future technological/societal changes.
- Cohort. Rather than by period, it is possible to specify mortality improvement by year of birth. The implication of specifying assumptions based on year of birth is that, in future years, the associated factors affect only the people born during a particular period rather than everyone passing through a certain age.

Historically, actuaries in the United States have tended to project gender-specific mortality improvements by age only; that is, a single perpetual improvement rate is applied in each age. However, in the United States and around the world, actuaries have begun to recognize a need for assumptions that transition from short-term to long-term effects, effectively creating a third dimension — calendar year — to mortality improvement rates.

- In 1992, Ronald Lee and Lawrence Carter published their seminal paper “Modeling and Forecasting U.S. Mortality,” which uses historical trends in mortality to project future mortality improvements that vary by age and projection year.
- In 2002, the Continuous Mortality Investigation (CMI) in the United Kingdom established mortality improvement rates that varied by gender, age, cohort and projection year and have since replaced that interim model with a more sophisticated version. The current model is discussed extensively in section V of this report.
- In the United States, the RPEC recently developed the interim mortality improvement Scale BB, which was created using rates that vary by projection year. However, the RPEC ultimately collapsed the rates into a set that does not vary by projection year to simplify use with existing modeling and valuation systems. The RPEC has stated its intention to produce a model that incorporates gender, age and calendar year.

A large number of factors influence the rate of mortality improvement. Many of those factors, however, are not independent of each other, which makes any analysis by factor a complex process. Literature generally classifies changes into technological, medical, environmental and societal categories. The Office of the Chief Actuary (OCACT) in the Social Security Administration suggests some likely factors that have influenced mortality improvements over the past century in their report “The Long-Range Demographic Assumptions for the 2012 Trustees Report”:

- Access to primary medical care for the general population (in particular, access due to Medicare and Medicaid health coverage for the elderly, disabled, and poor),
- Discovery and general availability of antibiotics and immunizations,
- Clean water supply and waste removal, and
- The rapid rate of growth in the general standard of living.

The report also lists some other factors that may influence future mortality improvements:

- The development and application of new diagnostic, surgical, and life-sustaining techniques,
- The rate of future increases in health spending and the efficiency of that spending relative to mortality improvement,
- The presence of environmental pollutants,
- Changes in amount and type of physical activity,
- Improvements in nutrition,
- The incidence of violence and suicide,
- The isolation and treatment of causes of disease,
- The emergence of new forms of disease,
- The evolution of existing forms of disease,
- Improvements in prenatal care,
- The prevalence of obesity,

- The prevalence of cigarette smoking,
- The misuse of drugs (including alcohol),
- The extent to which people assume responsibility for their own health,
- Education regarding health, and
- Changes in our perception of the value of life.

While it may be possible to analyze each of the above effects and use them to predict the path of future mortality improvements, to our knowledge no researcher has ever performed an analysis of this type and used it to create a projection of future mortality improvements.

Furthermore, future rates of mortality improvement may also be affected by the existence of a potential limit to the human lifespan. Such a limit would reduce the impact of mortality improvements at older ages for any long-term estimates.

We have reviewed existing literature pertaining to future mortality improvements and broken our research down into two main areas:

- Mortality forecasting models and techniques. We discuss various models that have been used to project mortality improvements and weigh some of the pros and cons of the different approaches. We also include a section on the model recently developed by the CMI as this is one of the more sophisticated approaches, and is under consideration by the RPEC for use as a mortality projection model in the United States.
- Model assumptions. We summarize research that can be used to develop assumptions for a mortality improvement projection model. In particular, we first discuss literature that focuses on the overall long-term rate of mortality improvement, and then discuss literature that focuses on different factors which influence mortality improvements, including age-period-cohort (APC) factors and other considerations.

## IV. Mortality forecasting models and techniques

This section provides a summary of models currently used to project mortality improvement from both a population and insured/pensioner perspective.

Mortality forecasting models can be classified into the following categories:

- Extrapolative. Extrapolative methods are based on projecting historical trends in mortality into the future. Simple extrapolative methods rely on the basic notion that the conditions which led to changing mortality rates in the past will continue to have a similar impact in the future. Advances in medicine or the emergence of new diseases that have a significantly different impact than those in the past could invalidate the results of an extrapolative projection. Insured mortality improvement scales used in the United States have generally been developed using extrapolative techniques combined with professional judgment.
  - *Parametric methods* involve fitting a parameterized curve to data and projecting trends in these parameters forward. However, the shape of the curve may not continue to describe mortality satisfactorily in the future. This includes penalized or P-spline interpolation/extrapolation and Lee-Carter–type approaches (discussed in more detail later).
  - *Targeting methods* involve assuming a long-term target or set of targets for mortality improvement that the population will approach over time. See section V.A.2 for more information on how this approach is used in the CMI model.
- Process-based. Process-based methods concentrate on the factors that determine deaths and attempt to model mortality rates from a bio-medical perspective. This class includes the cause-of-death-type of models. The main difficulty with these models is that they generally assume independence among the causes of death, while in reality the different causes can be interrelated.
- Explanatory. Explanatory-based models use regression to predict mortality based on economic or environmental factors (e.g., changes in lifetime smoking patterns). This type of model requires not only a determination of appropriate explanatory variables, but also their prediction, which might not be any simpler than predicting mortality directly. This type of model is not commonly used and will not be covered in this report.

Based on our literature review, it is a prevailing practice to consider multiple modeling approaches to produce a single projection.

The CMI evaluated several models before selecting their current modeling approach. In the following section, we describe some of the models considered by the CMI and present them as a sampling of approaches available to practitioners.

#### IV.A. Lee-Carter

Initially developed by Lee and Carter in 1992, the Lee-Carter model is an example of an extrapolative model used by demographers for projecting mortality. Historical age-specific mortality rates are entered into the model, and the model produces forecasted mortality rates by age and projection year. Various modifications to the Lee-Carter model have been proposed since its introduction in 1992, some of which are discussed later in this report.

The Lee-Carter model is purely extrapolative and does not incorporate any knowledge about medical, behavioral or social influences on mortality change. It is a basic time-series model that draws a trendline for each age into the future using historical mortality data. The Lee-Carter model's single combined estimation process results in similar trendlines for ages near each other.

As the model is purely extrapolative, accuracy relies upon the continuation of historical patterns. Despite this, it is interesting to note that Lee and Carter (1992) found a highly linear decline and relatively constant variance in the trend parameters over a 90-year period from 1900–89. This is surprising given the significant medical, behavioral and societal changes during the period. Nonetheless, the linearity and stability of this decline in mortality rates, despite the changing mix of factors driving mortality improvement, gives some researchers confidence there is a stable long-term trend that will continue.

Because the Lee-Carter model is a time-series model, it is possible to create a statistical distribution to measure uncertainty. This means that different “sample paths” of future mortality rates can be generated stochastically.<sup>3</sup> This is valuable as it recognizes that future mortality rates will likely unfold differently from current best-estimate assumptions. The potential variability is calibrated from historical data but also depends on the choice and structure of the statistical model being used. The Lee-Carter model, for example, can lead to narrower prediction intervals than other statistical models (e.g., the Cairns-Blake-Dowd model), which may not be a desirable characteristic given the intended use of the model.

The Lee-Carter model has been extensively studied, and many variations and improvements have been suggested. See Renshaw and Haberman (2006) and Li, Hardy and Tan (2009) for more information on adjustments to the Lee-Carter model.

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<sup>3</sup> The CMI working papers define a “sample path” to mean “a single realization of the future course of a quantity represented by a stochastic process...a single outcome of a probabilistic experiment.”

## Considerations around the Lee-Carter model

### Advantages

- Parsimonious. The model is relatively simple to specify and yet has been shown to successfully capture the high level trend in mortality improvement from 1900–89.
- Ability to generate sample paths. The model is a stochastic process model capable of generating sample paths and a range of possible outcomes.

### Disadvantages

- Cohort effect. The model does not explicitly allow for cohort effects.
- Stochastic capabilities. Sample paths may not represent biologically plausible futures, and the range of results may be too narrow.
- Narrow prediction intervals. The model setup is constrained and can lead to prediction intervals that are overly narrow since parameter uncertainty is ignored in the development of prediction intervals.
- Backtesting. Backtesting by the CMI Working Group (CMI 2007b) shows that projections using the Lee-Carter model, based on data to 1992, would not have worked well in recent years. It is difficult to judge whether the recent results represent a structural shift from the past, or if long-term trends will persist and current results are an anomaly.
- Extrapolation. The model is completely extrapolative and assumes that future mortality rates will follow long-term historical trends.
- Smoothing. The CMI Working Group concluded that the Lee-Carter model does not sufficiently smooth out the volatility in mortality rates between calendar years, which makes it difficult to visually identify features in the data (CMI 2007b).

## IV.B. Lee-Carter APC

The Lee-Carter APC model is an extension of the Lee-Carter model intended to capture age, period and cohort effects (Renshaw and Haberman 2006). The change from the original Lee-Carter model described above is the addition of a variable to capture the change in mortality between successive cohorts.

## Considerations around the Lee-Carter APC model relative to the original Lee-Carter model

### Advantages

- Cohort effect. Unlike the Lee-Carter model, the APC model incorporates a cohort effect.

### Disadvantages

- Smoothing. The CMI Working Group observed significant volatility in the fitted mortality rates between succeeding generations (CMI 2007b).
- Convergence issues. The CMI Working Group attempted to fit this model and had difficulty in converging to a unique solution. Direct application of numerical methods to estimate parameters was not a trivial exercise and the CMI Working Group had to place constraints on the fitted parameters to get unique solutions (CMI 2007b).
- Independence of the period and cohort parameters. The period and cohort parameters are assumed to be independent, which may not be appropriate.

## IV.C. P-spline

Penalized spline (P-spline) is part of the spline interpolation family. Interpolative splines fit each segment of the data to a continuous curve defined by a set of polynomials. P-splines introduce a penalty for lack of smoothness and — by adjusting the penalty — the researcher can balance between the fit to the data and smoothness. Higher penalties produce poorer fit but are much smoother, whereas no penalty produces a curve that fits every data point but is very rough. Readers interested in learning more about P-splines can reference CMI Working Paper 15 (CMI 2005), as well as working papers 3 and 20 (CMI 2007a) for other background discussions.

The following are the other key features of splines when applied to historical mortality data by age and period.

- The model can vary mortality rates by age and period.
- The mortality rates are assumed to be a linear combination of functions at each defined segment. Under one dimension (e.g., age), the functions are simple polynomial functions.
- The degree of the spline is selected. Usually, the degree is assumed to be as small as possible. Typically, a second degree spline is tested (i.e., quadratic regression) first. If the fit is not good enough, a cubic or higher-order regression can be tested. There is always a tradeoff between smoothness and goodness of fit. By adding higher order polynomials, a closer fit is generally achieved, but at the expense of smoothness between the data points.

An ideal smoothing technique would remove only the noise and retain all the key features inherent in the data. However, as this is not possible, the judgment of the researcher is the determining factor.

Once the set of formulas is determined, those formulas can be used to extrapolate future mortality improvements.

The P-spline model can be converted into a stochastic form by adding a random error term (noise) to the basic model. In practice, the error term is assumed to follow a normal distribution with a standard deviation developed from the variance matrix of the estimated parameters. This can be important to users; as set out in CMI Working Paper 3, the need for a new set of projections in the United Kingdom included a need for the models to give some indication of the uncertainty inherent in the projections, as well as provide transparency for risk management purposes.

### **Considerations around the P-spline model**

#### **Advantages**

- Backtested. Backtesting of the model by the CMI over the years 1984–2003 demonstrates that the projections would have worked well in recent years in the United Kingdom (CMI 2007a).
- Allowance for parameter uncertainty. Parameter uncertainty reflects the uncertainty inherent in a model calibration process that should be reflected in uncertainty with any subsequent projections using the model. The P-spline model allows for parameter uncertainty, as the variance matrix of the regression coefficients already incorporates such information (see CMI 2005).
- Incorporation of cohort effects. While the P-spline formulas are not specifically designed to capture cohort effects, the use of this type of interpolation allows cohort effects to emerge visually in the data.

#### **Disadvantages**

- Stability. The final trend (or slope) of mortality improvements may not be stable and can produce unreasonable values. This is commonly referred as “edge effects” and is discussed further in section V.A.1 of this report (see Li, Hardy and Tan 2010 and CMI 2009a and 2009b).
- Tradeoffs. There is an inevitable tradeoff between fit and smoothness, and the optimal balance requires judgment.



#### IV.D. CMI model

For future periods, the CMI model projects mortality improvement with three primary components:

- Current rates of mortality improvement
- Long-term rates of mortality improvement
- Convergence of the current rate to the long-term rate of mortality improvement

The current rates of mortality improvement are based on the final data coming from historical results after applying the P-spline interpolation and smoothing technique discussed above. Over a longer time horizon, the CMI approach allows actuaries to apply other techniques to develop a long-term rate. The convergence component determines exactly how the short-term view transitions into the long-term view.

##### **Considerations around the CMI model**

###### **Advantages**

- The intuitive structure of the CMI model allows the model to be easily understood and communicated.
- The model is separated into basic and advanced layers for differing needs and resources; this structure has been well received by U.K. practitioners.
- The use of a deterministic model was well-supported.
- The model is Excel-based and accessible to actuaries.
- The core layer of assumptions that the CMI develops does not incorporate any conservatism (although conservatism can be brought in through the choice of a long-term improvement rate or by adding a constant factor to mortality improvement rates).

###### **Disadvantages**

- The model does not quantify uncertainty around the projection nor the uncertainty of the parameters used. Similarly, the model does not provide any stochastic results or different paths that can be useful in many applications.
- The model does not allow for explicit consideration of trends in different causes of death. The CMI thought this would lead to a difficult-to-use, overly complex model.

The advantages and disadvantages of the CMI model are discussed in more detail in section V.

#### IV.E. Cause-of-death models

Future mortality improvements may be developed from a composite of anticipated changes in mortality attributable to various causes of death. The development of such a cause-of-death model in mortality improvement consists of three principal considerations:

- A historical analysis of trends by cause of deaths
- A sampling of expert opinions about future changes in each cause of death, including risk factors, medical breakthroughs and environmental factors
- A mapping of history and expert opinion into projections

The motivation for these types of models is that future mortality rates might be easier to interpret through an understanding of what drives the changes. Table 1 below summarizes mortality by cause of death in 1990.

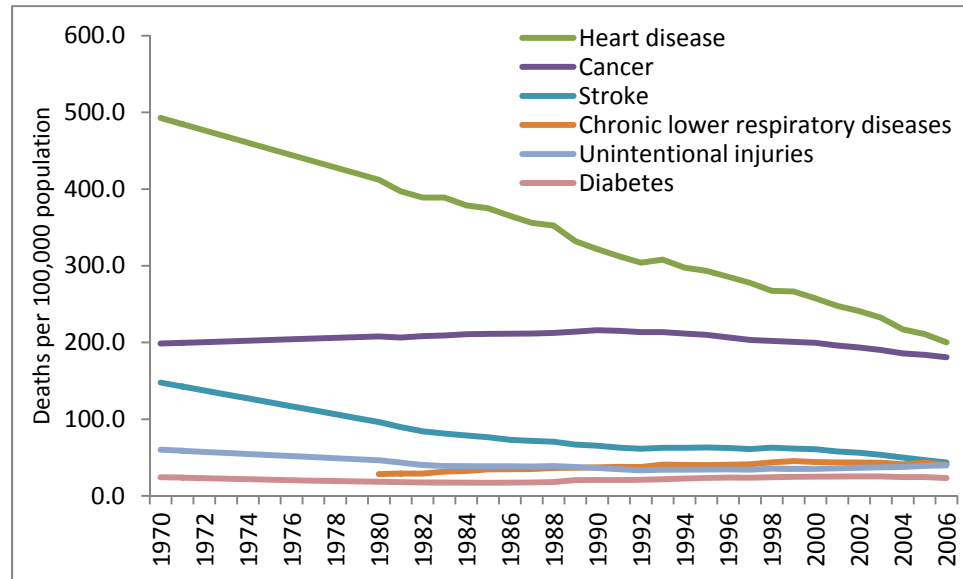
**Table 1. Fraction of total deaths attributable to selected causes in 1990**

**Source: Tuljapurkar and Boe (1998)**

<b>Cause of death</b>	<b>Male</b>	<b>Female</b>
Circulation diseases	40.0%	45.9%
Cancer	20.0%	19.8%
Accidents	9.7%	4.1%
Respiratory diseases	9.0%	8.9%
Digestive diseases	3.4%	3.6%
Infectious diseases	1.3%	1.5%

More sophisticated cause-of-death models can be developed to include the progression of different diseases and their interactions, as well as lifestyle factors. Figure 3 shows how the death rates by cause have changed from 1970 to 2006.

**Figure 3. Death rates for cause of death, across all ages/genders**  
**Source: CDC/NCHS, National Vital Statistics System**



Such a refined model can more accurately capture the dynamics of past improvements, but also requires considerably more data to develop.

### Considerations around cause-of-death models

#### Advantages

- Potentially more accurate projections. With sufficient data, cause-of-death models can represent an improvement over extrapolative mortality models.
- Insights on past changes. The models may reveal patterns around causes of death that can better inform and educate the user on the trends underlying the aggregate mortality rates. This knowledge can be applied to judgment in setting future improvement rates.

#### Disadvantages

- Data. There is a lack of credible data, including difficulty determining cause of death and classifying causes of death into categories.
- Final cause of death. The final cause of death may not be representative of other underlying diseases.
- Interaction. There is substantial interaction between different causes of death.
- Expert opinions. There may be imprecision in expert opinions about the future direction of each cause of death and where society will choose to devote resources.

## IV.F. Comparison of modeling approaches

In this section, we provide a comparison of the modeling approaches discussed above.

The criteria below were used by the CMI Working Group to assess the following models: P-spline age-cohort, P-spline age-period, Lee-Carter and Lee-Carter APC. We found this approach to be useful when considering the suitability of models for forecasting mortality improvements in the United States, and we extended our analysis to include cause-of-death models as well. The model criteria include:

- Ease of use. A model that is generally easier to understand and explain to others will likely result in a higher adoption rate.
- Ability to interpret parameters. If the parameters can be interpreted intuitively, it is easier to understand whether the fitted parameters are reasonable and whether features in the underlying data can be explained.
- Model structure and fit. The model should fit the data well, incorporate requirements of parsimony and adherence to the data, trade-off between smoothness and goodness of fit, and produce a smooth transition between region of historical data and projection.
- Cohort effects. Where cohort effects are known/thought to exist in the data, the model should be able to reflect these effects in the projection. The criteria are only relevant if the data suggests that such an effect exists and is significant.
- Best estimate. The model should be consistent with the recent past and can take relevant trends into account.
- Confidence intervals. The model or method should be able to quantify uncertainty.
- Ability to generate sample paths. The model should reflect volatility and trends in mortality rates between calendar years, giving an indication of the uncertainty in projections for risk management and other purposes.
- Data requirement. The model should take advantage of existing data sources, as a model that requires difficult-to-obtain data is of limited use. For calibration to be performed, some models may also have more intensive data requirements.

We summarize a ranking of the models for each of the following criterion based on our analysis of the CMI working papers and other available literature:

- 1: Well suited for the objective
- 2: Adequately suited for the objective
- 3: Poorly suited for the objective

**Table 2. Comparison of modeling approaches**

	Cause-of-death models	Lee-Carter	Lee-Carter APC	P-spline age-period	P-spline age-cohort	CMI
Model description	Process-based/bio-medical	Extrapolative, times series parametric, trend based	Extrapolative, times series	Extrapolative, regression, non-parametric, smoothing	Extrapolative, regression, non-parametric, smoothing	Extrapolative with use of target and convergence
Deterministic vs. Probabilistic	Deterministic	Probabilistic	Probabilistic	Deterministic	Deterministic	Deterministic
Ease of use	3	2	2	2	2	2
Ability to interpret parameters	1	1	1	3	3	1
Model structure and fit	2	2	2	1	1	1
Cohort effects	3	3	1	3	1	1
Best estimate	2	1	1	1	1	1
Confidence intervals	2	1	1	1	1	3
Ability to generate sample paths	2	1	1	3 <sup>4</sup>	3	3
Data requirement	3	2	2	2	2	1

We note that none of the models meet all the desired objectives of the CMI. More information can be found on the CMI analysis in CMI Working Paper 25.

The relative ranking of the different models depends on the importance of each objective and criterion from the user’s perspective. For example, when recommending a single valuation standard to be used for pensioner populations, the ability to generate sample paths may have little to no importance when compared to other objectives, such as the ease of use and the ability to explain and interpret parameters.

We further note that the above comparisons are not intended to be exhaustive, but are representative of the classes of models encountered in our research. For example, in the table above, we considered the basic Lee-Carter model and Lee-Carter APC, but not more complicated model structures such as various other extensions that have been proposed for the Lee-Carter model (e.g., incorporating structural changes to the trend parameter) or other structures such as the Cairns-Blake-Dowd (CBD) models. Nonetheless, the table can be seen as comparing the class of statistical extrapolation models, such as the Lee-Carter model, against other models that are fundamentally different, such as the CMI model.

<sup>4</sup> Note that the P-spline models can be used to generate percentiles but not sample paths. This means that while the uncertainty in the estimates can be quantified, the volatility of mortality rates between calendar years cannot be properly captured. This is important for many businesses where the actual path taken by mortality rates can affect the risk profile of the business.

Available literature indicates that cause-of-death models are severely restricted by data requirements and are, therefore, difficult to use. P-spline type models present challenges for users to understand, interpret and communicate the parameters. The Lee-Carter class of extrapolation models appears promising, but is not always easy to fit to data and requires the modeler to have a strong understanding of the underlying statistics. Finally, a CMI type of model also appears promising, but suffers from not being able to produce sample paths, and judgment is required to set the long-term improvement rate.

#### IV.G. Backtesting of mortality improvement models

Backtesting<sup>5</sup> of models is valuable as complex models are often able to provide a good fit to historical data and produce plausible forecasts, but can still result in forecasts that differ significantly from future realized outcomes. Backtesting is a good way to assess the out-of-sample performance of a model, which can provide an indication of the model's reliability.

We were able to find more discussion around the backtesting of statistical extrapolation models as applied to data in other countries, particularly the United Kingdom (see, for example, Dowd et al. 2008). We found one instance of backtesting performed with a statistical extrapolation model on U.S. data (Li, Hardy and Tan 2009), which illustrates the "excessively narrow" prediction intervals of the Lee-Carter model. We consider this type of research valuable as it clearly illustrates the model's performance and shortcomings. The research also points to areas where the models can be improved. In the case of the Li, Hardy and Tan (2009) paper, the Lee-Carter model was successfully adjusted in ways that produced wider forecast intervals, which better captured the actual realizations in the backtesting analysis.

Interested readers should also consider other statistical models that have been developed. For example, see Cairns et al. (2007), which compares the fit of eight models to both U.S. and U.K. data.

To the best of our knowledge, a CMI type of model has been backtested with U.K. data, but not with U.S. data. This may be because of difficulty incorporating the judgment aspect of the CMI model into a backtesting framework, in particular the setting of the long-term mortality improvement rate.

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<sup>5</sup> Backtesting a model refers to the process of testing the model projections against actual historical data (with the historical data being "out of sample," i.e., the data was withheld when calibrating the model).

## V. CMI model overview and considerations

This section discusses the model developed by the CMI in the United Kingdom in more detail, as this is one of the more sophisticated approaches and is under consideration by the RPEC for use as a mortality projection model in the United States. In this section, we provide:

- An overview of the model components
- A discussion of each component necessary to implement a projection
- A summary of practitioners' feedback to the CMI

### V.A. Model

As noted earlier, the CMI model projects mortality improvement with four primary components:

- Current rates of mortality improvement
- Long-term rates of mortality improvement
- Convergence of the current rate of mortality improvement to the long-term rate
- Data and population set

Current rates of mortality improvement are developed from historical data subjected to P-spline interpolation and smoothing. Over a longer time horizon, the CMI approach allows actuaries to apply different techniques to develop a long-term rate. The convergence component determines exactly how the short-term view transitions into the long-term view.

The CMI model contains two layers: core and advanced. The core layer is intended for users who would like to select default assumptions developed by the CMI Working Group, whereas the advanced layer provides the ability to modify model parameters.

#### **Practitioners' insight<sup>6</sup>**

- The great majority of U.K. users employ the core layer for publishing purposes (i.e., reserving or embedded value reporting). Users tend to lack the statistical sophistication to utilize the advanced layer.

For more information on the overall structure of the latest CMI model, see CMI Working Papers 38 and 39.

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<sup>6</sup> Based on discussion with U.K. practitioners

### V.A.1. Current rates of mortality improvement

Historical mortality data is interpolated and smoothed using the P-spline technique to identify the underlying trends. The P-spline interpolation uses function segments that are four years long, and the ends of each of the segments are forced to connect and form a smooth curve.

The CMI was concerned about edge effects, meaning that estimates can be unduly influenced by the experience in the final years of data under P-spline interpolation. The final years of data form the end of a segment, and as that segment end has no corresponding end from another segment to connect with, the estimation of that final segment function can be unstable.

After considering the potential impact of edge effects, the CMI settled on a two-year setback to alleviate the problem. A two-year setback effectively means that the “current” mortality improvement rate is estimated without including the most recent two years of experience. The final two years of data are used to create an additional segment, which produces a more stable “current” mortality improvement rate.

At the time of this report, the 2012 CMI model is the latest version and has mortality improvement rates in the core layer covering 1991–2009 for individual ages 20 through 100. For ages over 100, the CMI model tapers off initial mortality improvement rates by 0.1 percent for each year above age 100.

At a high level, the aggregate mortality improvement rate is determined by first allocating the improvement between an age/period component and a cohort component, and then recombining the two components. This is necessary because the two components are run off differently over the course of the projection, discussed further in section V.A.3.

This process can be broken down into a series of detailed steps.

- Begin with smoothed data coming out of the P-spline methodology as described in section IV.C.
- The model splits the aggregate mortality improvement rates into age/period and cohort components so they can be projected separately.<sup>7</sup> This is done by entering the aggregate mortality improvement rates into an APC statistical model created specifically for this purpose.
- The aggregate mortality improvement rates are split into age, period and cohort components, and the age and period components are combined into a single age/period component.
- The APC model leaves residual mortality improvements that are unallocated at each age. To ensure that the initial improvement rates in the age/period and cohort

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<sup>7</sup> For example, a 2 percent aggregate improvement might be allocated as 0.8 percent to the cohort and 1.2 percent to the age/period components.



components add back to the totals, the residuals are then allocated to the age/period and cohort components as follows.

- Below age 30, all residual errors are allocated to the age/period component. The rationale is that these deviations are short-term and should run-off relatively quickly.
- Above age 60, all residual errors are allocated to the cohort component. The rationale is that the mix of causes of death changes slowly for middle and higher ages.
- The model transitions linearly between ages 30 and 60.

The mechanics of the APC model were not made publicly available, although some of the technical specifications, as well as the judgments made in allocating the residuals, are discussed in the appendix of CMI Working Paper 39.

The advanced layer of the model allows the initial rate to be set by the age/period and cohort components, which are set by individual age and year of birth, respectively.

For more information on the initial rate of improvement in the CMI model, see CMI Working Papers 38 and 39.

### **Observations**

- Adjustment provides year-over-year stability of the estimates through less volatility compared to other methods being introduced when an extra year of experience is added.
- This technique effectively captures the main features of the data.
- This technique tends not to identify false features of the data.
- Using a two-year setback means that the most recent data is not directly incorporated in the current assumption estimates, and could delay the recognition of abrupt trend changes in mortality improvement rates.
- The splitting into age/period and cohort components leads to a conceptually simpler model that can be thought of as a base projection + cohort model.
- Splitting out the age/period and cohort components allows them to be projected separately via different convergence assumptions to the long-term improvement rates.
- The residuals from the fitting of the model were attributed to the age/period and cohort components using judgment and arbitrary cutoffs.
- Some actuaries are concerned about assuming that improvement slows at the oldest ages.

## V.A.2.Long-term rates of mortality improvement

The CMI model does not supply a default assumption for the long-term rate of mortality improvement, even as part of the core layer.

Under the core layer, the user is required to enter a single number for the long-term rate of improvement; this number is used for all ages up to 90, then grades to zero by age 120. The entire input is used to calibrate the age/period component. No calibration is mapped to the cohort component. This effectively means that the influence of the year of birth will dissipate over the period of convergence. As a result, the long-term improvement rate under the core setting does not vary by age or cohort (other than above age 90 when it is assumed to begin to decrease).

Under the advanced layer, the long-term rate inputs can vary by age and be allocated to both the age/period and cohort components.

### Practitioners' insight

- In the United Kingdom, the average long-term general population mortality improvement assumption was 0.5 percent in the 1990s. After reviewing the general population experience and expert opinions, the average assumption was increased to 1.0 percent. Furthermore, the mortality improvement in the working population was found to be 0.4 percent higher. Insurers and pension plans currently use a long-term assumption between 1.5 and 2.0 percent and use 1.0 percent as a floor.
- Some companies were disappointed that the CMI did not specify a default long-term estimate.

For more information on the long-term rate of improvement in the CMI model, see CMI Working Papers 38 and 39.

### Observations

- Targeting a long-term rate of improvement can overcome some of the weaknesses of a purely extrapolative approach, since the targets chosen can take into account other factors that may influence the overall direction of mortality in the future.
- Through sensitivity testing, the long-term mortality improvement rate was determined to be the most critical assumption affecting annuity values.

### V.A.3. Convergence of the current rate of mortality improvement to the long-term rate

The current CMI model fits a cubic curve (i.e., third degree polynomial) to interpolate between the initial mortality improvement rates and the long-term rates, creating a path of convergence. The age/period effect converges to the long-term rates. The cohort effect converges to zero in the core layer, or a user-specified set of numbers by year of birth in the advanced layer.

The core layer assumes that 50 percent of the convergence is achieved by the midpoint of the convergence period. In the advanced layer, the convergence period can vary by age and year of birth. When a user adjusts the proportion of convergence achieved at the midpoint of the projection, the shape of the interpolated polynomial is altered to meet that requirement.

The default convergence period differs between the age/period component and the cohort component:

- Age/period
  - 10 years for all ages up to 50
  - 20 years for all ages 60 to 80
  - Five years for all ages 95 and above
  - Linear transitions between ages 50 and 60 and 80 and 95
  - The CMI bureau judged that there is greater room for sustained improvement for the 60–80 age group, as mortality in those ages is currently dominated by a small number of causes.
- Cohort
  - Five years for age of birth cohorts 1910 and earlier
  - 40 years for all birth cohorts 1945 and after
  - Linear transition between 1910 and 1945
  - The CMI bureau judged that cohort effects are generally longer running than age/period effects. Convergence is capped at 40 years due to concerns about projecting weaker cohort features far into the future for younger ages.

The CMI recommends the same convergence basis be used for male and female lives, as they believe there was not enough evidence to support separate assumptions.

For more information on the convergence methodology in the CMI model, see CMI Working Papers 38 and 39.

### **Observations**

- The convergence methodology is relatively transparent and easy to understand.
- The CMI model uses the current level of mortality improvement, but disregards the current trend. In other words, if mortality improvements have been trending upward in recent years, but the long-term rate is below the current rate, the projected trend will immediately begin a descent and the current upward trend will be disregarded.

#### **V.A.4.Data and population set**

Because insured and pensioner data were insufficient, CMI relied on the England and Wales population data for building the mortality improvement model. This is significant as the CMI found that the conclusions drawn from different smoothing techniques weakened when using nonpopulation data (CMI 2009b). The correlation of results between P-splines and other smoothing methodologies weakens, indicating that the features of the data become less reliable and more dependent on the smoothing technique employed. In particular, the CMI found that cohort effects are less prominent in nonpopulation data.

### **Practitioners' insight**

- The migration from insured/pensioner data to general population data by the CMI was well received by the insurance and pension communities.

The CMI investigated whether these observations were driven by a genuine difference in features of the population or as a result of studying smaller (and less credible) data. They tested this by scaling the population data set down to the size of the insured/pensioner data sets, and found that some of the patterns in the data were lost and the lower data volume didn't allow for good separation between age, period and cohort effects. They concluded that some of the perceived features or lack of features in the insured and pensioner data sets were likely due to lack of sufficient data (CMI 2009b).

U.K. population data was used to calibrate the initial rate of improvements. Industry data for life insured and pensioner populations were considered and analyzed, but were not offered as an option/alternative in the core model.

For more information on the most recent data underlying the CMI model, see CMI Working Paper 55 (2011).

### Observations

- The use of population data provided a common baseline for most actuaries to calibrate their models.
- Population data was large enough to credibly identify features in the data.
- Many actuaries expressed a desire for more explanation regarding the features seen in the data.
- Many actuaries expressed a preference for the model to be calibrated with life insured or pensioner data. (The advanced layer does permit use of alternative baseline data.)

## V.B. Considerations regarding the CMI model and alternative approaches

The CMI uses a sophisticated framework that first determines current rates using interpolation mechanisms, a long-term rate and a formula allowing flexibility in convergence. We find this is a reasonable approach to projecting mortality improvements. We also recommend certain modifications be considered for a parallel approach the RPEC is considering for use in the United States.

- The CMI approach uses the current mortality improvement rates, but not the current trend in mortality improvement rates. An alternative approach may be to run a single optimization routine that incorporates the current trends along with the convergence formula, which would produce a continuous first derivative (slope) moving from current to projected rates.
- Alternatively, the RPEC can consider developing a short-term trend in mortality improvement rates based on recent data (e.g., five years) to overcome the instability in the trend the CMI is attempting to avoid.
- The CMI model separates the impacts of age, period and cohort and projects them forward. This level of sophistication is only necessary if those effects are apparent in U.S. data. Based on the results presented later in this report, we do believe that age, period and cohort effects exist in the United States, but the RPEC should review the results and come to its own conclusion.
- The CMI does not provide a default long-term estimate for mortality improvements in the United Kingdom. Insurers in the United Kingdom noted that this was the most important assumption in the model in terms of impacting annuity values. If the RPEC chooses to go down a similar path, we recommend they point users to “The Long-Range Demographic Assumptions for the 2012 Trustees Report” produced by the Social Security Administration’s

OACT or the 2011 Technical Panel on Assumptions and Methods to the Social Security Advisory Board (discussed in section VI.B below).

## VI. Long-term mortality improvement assumptions

### VI.A. Introduction

Over the past 20 years, demographers and actuaries have used a variety of techniques to project future mortality improvements. These are typically forms of extrapolation, that is, creating a trend from prior data. Researchers use models to analyze mortality data over a certain period, measure past changes in mortality rates or life expectancy, and then project the changes in mortality rates into the future. The final result can depend on the shape of the curve drawn, the level of granularity, credibility associated with the data, and the time period used.

Many researchers find it useful to examine the factors that contributed to the variations in historical mortality declines. In forecasting mortality improvement trends, they make adjustments based on their understanding of those factors, the impact on mortality improvement and the likelihood of such factors repeating. Section 0 provides a summary of researchers' opinions on long-term mortality improvement forecasting.

#### The Epidemiologic Transition

In 1971, demographer Abdel Omran, author of "The Epidemiologic Transition: A Theory of the Epidemiology of Population Change," postulated a three-epoch theory of epidemiologic transitions. The three stages correspond to the observed mortality trends in the United States (Omran 1971):

- The age of pestilence and famine before the 19<sup>th</sup> century
- The age of receding pandemics from the mid-19<sup>th</sup> century to the early 20<sup>th</sup> century
- The age of degenerative and manmade diseases in the latter half of the 20<sup>th</sup> century, such as cardiovascular diseases and cancer

Table 1 in section IV.E showed the primary causes of death in the United States in the second half of the 20<sup>th</sup> century. The majority of deaths came from degenerative diseases, corresponding to the third stage of the epidemiologic transition, where a level of equilibrium was reached with considerably lower mortality than the first stage.

However, by the end of the 20<sup>th</sup> century, with the development of new drugs and antibiotics and improved methods of diagnosing and treating degenerative diseases and their complications, the health care community became increasingly successful in postponing deaths from degenerative diseases by slowing the rate of chronic disease progression and by reducing case-fatality rates. Therefore, some demographers, including Olshansky and Ault (1986), suggest a fourth stage of the epidemiologic transition with the following characteristics:

- Rapidly declining death rates that are concentrated mostly in advanced ages and which occur at nearly the same pace for males and females
- The age pattern of mortality by cause remains largely the same as in the third stage, but the age distribution of deaths for degenerative causes are shifted progressively toward older ages
- Relatively rapid improvements in survival are concentrated among the population in advanced ages

Researchers appear to agree that the long-term effects of degenerative disease will drive mortality improvements in the future. However, there is a wide divide between many researchers attempting to predict how much progress society can make in eliminating and delaying degenerative diseases, and that is the focus of the following section.

## VI.B. Literature review

Demographers and actuaries have formed a variety of opinions on future life expectancies and related mortality improvements in the United States. In this section, we summarize the analysis performed by several independent researchers along with their conclusions.

### Social Security Administration Trustees Report and Technical Panels

“The Long-Range Demographic Assumptions for the 2012 Trustees Report” produced by the Social Security Administration’s OCACT includes assumptions for long-term mortality improvements and a cause-of-death analysis of mortality improvements in the United States. In determining the assumptions, the OCACT examines historical U.S. mortality improvement since 1900 using cause- and age-specific extrapolation. Five causes of mortality are considered: cardiovascular disease, cancer, violence, respiratory disease and “other.” Mortality improvement rates by cause of death are used as a tool in assessing the overall long-term mortality improvement (OCACT, 2012).

The OCACT developed three sets of average percentage mortality improvement projections by age group and cause of death; Alternatives I, II and III represent the OCACT’s low-, intermediate- and high-cost assumption sets, respectively. The intermediate-cost set of assumptions represents the best estimate for future experience. To provide stability to the forecast, they use a set of mortality rates calculated to be consistent with the trend in the last 12 years of available data. The initial rates are set to converge over 25 years to long-term rates that vary by age group. The long-term rates are also age specific and incorporate significant judgment.

Every four years, the Social Security Advisory Board, an independent, bipartisan board created to advise the President, Congress and Commissioner of Social Security on matters related to Social Security programs, appoints a technical panel of expert actuaries, economists and



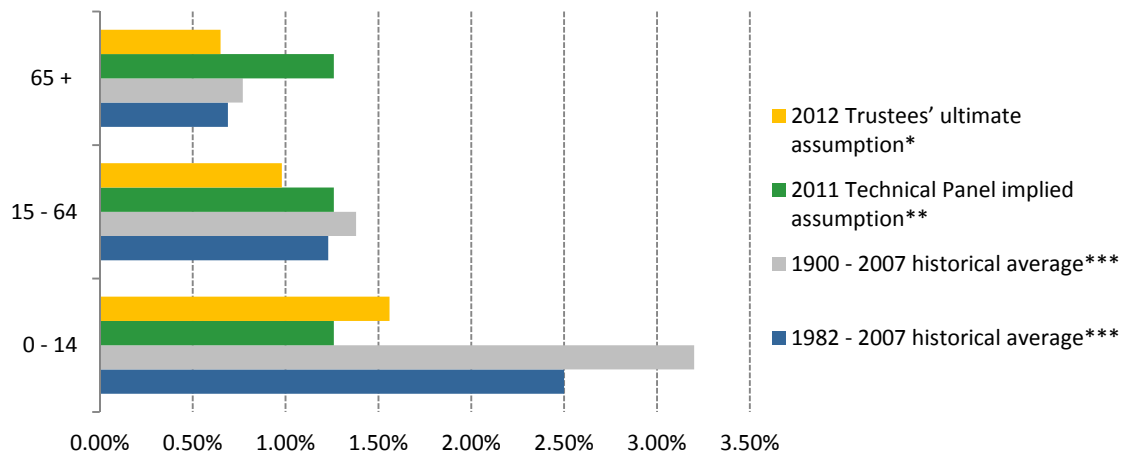
demographers to review the methods and assumptions used in the most recent OCACT Trustees Report.

The 2011 Technical Panel on Assumptions and Methods recommended a more rapid increase in life expectancy over the coming decades compared to prior technical panels and the 2012 Trustees Report. The 2011 Technical Panel recommended a life expectancy assumption of 88.7 years in 2085. According to the OCACT, this life expectancy target can be obtained by assuming a long-term annual mortality improvement rate of 1.26 percent for all ages and both sexes combined (OCACT, 2012). This implied rate represents an increase over the 1 percent annual long-term mortality improvement rate recommended by the 2007 Technical Panel.

Consistent with the prior Technical panel’s approach, the 2011 Technical Panel on Assumptions and Methods used age-specific extrapolation to avoid the complexity in cause-of-death analysis. They recommended the elimination of the cause-specific component of the methodology in the Trustees Report. The 2011 Technical Panel stated that “a model based on separate projections by cause of death over a long time horizon is both implausible and inconsistent with historical experience.” Instead, the panel examined the aggregate U.S. population life expectancy trends by gender and compared these trends with those of other industrial countries. The 2011 Technical Panel showed that the U.S. demonstrates poorer longevity performance due to smoking and obesity relative to other large high-income countries. The 2011 Technical Panel considered such performance in its long-term mortality improvement recommendations.

Figure 4 compares the projected mortality improvements from the 2012 Trustees Report and the implied rate from the 2011 Technical Panel on Assumptions and Methods to historical averages for three age groups.

**Figure 4. Historical and assumed annual rates of reduction in aggregate mortality**  
**Source: Office of the Chief Actuary 2012**



\* Ultimate intermediate assumption for period 2036–86 in Board of Trustees, Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds 2012

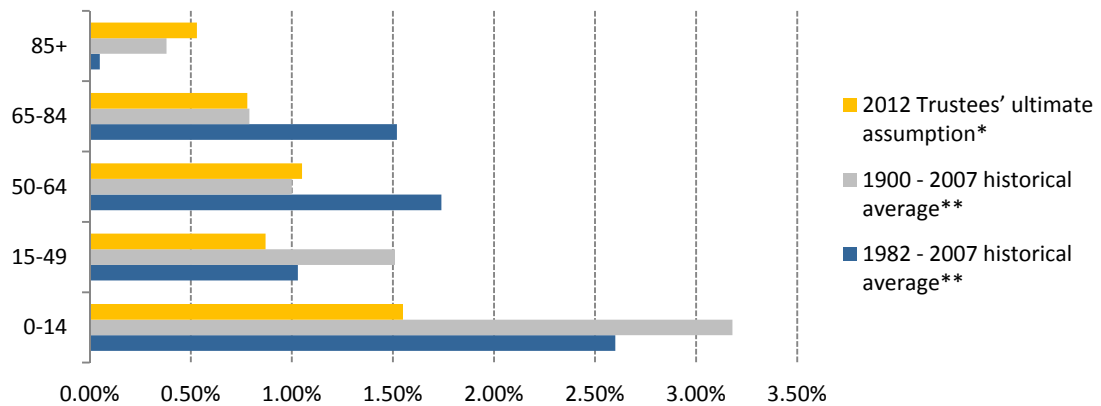
\*\* Derived from the 2011 Technical Panel on Assumptions and Methods unisex period life expectancy at birth in 2085 in Office of the Chief Actuary 2012

\*\*\* Historical average annual percent reductions in age-adjusted death rates are based on 2000 Census resident population and are “ultimate” rates of reduction after year 2036

Figure 5 and Figure 6 below further analyze assumptions by gender and more granular age groups.

**Figure 5. Historical and assumed annual rates of reduction in mortality (male)**

Source: Office of the Chief Actuary 2012

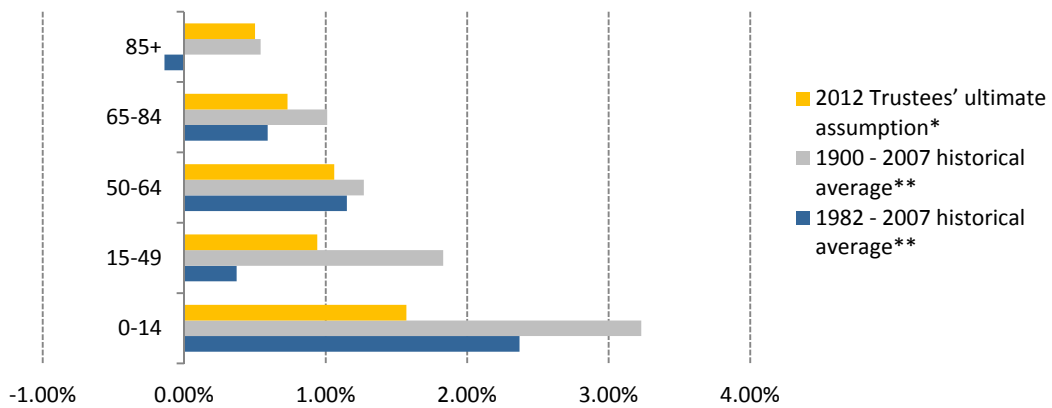


\* Ultimate intermediate assumption for period 2036–86 in Board of Trustees, Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds 2012

\*\* Historical average annual percent reductions in age-adjusted death rates are based on 2000 Census resident population and are “ultimate” rates of reduction after year 2036

**Figure 6. Historical and assumed annual rates of reduction in mortality (female)**

Source: Office of the Chief Actuary 2012



\* *Ultimate intermediate assumption for period 2036–86 in Board of Trustees, Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds 2012*

\*\* *Historical average annual percent reductions in age-adjusted death rates are based on 2000 Census resident population and are “ultimate” rates of reduction after year 2036*

In contrast to prior Technical Panel recommendations, the 2012 Trustees Report assumes that for populations over age 65, the ultimate mortality improvements will be only slightly lower than historical experience over the last century (OCACT, 2012).

We also see in the figures above that the rate of mortality improvements in the United States has fluctuated over time. After a relatively rapid rate of improvement in mortality from 1968 to 1982, improvements were more moderate between 1982 and 2007. John R. Wilmoth, professor in the Department of Demography at Berkeley, notes that the slow rate of mortality improvement in the United States during the 1980s and 1990s was not typical among industrialized nations (2005). Many, including the National Research Council (NRC), suggest that the slow mortality decline reflects effects of increased smoking and obesity in the United States during the prior decades (Crimmins et al, 2011). Although recognizing diminishing smoking effects on mortality, the 2012 Trustees Report still notes concerns of obesity based on recent releases from the National Center for Health Statistics (NCHS) that reported a substantial increase in the prevalence of obesity. (OCACT, 2012)

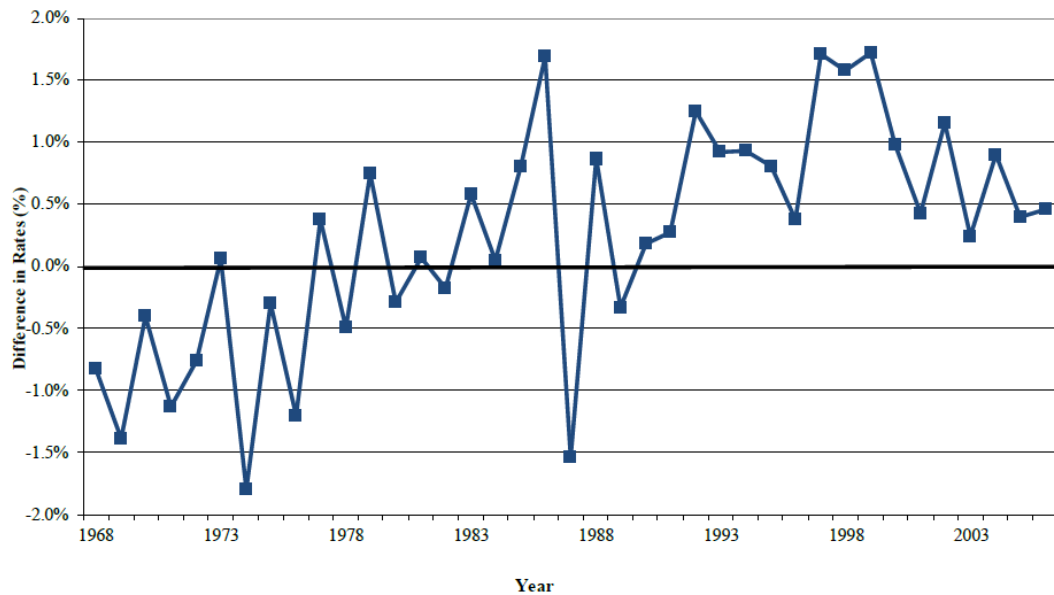
Figure 5 and Figure 6 show how historical mortality improvements have evolved by age group. We observe that 1900–2007 experience shows mortality improvement rates decreasing steadily by age group, while 1982–2007 experience shows higher improvements in ages 65–84 compared to ages 15–49 for both females and males. This may indicate an “aging of mortality improvements” similar to the effect identified by Willets et al. (2004) in England and Wales, which is discussed below.

The 2012 Trustees Report notes a change in the relationship between male and female mortality improvement over time. Based on Figure 5 and Figure 6 above, in the more recent years from 1982 to 2007, the average annual rate of improvement for females was substantially lower than that for males. However, males experienced slower improvements than females prior to 1982. This is likely due to increased male death rates from cardiovascular disease from 1950–70 (OCACT, 2012)

Figure 7 below illustrates the difference between male and female mortality improvement for the population beyond age 65. For example, in 1974 the female annual mortality improvement rate was approximately 1.75 percent higher than the male rate. On the other hand, in 1998 the male annual mortality improvement rate was about 1.5 percent higher than the female rate.

**Figure 7. Difference between male and female annual percent reduction in age-adjusted death rates for population 65+**

**Source: Office of the Chief Actuary (2012), based on U.S. Medicare data. Reprinted with permission.**



Similar to the approach in prior years, the 2012 Trustees Report determines the trends in death rates separately for five causes of death, by age group and gender, over the period 1979–2007. For all ages combined, cardiovascular disease had the largest impact on mortality reduction, while it is notable that respiratory diseases had significant mortality deterioration for women. Table 3 summarizes the findings across all age groups.

**Table 3. Average annual mortality improvement by cause of death (1979–2007)**  
**Source: Office of the Chief Actuary (2012)**

<b>Cause of death</b>	<b>Male</b>	<b>Female</b>
Cardiovascular disease	2.49%	2.14%
Violence (including accidents)	0.84%	0.20%
Cancer	0.64%	0.16%
Respiratory diseases	-0.06%	-2.27%
Others	-0.85%	-1.57%

The 2012 Trustees Report notes that many factors are responsible for the acceleration of U.S. population mortality improvements in the past decades, including increased medical knowledge, increased availability of health care services, and improvements in sanitation and nutrition. However, the OCACT believes that effects from these developments have been diminishing. In addition, they also qualitatively consider potential impacts from socioeconomic factors, economic factors and biological limitations of the human life span. (OCACT, 2012)

The Social Security Administration believes there will be a trend toward slower mortality reduction in the future. In particular, the 2012 Trustees Report states that slowing improvements are due to expectations of external factors including increased negative side effects from invasive surgical procedures, decreased air quality, and increased prevalence of obesity and diabetes. However, the report does not attempt to specifically quantify the impact of changes in external factors on future mortality improvements.

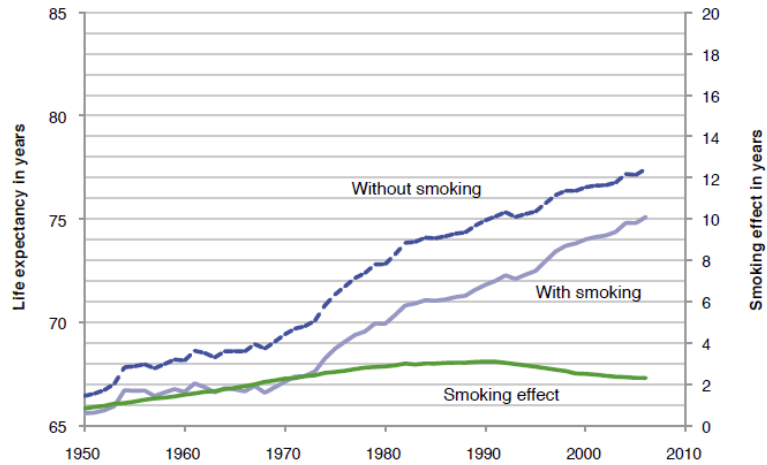
Experts on the 2011 Technical Panel further investigated the adverse effects of cigarette consumption and obesity in forecasting future mortality improvements.

#### Smoking effect

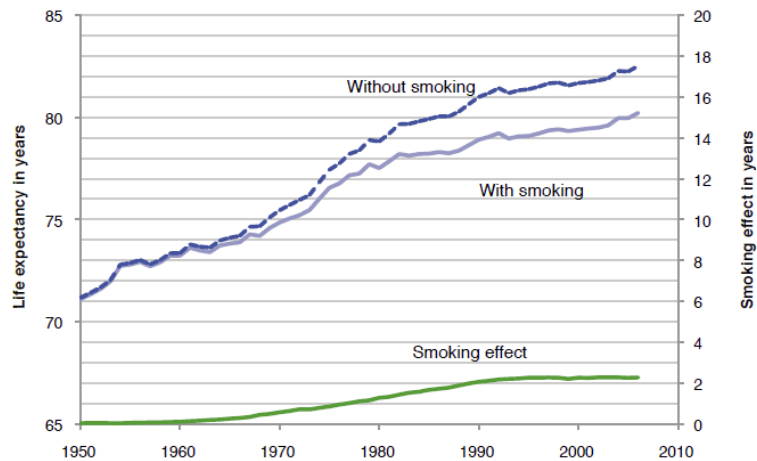
To measure the impact of smoking on the U.S. population, researchers compared the actual life expectancy trend to a hypothetical life expectancy that would be observed in the absence of smoking. Figure 8 and Figure 9 below illustrate the life expectancy trend comparison in the U.S. male and female population.

#### **Figure 8. Smoking effect on U.S. life expectancy at birth from 1950–2006 (male)**

**Source: 2011 Technical Panel on Assumptions and Methods 2011. Reprinted with permission.**



**Figure 9. Smoking effect on U.S. life expectancy at birth from 1950–2006 (female)**  
**Source: 2011 Technical Panel on Assumptions and Methods 2011. Reprinted with permission.**



Although the smoking effects generally rose over the past 50 years, the impact is different for males and females. The negative smoking effect for males increased until year 1990, when it peaked at 3.1 years in life expectancy; it subsequently declined by approximately one-fourth of that amount. The negative effect for females, however, started increasing later and peaked in year 2002 at 2.3 years in life expectancy.

The panel notes that due to the delay in the effect of smoking on mortality, we expect to see mortality trends reflecting cigarette consumption from the prior two to three decades. For example, the decline in smoking effect on mortality after 1990 corresponds to the decline in

tobacco consumption in the mid-1960s. The panel expects to see a declining trend continuing into the future.

See section VIII.B for further discussion on this topic.

Obesity effect

Demographers and actuaries have debated how obesity will impact future mortality improvement levels in the United States. Table 4 below summarizes the estimated impact of obesity on life expectancy from several studies to which the 2011 Technical Panel refers.

**Table 4. Impact of obesity on life expectancy—reduction in years\***  
**Source: 2011 Technical Panel on Assumptions and Methods 2011**

Study	Males	Females
Olshansky et al. (2005, white population)	0.33–0.99	0.30–0.81
Olshansky et al. (2005, black population)	0.30–1.08	0.21–0.73
NRC based on Adams et al. (2006)	0.52	0.71
NRC based on Mehta and Chang (2010)	0.64	0.61
NRC based on Preston and Stokes (2009)	1.61	1.28

*\*Olshansky measures life expectancy at birth and other studies measure at age 50*

Results vary substantially among these studies. The Technical Panel assumes that the current impact of obesity is one year in life expectancy measured at birth and believes that the additional impact by 2085 will also be one year given the potential delayed effect of obesity.

See section VIII.B for further discussion on this topic.

James F. Fries

James F. Fries, M.D., Professor of Medicine, Stanford University , School of Medicine, proposed the concept of mortality compression (Fries, 1980), meaning that if there is an upper limit to the human lifespan, any mortality improvements will compress mortality experience into a smaller range of years without extending lifespans beyond some point (e.g., 85 years). Fries supported his view by showing how life expectancy trends had flattened in the United States in Figure 10 below.

**Figure 10. Changes in life expectancy from different ages in the 20th century**  
 Source: Fries (1980). Reprinted with permission.

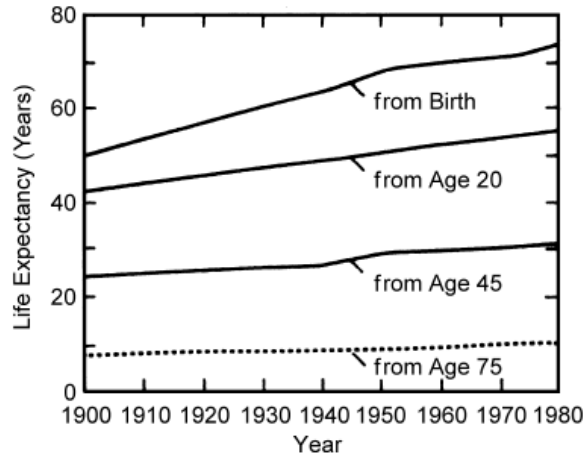


Table 5 below further supports his argument with a comparison of life expectancy improvement from 1980 to 2011 at different ages.

**Table 5. Life expectancy improvement from 1980 to 2011**

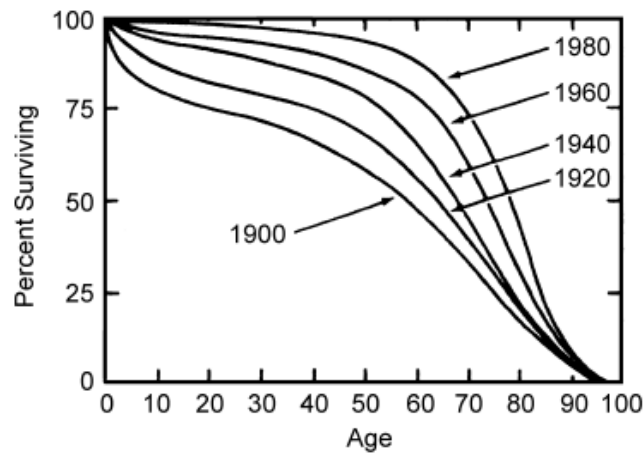
Source: Board of Trustees, Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds 2012

Age	Male life expectancy gain	Female life expectancy gain
At birth	6.0	3.1
At age 65	3.7	1.6

Many demographers, including Fries and Himes (Himes 1994), also note the “rectangularization” or “squaring” of the life table survival curve, which visually represents the concept of mortality compression. The rectangularization process in the past decades has been developing at an unprecedented rate among the population above age 65 due to the elimination of premature deaths. Figure 11 illustrates this observation with the progression of the survival curve.



**Figure 11. Changes in survivorship curves in the United States in the 20th century**  
**Source: Fries and Crapo (1981). Reprinted with permission.**



Based on these observations, Fries and others propose that senescence,<sup>8</sup> rather than disease, drives mortality (Fries 1980). They believe that historical trends of mortality improvements will not continue indefinitely as humanity reaches biological limits. Fries further points out flaws in other life expectancy projection models, which do not account for the mortal effects of physiologic frailty or assume constant rates of change (e.g., percentage changes) in mortality rates rather than absolute changes in projections, and states that as a result, they tend to underestimate mortality at higher ages. This suggests decreasing long-term projected mortality improvements.

S. Jay Olshansky

Similar to Fries, S. Jay Olshansky, Research Associate at the Center on Aging at the University of Chicago, proposes that senescence causes average life expectancy to eventually reach an upper limit. Rather than estimating a biological upper limit to life span, he attempts to estimate practical limits. In his research with Carnes and Cassel (1990), he estimates the upper limit based on hypothesized reductions in current mortality rates necessary to achieve a life expectancy at birth from 80 to 120 years, and a life expectancy at age 50 from 30 to 70 years. He compares the mortality reductions necessary to achieve the target life expectancies against those resulting from elimination of major causes of deaths—cardiovascular diseases, ischemic heart disease, diabetes and cancer.

Figure 12 illustrates the percentage of mortality reduction from 1985 levels that would be required to increase life expectancy at birth from 80 to 120 years, along with the impact of the

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<sup>8</sup> The biological process of growing older in a deleterious sense

elimination of common causes of death. For example, eliminating all cardiovascular diseases would increase life expectancy to 86.42 for males and 94.1 for females.

**Figure 12. Percentage of mortality reduction for life expectancy at birth**

Source: Olshansky, Carnes and Cassel (1990). Reprinted with permission.

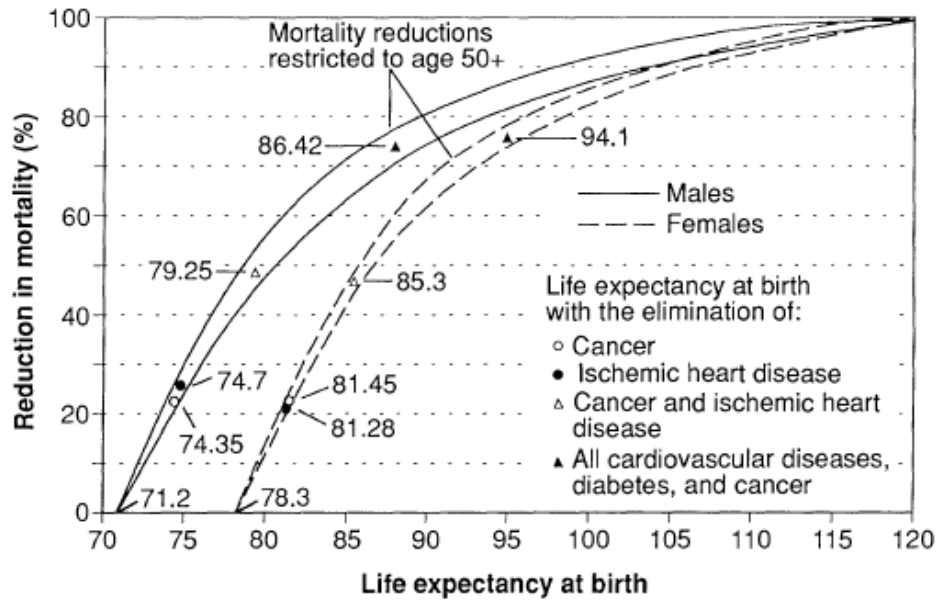
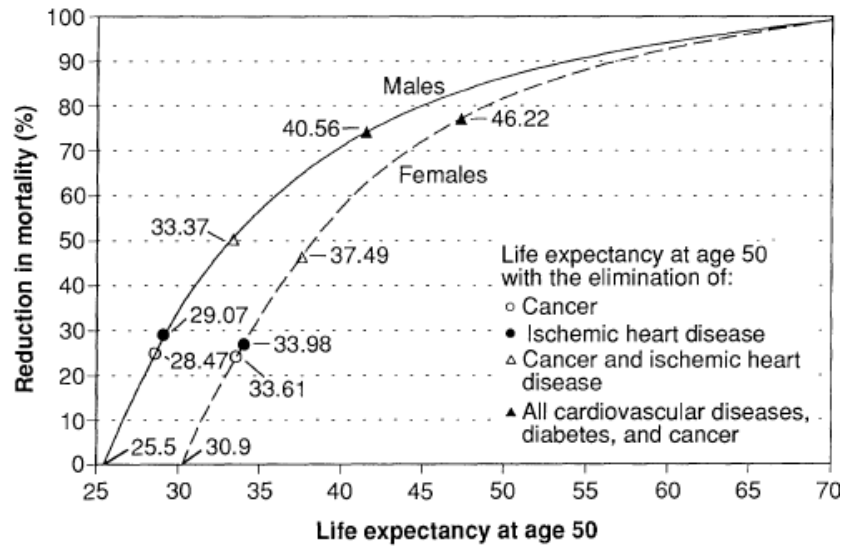


Figure 13 shows the required mortality reduction percentage to increase life expectancy at age 50 from 30 to 70 years.

**Figure 13. Percentage of mortality reduction for life expectancy at age 50**  
 Source: Olshansky, Carnes and Cassel (1990). Reprinted with permission.



Olshansky’s results show that for life expectancy at birth to increase from levels in 1990 to the average biological limit of life assumed by Fries (1980) — age 85 — male mortality from all causes of death would need to decline at all ages by 55 percent, and at ages 50 and over by 60 percent. On the other hand, hypothetical elimination of all above-mentioned major degenerative diseases would reduce overall mortality by 75 percent.

Olshansky finds that the past mortality improvements are mainly at younger ages, and further life extension in the U.S. population will happen only if there is another era of significant mortality improvement among the older population (Olshansky et al. 2005).

As his results show, even if we eliminate most heart disease, cancer and diabetes — the major causes of death in aging adults — life expectancy from birth in the United States would still not advance much beyond age 85. For example, a cure for cancer, he calculated, would only add four to five years of life across the U.S. population. Consequently, he concludes that it seems highly unlikely for life expectancy to exceed 85 years at birth and 35 years at age 50 unless major breakthroughs occur in controlling the fundamental rate of aging.

However, in subsequent research (Olshansky et al. 2009), Olshansky examined the 2008 Social Security Board of Trustees’ projections and concluded they may be underestimating male and female life expectancy from birth in 2050 by as much as 3.1 and 4.5 years, respectively.

His conclusion is based on the premise that government agencies assume mortality improvements in the coming decades will decelerate, whereas he forecasts that a combination of control of behavioral risk factors and new advances in medical technology that slow aging will

accelerate reductions in death rates. His forecast recognizes that health and longevity benefits most likely will be phased in over time as not everyone will benefit from advances in biomedical technology equally or at the same time.

Olshansky also believes there is a possibility that delayed aging could extend the human life span by several years, while offering the added bonus of compressing morbidity, disability, frailty and mortality into a shorter duration of time near the end of life, similar to results from research performed on mice (Olshansky et al., 2009).

#### Kenneth G. Manton

Kenneth G. Manton, Scientific Director at the Center for Demographic Studies, Duke University, estimates human life span with a time-series risk-factor model. Based on mortality data in the Framingham, Massachusetts Heart Study from 1950–84, risk-factor levels, changes and their interaction with mortality are examined. Eleven risk factors representing circulatory risk factors and markers of aging are modeled. In determining the limit to life expectancy, Manton assumes no risk heterogeneity (i.e., zero variance in risk factors) and optimum risk levels observed. Results indicate a maximum achievable life expectancy of 100 years for males and 97 years for females (Manton, Stallard and Tolley 1991).

#### James W. Vaupel

James Vaupel, professor at the Max Planck Institute for Demographic Research, is a strong proponent of higher mortality improvement rates in the future. He states that U.S. data at older ages, especially for those beyond age 85, is known to be flawed and unreliable. Instead, he focuses on certain international populations and often focuses on the oldest of the old. In his research with Jim Oeppen, professor at Cambridge Group for the History of Population and Social Structure, they observe that the limits set by demographers have consistently been proven wrong. The highest observed life span of any country has increased approximately at a constant rate, which implies a lack of compression in mortality improvement rates (Oeppen and Vaupel 2002).

In their research, they use linear extrapolation on international life expectancy trends (Oeppen and Vaupel 2002). The research involves a two-step analysis:

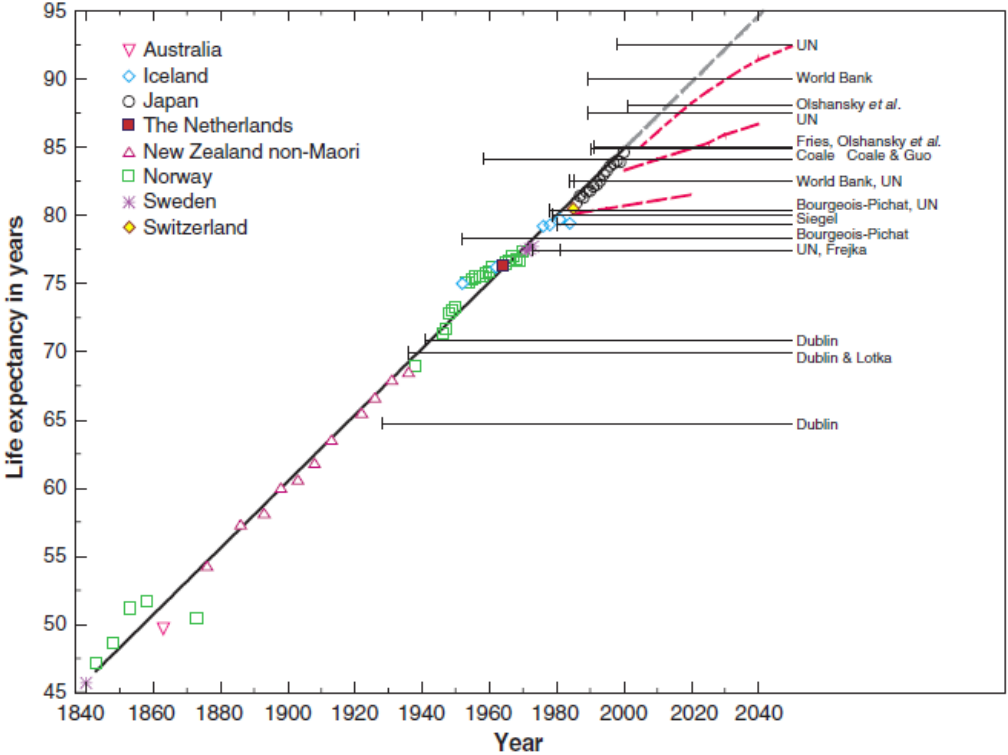
Trend in record life expectancy. Vaupel first analyzes the trend of the record life expectancy at birth<sup>9</sup> using linear regressions. He extrapolates historical linear trends and concludes that for 160 years, record life expectancy in the world has steadily increased by almost three months per year (slope of 0.24 years for females and 0.22 years for

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<sup>9</sup> Defined as the largest life expectancy at birth across all countries in a given period. The gap between the record and the national level is a measure of how much better a country might do at current states of knowledge and demonstrated practice (Oeppen and Vaupel 2002).

males). Figure 14 below shows his analysis of the female population, including future projections proposed by various researchers.

**Figure 14. Record female life expectancy at birth from 1840 to the present**  
**Source: Oeppen and Vaupel (2002). Reprinted with permission.**

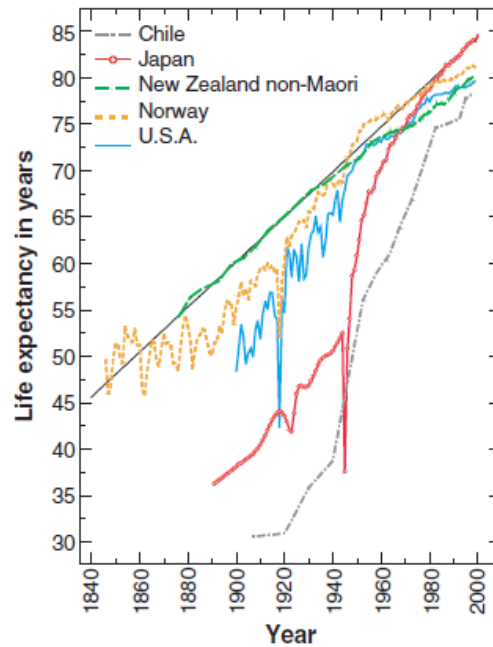


*\*The linear regression trend is depicted by a bold black line (slope = 0.243) and the extrapolated trend by a dashed gray line. The horizontal black lines show asserted ceilings on life expectancy, with a short vertical line indicating the year of publication. The dashed red lines denote projections of female life expectancy in Japan published by the United Nations in 1986, 1999 and 2001.*

Measure the gap between record and average. For each country, the gap between the record and the national average life expectancy levels is used as a measure of how much the country could improve in the future. Figure 15 shows that the large gap between U.S. female life expectancy and record life span has significantly narrowed in the past decades, varying between less than a year and about five years.

**Figure 15. Female life expectancy in Chile, Japan, New Zealand (non-Maori) and the United States compared with the trend in record life expectancy**

**Source: Oeppen and Vaupel (2002). Reprinted with permission.**



Thus, Vaupel proposes that life expectancy in the U.S. population will continue to rise linearly along the trend in world record, and that the human life span has no upper limit. Assuming that such trends in record life expectancy continue and the U.S. disadvantage is between a year and 10 years in 2070, Vaupel estimates that the female life expectancy would be between 92.5 and 101.5 years in the United States.

Vaupel also studied the pattern of deaths among twins in Scandinavia, and his results show that the average age at which senescent death occurred was beyond age 110 (Barinaga 1991).

It is worth noting that Ronald Lee, co-creator of the Lee-Carter mortality forecasting model, further examines the regularity of the linear increase in record life expectancy based on Vaupel's data (Lee 2003). Average rates of life expectancy increase by sex and subperiod in

Table 6 below and suggest an S-shaped pattern of past trends. For males, in particular, there has been a noticeable deceleration since 1950.

**Table 6. Average annual rates of decline of record life expectancy in the United States**  
Source: Lee (2003)

	Females	Males	Average
1840–1900	0.24	0.24	0.24
1900–1950	0.27	0.26	0.27
1950–2000	0.23	0.15	0.19

Lee finds that Vaupel’s use of a strictly linear trend overestimates future mortality improvements.

Kevin M. White

Kevin White also predicts faster gains in life expectancy based on linear extrapolation on international data. He examines the U.S. sex-combined life expectancy trend along with 20 other industrial nations based on data from 1955 to 1991. He finds that an extrapolative model based on linear trend in life expectancy fits better to most countries’ experience, compared to one based on the log of the age-standardized death rate as proposed by Lee (Lee and Carter 1992). Results show that life expectancy has been growing at a rate of 0.208 years per annum (White 2002).

Similar to Vaupel, White observes a decrease in life expectancy variability between countries and in variability of life expectancy improvements. He finds that life expectancy increased more rapidly in countries with a lower starting level of life expectancy in 1955. The trend toward convergence suggests that forecasting mortality improvements for the United States should be considered in an international context. As the United States currently exhibits below-average life expectancy and life expectancy gains, White (2002) projects a slight increase in the speed at which U.S. life expectancy advances.

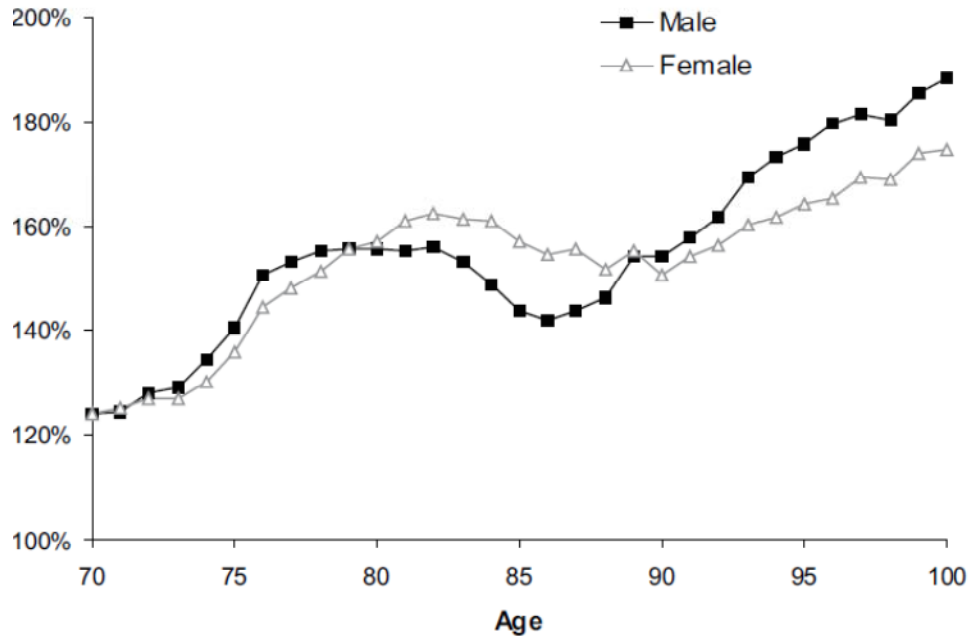
Richard Willets

Willets et al. (2004) analyzed what they refer to as the “aging of mortality improvement,” which incorporates two observations of mortality improvement: (1) the ages showing the greatest rates of improvement have been increasing over time, and (2) the pace at which mortality is improving at older ages is accelerating over time. Figure 16 illustrates the “aging” effect.



**Figure 16. Ratio of average annual rates of mortality improvement over the last 10 years versus the previous 30 years; average over five countries (England and Wales, United States, Japan, France and West Germany)**

Source: Willets et al. (2004), The Institute and Faculty of Actuaries. Reprinted with permission.



Willets et al. also observed that mortality improvements for young men in the United Kingdom have been on the decline since the end of World War II. They find that the future course of mortality rates for younger adults is subject to considerable uncertainty.

## VI.C. Summary considerations in long-term mortality improvement forecasting

The following table summarizes the opinions of various researchers discussed in this section.

**Table 7. List of demographers and actuaries and their mortality improvement studies**

Main researcher	Year of study	Forecasting technique	Forecast of U.S. mortality improvements
2012 Social Security Administration (SSA)	2012	Cause- and age-specific extrapolation	Ultimate average annual mortality improvement of 0.75% for males (83.4 years life expectancy) and 0.71% for females (86.5 years life expectancy); ultimate annual mortality improvement of 1.56% for ages 0–14, 0.90% for ages 15–49, 1.05% for ages 50–64 and 0.65% for ages 65 and above
2011 Technical Panel	2011	Age-specific extrapolation	Life expectancy of 88.7 years in 2085 (males and females combined); annual implied mortality improvement of 1.26% into the future
James Fries	2003	Other	Maximum average life expectancy of 87.8 years (males and females combined)
James W. Vaupel	2002	Linear extrapolation of record life expectancy and linear convergence of life expectancies	Life expectancy of 92.5 to 101.5 years for females in 2070
Kevin M. White	2002	Other	Life expectancy of 83.3 years in 2030
S. Jay Olshansky	1995	Other	Maximum average life expectancy of 85 years
Kenneth G. Manton	1991	Time-series risk-factor model to calculate a maximum achievable life expectancy	Maximum achievable life expectancy of 97 years for females and 100 years for males

All sources agree that historical data shows some degree of continuous mortality improvement in the overall population in the United States over the last century. The uncertainty relates to the exact shape of this curve (accelerating, decelerating, linear) and how far into the future it can be projected before an upper limit to the human life span creates a barrier.

The ultimate achievable life expectancies proposed by the various researchers listed above range from approximately the mid-80s to high 90s. Unfortunately, most researchers do not translate this into a long-term rate of mortality improvement. However, the Social Security Administration does project a long-term rate of 0.73 percent for years 2036–86, all ages and

both sexes combined, under the Intermediate Alternative, and the 2011 Technical Panel projects an implied long-term rate of 1.26 percent.

In reviewing available literature and the research performed, we found that academic researchers tended to fall into two extremes, with very little middle ground. In particular, Vaupel is recognized as a leading figure in favor of a (practically) unlimited human lifespan. Tuljapurkar and Boe (1998) reviewed existing work and literature and argued there is little basis, in theory or observation, for the existence of a component of mortality that will never be reduced by human intervention, and substantial evidence against the existence of a precisely defined limit. Willets et al. (2004) note that medical developments and changes in behavior (such as reduced smoking and better diet) are likely to lead to significantly lower mortality rates among the elderly.

On the other hand, Fries and Olshansky are recognized in the industry as leading proponents of the theory that human life span is more limited. Willets et al. (2004) observe that the proponents of this view still believe that substantial reductions in mortality are possible; however, these will come from the elimination of deaths from age-related diseases, such as heart disease and cancer. Life expectancy will increase, but the potential increase will be limited by the inevitable processes of aging and damage accumulation.

The two camps have not attempted to arrive at a consensus. We refer the reader to the intermediate-cost assumptions used in the 2012 Trustees Report (0.73 percent long-term assumption for years 2036–86, all ages and both sexes combined), which provides a lower bound for the long-term mortality improvement rates among the papers included in this literature review – including the decreasing shape of the mortality improvement curve by age. We believe the implied annual mortality improvement assumption of 1.26 percent in the 2011 Technical Panel on Assumptions and Methods represents an approximate middle ground for the range of long-term rate assumptions found in our review. We were unable to identify any reliable estimates of an upper bound for long-term mortality improvement rates in the United States.

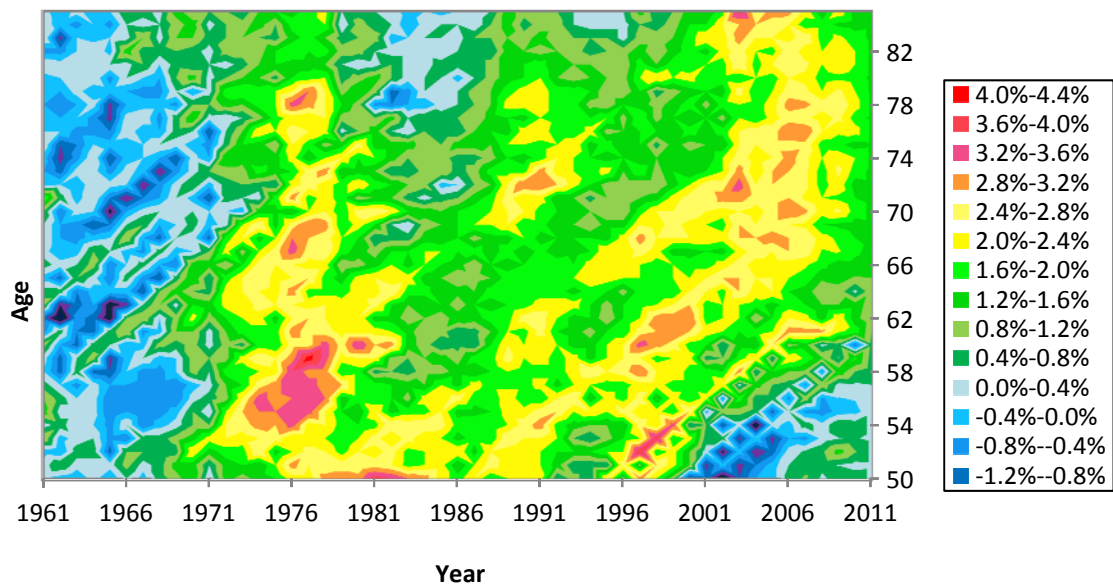
## VII. Analysis of age-period-cohort factors

Some of the more recent modeling approaches actuaries are using around the world are based on projection capabilities by age, period and cohort. In this section, we review literature that analyzes U.S. data to determine which of these effects have historically been significant in the United States.

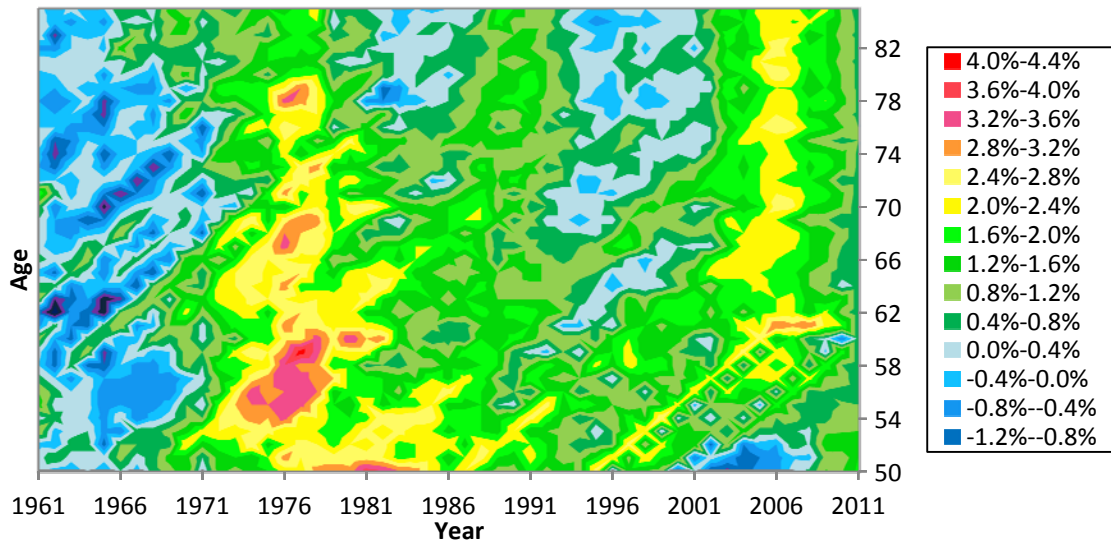
One of the main ways actuaries and demographers analyze historical effects centers on the ability to visualize historical data. As shown in the introduction of this paper, this is generally done through a heat map. Figure 17 and Figure 18 below show heat maps corresponding to males and females in the United States.

**Figure 17. United States mortality improvement for males, ages 50–85**

Source: Data from Human Mortality Database, converted by Ernst & Young LLP



**Figure 18. United States mortality improvement for females, ages 50–85**  
**Source: Data from Human Mortality Database, converted by Ernst & Young LLP**



The heat maps contain a grid of historical mortality improvement rates by age (y-axis) and year (x-axis). Each color represents a different rate of mortality improvement. The color red represents a reduction in mortality of about 4 percent, whereas the blue areas represent a reduction in mortality of about -1 percent (in other words, mortality increased).

The heat map itself requires some effort to construct. The underlying mortality data tends to be extremely noisy, and we can only see broad trends by smoothing the data. For example, as described in section IV.C., splines are a class of interpolation techniques that can be combined with a penalty function to produce smoothed interpolated data.

Heat maps are typically used to seek out visual evidence of three types of effects:

- Vertical patterns: Period effects
- Horizontal patterns: Age effects
- 45° diagonal patterns: Year-of-birth/cohort effects

#### Period effects

Males and females show broadly similar period effects. We see increasing mortality rates in the 1960s, and decreasing mortality in the mid 1970s, the late 1980s and the mid 2000s. The increasing mortality rates are generally higher for males, particularly after about 1985. 2005 shows a period effect of high mortality improvement for both males and females.

It is difficult to tell whether there is a period effect in progress as of 2011.

### Age effects

The heat maps as presented contain data for ages 50+, so they are not ideal for analyzing age effects across the entire age spectrum. However, for the purpose of pension plan practitioners, this may be less concerning. We observe that there are no distinct horizontal lines in either graph. This does not mean there are no age effects; it merely suggests that any age effects do not target a particular band of ages, but act much more broadly. For example, the decrease in mortality rates occurring in the mid 2000s primarily occurs in ages 65+. It is possible improvements in this period were due to improved medical procedures targeting older ages.

### Cohort effects

A year-of-birth cohort is a subset of the population born around the same period.

The term “cohort effect” is commonly used in literature about longevity. Yang (2008) provided a reasonable definition for the term that we adopt here.

Cohort effects represent variations in mortality across groups of individuals born in the same year or years. Cohort effects may arise when each succeeding cohort carries with it the imprint of physical and social exposures from gestation to old age that bear upon its morbidity and mortality risk in a specific way.

Alternatively, the term was defined by Mason and Wolfinger (2001) as follows.

A cohort is a set of individuals entering a system at the same time. Individuals in a cohort are presumed to have similarities due to shared experience that differentiate them from other cohorts. Cohort analysis seeks to explain an outcome through exploitation of differences between cohorts, as well as differences across two other temporal dimensions.

In our own words, a “cohort effect” is present when some subset born around the same period shows a pattern of mortality improvement distinct from those born before or after that subset.

In heat maps, the 45° diagonal lines represent a cohort, or group of people, moving through time. For example, in the graph for males, Figure 17, there is a distinct yellow line beginning at the bottom of the graph starting at 1978, and moving diagonally upward with each passing year. This is because males that were age 50 in 1978 are 51 in 1979, 52 in 1980 and so forth. There does appear to be a slight increase in mortality improvements in this particular cohort over females who were born before or after that cohort.

We do generally observe diagonal patterns throughout the graphs for males and females. The patterns generally appear stronger for males, particularly in the late 1970s and late 1980s. Cohort patterns also appear to be of very long duration, extending for the life of the cohort.

These patterns often fade in and out over the life of the cohort as they pass through periods with higher and lower mortality improvements.

We use the remainder of this section to summarize the analyses performed by various researchers in identifying these age, period and cohort effects. In some cases, researchers also provide insight into the cause of these effects, and in some cases, researchers compare the patterns in the U.S. data to those in other countries.

## VII.A. Literature review

### Andrew Cairns

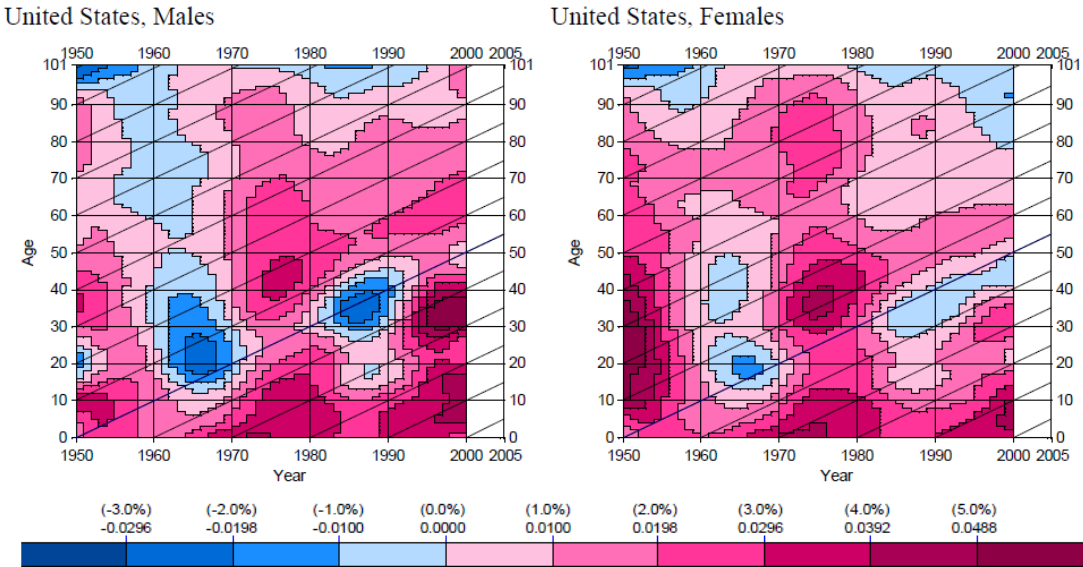
Cairns uses extrapolative models to forecast the impact of age, period and cohort effects in the United States and England/Wales (Cairns et al. 2007). The models include the original and extended versions of the Lee-Carter model, the CBD model, and multiple spline (interpolation) techniques. They analyze males aged 60–89. In the United States, they consider data from 1968–2003, and in England and Wales, they consider data from 1961–2004. Their findings are largely consistent across all models tested.

- Age. Lower ages show a greater mortality improvement than higher ages. They find that the relationship between age and mortality improvement is slightly curved and can be represented with a quadratic function.
- Period. They find that mortality rates have improved over time for all ages in both the United States and England and Wales. The analysis shows there have been approximately linear improvements over time in mortality rates at all ages.
- Cohort. They find cohort effects in both countries, although improvements are more prominent and systematic in England and Wales.

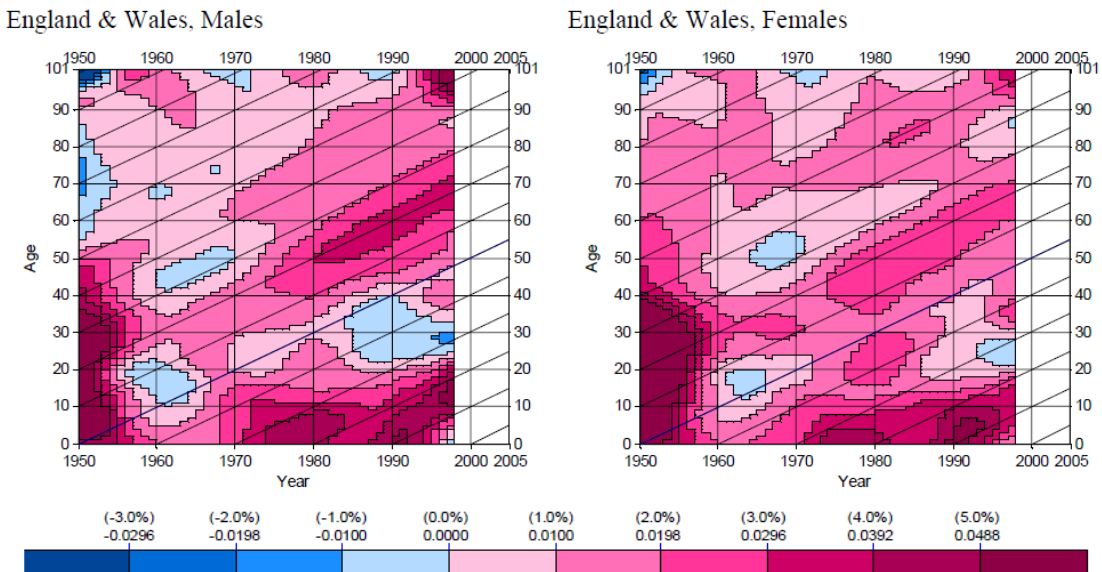
### Kirill Andreev and Vaupel

Andreev and Vaupel used splines (smoothing) to visualize the historical patterns in mortality improvements similar to our own analysis above (Andreev and Vaupel 2005). They applied their technique across 18 countries. We focus on the results for the United States, but compare it to the England/Wales results as well.

**Figure 19. Historical patterns in mortality improvements, United States**  
 Source: Andreev and Vaupel (2005). Reprinted with permission.



**Figure 20. Historical patterns in mortality improvements, England and Wales**  
 Source: Andreev and Vaupel (2005). Reprinted with permission.



In the above graphs, blue regions indicate negative mortality improvement and magenta regions indicate positive mortality improvement. To illustrate the evidence of the APC effects, we specifically discuss the two regions, England and Wales, and the United States.



- Age. An age effect is observable in both countries; however, it is more erratic in England and Wales than in the United States. In the United States, aside from the 1960s and 1980s, mortality improvement is higher at younger ages (<50 years old).
- Period. Period effects are more distinct in the United States, and mortality improvement levels alternate each decade. In the 1950s, 1970s and 1990s, mortality decreased, and in the 1960s and 1980s, mortality varied by age but overall did not move significantly.
- Cohort. They find no significant cohort effect for males in the United States (at variance to our own observation noted earlier), but they do find a cohort-like effect for females born in the mid 1950s. In England and Wales, they find more significant effects for males and females born in the 1930s.

### Yang Yang

Yang (2008) analyzes the impact of changes in cause of death over time on age, period and cohort effects in the United States during the 20<sup>th</sup> century.

Table 8 below provides an overview of her findings by cause of death.

**Table 8. Age, period and cohort effects by cause of death**

<b>Cause of Death</b>	<b>Age</b>	<b>Period</b>	<b>Cohort</b>
Heart disease	Increases exponentially with age	Modest impact	Large monotonic decline from the earliest to the latest cohort
Stroke	Increases exponentially with age	Modest impact	Large monotonic decline from the earliest to the latest cohort
Lung cancer	Increases rapidly with age from early adulthood to peak near ages 80–85, then levels off	Monotonic increase over time	Increases for cohorts through 1905 and decreases for recent cohorts
Breast cancer	Increases with age, but increases slow around menopause	Modest impact	Steady declines in mortality from breast cancer from the earliest to the latest cohort

Yang found that large reductions in mortality since the late 1960s continued well into the late 1990s, and that these reductions were predominately attributed to cohort effects. Cohort effects differ by specific causes of death, but generally show substantial survival improvements.

Her analyses provide new evidence of persistent cohort differences in mortality rates for all causes of death examined. One key finding is the dominance of cohort effects in explaining recent trends in mortality reductions. The effects associated with birth cohorts reflect processes of differential cohort accumulation of lifetime exposure to risk factors: education, diet and nutrition, physical activity, and smoking.

Yang found that period effects are generally small or modest when birth cohort and age effects are simultaneously controlled. Specifically, she found virtually no period effect for heart disease mortality, and a very moderate decrease in stroke mortality since 1975. Period effects are likely more prominent in times of wars or other major events that have massive social impacts (Yang 2008).

#### Nadine Ouellette, Magali Barbieri, and John Wilmoth

Similar to Yang, Ouellette, Barbieri, and Wilmoth (2012) investigated cause-specific mortality trends at adult ages that occurred in many developed countries in the late 1960s or early 1970s. However, while not ruling out some cohort factors as drivers of the reduction in death rates (especially with regard to smoking-related cancers), the authors found that period effects played a dominant role in the most significant epidemiologic transformation in that era (Ouellette, Barbieri, and Wilmoth 2012).

The authors suggest that cardiovascular disease is affected more by current or recent smoking status than by past smoking history and, therefore, smokers have higher cardiovascular disease risks compared to nonsmokers regardless of their smoking history (i.e., a cohort effect).

In contrast, the risk of smoking-related cancers is determined not so much by current smoking as by a person's lifetime history (i.e., smoking duration and intensity). For certain cancers, the cumulative effects of smoking are more clearly attached to specific cohorts as a result of their smoking histories. Smoking cessation has a smaller, delayed impact on such causes of death.

#### Willets et al.

Willets et al. (2004) identified examples of birth cohorts in other countries including Japan and the United Kingdom. They observed that Japanese born between 1910 and 1925 have continued to experience rapid improvement far into old age, which indicates that cohort effects may never converge or wear off.

In the United Kingdom, the authors observed cohort effects for specific causes of death including circulatory disorders, cancer, and respiratory disorders. The authors also observed evidence of early life experience impacting health later in life by studying the cohort of people born in the 1940s (during World War II).

## VII.B. Summary considerations in age-period-cohort effects

In reviewing available literature and the research performed, we found that academic researchers have emphasized the extent and interaction of age, period, and cohort effects in the analysis of U.S. mortality improvement. However, there seems to be a lack of consensus regarding which factor is dominant. While Yang (2008) considers cohort effects to contribute more predominantly to mortality improvement, Andreev and Vaupel (2005) and Ouellette, Barbieri, and Wilmoth (2012) consider period effects to be more predominant. The research reviewed was focused on studying the predominance of APC effects in U.S. mortality improvement. There were no specific suggestions on appropriate convergence periods for APC factors.

Overall, practitioners should be aware that mortality improvements resulting from advancements in medical measures (measures that tend to persist after they are introduced) will probably manifest as a cohort declines since the cumulative effects are more pronounced in successive cohorts compared with period effects. Period effects, on the other hand, have manifested in times of wars or other major events that have large impacts across a broad spectrum of ages. We refer practitioners to the CMI methodology discussed in section V, which provides a useful reference to incorporate APC factors into short-term and long-term mortality improvement assumptions. Research in U.S. historical mortality improvement does not provide evidence against the CMI methodology in this regard.

## VIII. Analysis of other factors that affect base mortality rates and mortality improvement

In this section, we review literature covering socioeconomic and lifestyle factors affecting mortality improvement. This discussion is intended to provide some context for actuaries to understand how certain subpopulation mortality improvement rates will compare to the general population.

### VIII.A. Socioeconomic status

Research generally recognizes socioeconomic status as one of the most significant factors that divide a population into different groups with respect to mortality. Socioeconomic status is a combined measure of a person's sociological and economic status. Longevity research makes use of this term to study differences in mortality due to wealth, education, occupation and other factors that may affect mortality. Unfortunately, in most cases, socioeconomic status is not directly measurable; therefore, academic research commonly uses education or wealth as a measurable proxy to determine the impact of socioeconomic status on mortality. It is important to recognize that good proxies will be highly correlated with each other and, therefore, cannot be used separately as if they were independent of each other.

Over time, research appears to have shifted toward education as a good proxy. Kruger et al. (2003) (discussed further below) observed that income tends to change over the course of a person's lifetime, which can make analysis based on income or wealth more complicated. Generally, once a person passes a certain age, the level of educational attainment remains fixed.

In this section, we step through key research that analyzes the impact of socioeconomic status on mortality. As a foundation to more recent research, we summarized findings by Evelyn Kitagawa and Phillip Hauser for studies performed prior to the 21<sup>st</sup> century. For research after 2000, we found the research performed by Olshansky et al. (2012) to be particularly useful as it uses recent data, measures interaction with other key variables, including race, and translates results into life expectancies. They found an eight-year differential in average life expectancy between the lowest and highest educated groups.

#### VIII.A.1 Education as a proxy for socioeconomic status

Some academic researchers have favored education level as a proxy for socioeconomic status as it offers two main advantages: It is available for people who are not in the labor force and its value is less influenced by health problems that develop in adulthood (Preston and Elo 1995). The following literature review examines the impact on education levels across different population groups.

### Kitagawa and Hauser

According to a review by Jonathan S. Feinstein, Kitagawa and Hauser were the first to publish a large-scale study in the United States measuring socioeconomic status in their 1973 report “Differential Mortality in the United States: A Study in Socioeconomic Epidemiology.” (Feinstein, 1993)

The authors observed a clear inverse relationship between education and mortality for the age group 15–64, but did not find a significant effect above age 65 (with the exception of white females, where there was a significant effect).

**Table 9. Kitawaga and Hauser impact of education on mortality**

Mortality rates of subgroup relative to total population mortality rates								
Population	White male		White female		Nonwhite male		Nonwhite female	
Age group	25–64	65+	25–64	65+	25–64	65+	25–64	65+
Lowest educated (0–4 years)	115%	102%	160%	117%	114%	104%	126%	105%
Highest educated (college graduate)	70%	98%	78%	70%	87%	97%	74%	101%

### Samuel Preston and Irma Elo

Preston and Elo questioned the results of Kitagawa and Hauser, expecting to find a greater difference in mortality above age 65. The authors cite sharp differentials in disability rates due to educational level and questioned why mortality should not follow suit (Preston and Elo 1995).

The authors performed their own study and concluded that:

- Education does impact mortality across all ages.
- Education impacts male mortality more than female mortality, possibly because female mortality was historically tied to the educational attainment of their spouse.

### Olshansky et al.

Olshansky et al. (2012) analyzed the impact of education across age, race and gender. They observed widening disparities in mortality among the different groups, where mortality has been improving quickly for certain groups and slowly for others. They noted that in 2008, black males and females with fewer than 12 years of education had life expectancies similar to all adults in the 1950s and 1960s.

The study shows that the differential due to education varies by population, but overall the authors found a difference of approximately eight years in life expectancy between the least

educated and the most educated. The majority of the impact appears to come from having some education beyond high school (13–15 years of education).

The authors also found that the disparities by group appear to be widening over time, as shown in Table 10 below.

**Table 10. Disparity in life expectancy at birth between most and least educated**

**Source: Olshansky et al. (2012)**

<b>Year</b>	<b>Male</b>	<b>Female</b>
2000	13.4 years	7.7 years
2007	14.2 years	10.4 years

The authors believe the gap between the most and least educated will continue to grow in the future.

#### Diane Lauderdale

Lauderdale (2001) examined the effect of education differentials in mortality improvements in ages 65+, seeking to resolve conflicting results in other research. She analyzes data for cohorts born between 1895 and 1955, comparing people with a post-graduate education with people who have less than 12 years of education. She finds that the differences in other results are due to interaction between age, period and cohort effects, and presents her own findings separating the impact of age and period effects caused by educational differences.

- Age. She analyzed the impact of age within cohorts and found that mortality differentials between the most and least educated grew significantly within the cohorts at older ages.
- Period. Education differences in mortality have increased between 1960 and 1990. She also notes that the decline of coronary heart disease since 1960 accounts the most for the decline, and heart disease is more significant for those with the least education.

**Table 11. Relative survival of people with 13+ years of school compared with 0–11 years**  
**Source: Lauderdale (2001)**

Birth years	1960 to 1970 coefficient		1970 to 1980 coefficient		1980 to 1990 coefficient	
	Male	Female	Male	Female	Male	Female
1895–1905	1.06	1.07	1.29	1.29	1.44	1.33
1905–1915	1.10	1.05	1.20	1.19	1.38	1.34
1915–1925	1.14	1.11	1.21	1.24	1.42	1.37
1925–1935	1.21	1.15	1.29	1.39	1.34	1.41
1935–1945			1.50	1.59	1.38	1.57
1945–1955					1.48	1.73

We observe that mortality differentials have widened over time. However, the author stated it was difficult to determine whether this was the result of a period effect or an age effect.

#### VIII.A.2 Wealth as a proxy for socioeconomic status

Income and occupation have been a common proxy for socioeconomic status. The following literature review examines the impact on income levels and sources of income across different population groups.

##### Kitagawa and Hauser

Kitagawa and Hauser also studied the impact of wealth by attempting to link income, expenses and other correlating factors with mortality (1973). In Table 12 below, we summarize their results where they observe a clear inverse relationship between income and mortality. The authors also cautioned that poor health may force an individual to take a lower income job, distorting the causal effect.

The authors observed an inverse relationship between household income and mortality.

**Table 12. Mortality relative to total population by household income**  
**Source: Kitagawa and Hauser (1973)**

Coefficient <sup>10</sup>	White male family members		White female family members		White female family members		White female family members	
	25–64	65+	25–64	65+	25–64	65+	25–64	65+
Age group								
Income <\$2,000	1.51	1.1	1.2	0.96	1.26	1	1.27	1.05
Income \$8,000+	0.84	0.96	0.86	1.01	0.77	1.01	0.79	0.8

<sup>10</sup> “Coefficient” represents the mortality ratio between the group and the general population.

Morris Silver

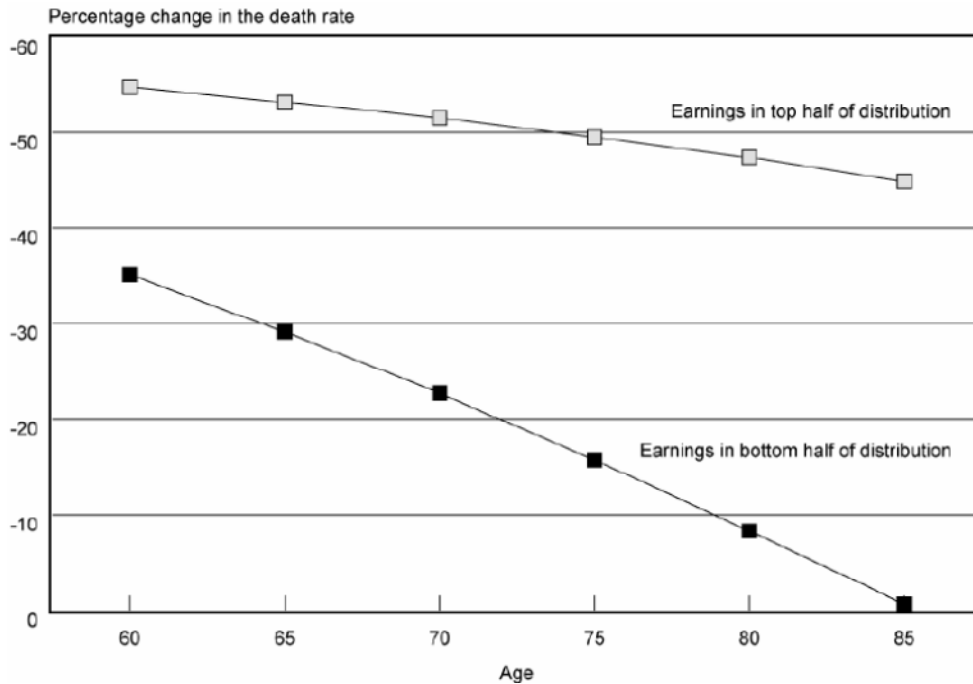
Silver performed similar research to Kitagawa and Hauser. However, Silver used a much wider range of indicators to measure living standards, such as median household income and the number of physicians in the neighborhood area. Despite a somewhat unique approach, his results largely corroborate Kitagawa and Hauser’s findings (Silver 1972).

Hilary Waldron

Waldron (2007) analyzed trends in mortality differentials and life expectancy by average relative earnings for male Social Security-covered workers age 60 or older. The author found that, for birth cohorts spanning the years 1912–41, workers with above-average earnings experienced higher rates of mortality improvement than workers with below-average earnings at all ages studied. Those born in 1941 who had average relative earnings in the top half of the earnings distribution and who lived to age 60 would be expected to live 5.8 more years than their counterparts in the bottom half. In contrast, the equivalent differential for those born in 1912 was 1.2 years.

**Figure 21. Death rate percentage change for selected cohorts**

**Source: Waldron (2007). Reprinted with permission.**





Krueger et al.

Krueger et al. (2003) examined the independent effects on mortality of different sources of income — employment, self-employment, interest and dividends. The authors used National Health Interview Survey data between 1990 and 1997, which provided information on the sources of income and linked it to mortality data.

They observed two patterns from the results.

- As we move from lower age groups to higher age groups, the average job income tends to decrease and the average dividend income tends to increase.

**Table 13. Average income by source**

Source: Krueger et al. (2003)

Age	25–44	45–64	65–74	75+
Job Income	\$23,016	\$20,356	\$2,607	\$444
Dividend Income	\$388	\$1,232	\$1,529	\$1,342

- They found higher mortality among those with lower levels of income or fewer sources of income. For example, within ages 25 to 44, the group with one or no sources of income experienced 1.7 percent mortality, whereas the group with four or more sources of income experienced only 0.5 percent mortality. Similar patterns persist across all age groups.

**Table 14. Likelihood of death over observation period from 1990–97**

Source: Krueger et al. (2003)

Age		25–44	45–64	65–74	75+
Sources of income	0–1	1.7%	6.9%	19.5%	35.1%
	1	1.2%	5.6%	17.5%	35.4%
	3	0.7%	4.1%	15.0%	33.4%
	4+	0.5%	3.2%	11.6%	29.2%

Willets et al.

Willets et al. (2004) observed that, in recent decades, U.K. population data has shown widening mortality differentials by socioeconomic class. Their analysis suggests cohort effects may be seen more strongly in higher socioeconomic classes, such as the mortality of annuitants.

Willets et al. add that it is difficult to draw firm conclusions about the precise causes of class differentials. They reference Vallin, Mesle and Valkonen (2001), who came to the conclusion

that: “The explanations are likely to be different for different causes of death and in different countries and time periods. No universally valid explanations exist.”

### VIII.B. Smoking and Obesity

Other lifestyle decisions also have the potential to influence mortality improvements and divide the population into subgroups with different trends. Literature tends to focus on the impact of smoking and obesity as factors changing mortality in the United States. The Centers for Disease Control and Prevention suggested in 2000 that 18 percent of deaths in the United States were attributable to smoking and 15–17 percent to obesity (Preston et al. 2012). Allison et al. (1999) find that life expectancy for severely obese people is reduced by somewhere between five and 20 years.

In this section, we summarize literature from other independent sources that discuss the impact of obesity and smoking.

#### 2011 Technical Panel

We discussed the 2011 Technical Panel analysis of smoking and obesity above in section VI.B. They concluded as follows:

- Smoking. The panel expects we will continue to see mortality improvements in the future as a result of reductions in smoking behavior from the prior two to three decades.
- Obesity. Results vary substantially among these studies. The Technical Panel assumes the current impact of obesity is a decrease of one year in life expectancy and believes the additional impact by 2085 will also be a decrease of one year given the potential delayed effect of obesity.

#### Samuel Preston and Haidong Wang

Preston and Wang (2005) examined the role of cohort smoking patterns in the United States. The authors concluded that significant reductions in mortality have already taken place, and they expect these reductions to continue into the future.

**Table 15. Estimated changes in probabilities of surviving from age 50 to 85 if smoking were reduced or eliminated**

**Source: Preston and Wang (2005)**

	Male	Female
1. U.S. Life Table of 2003	.302	.464
2. 2003 Prediction with actual smoking history	.304	.468
3. 2003 predictions with 2000 current smoking behavior	.384	.479
4. 2003 predictions with no smoking	.464	.519

In

Table 15. Estimated changes in probabilities of surviving from age 50 to 85 if smoking were reduced or eliminated

Source: Preston and Wang (2005)above, the authors show the impact of changes in smoking patterns. Row 2 represents how the author’s APC model comes close to replicating the actual survival probability in the official U.S. Life Table for 2003. Row 3 represents how a certain cohort should react given the changes that have already occurred in smoking behavior through 2000. They expect a jump in survival probability for males between ages 50 and 85 from 30.4 percent to 38.4 percent. Further, Row 4 shows that if this cohort would cease all smoking, survival probability could rise up to 46.4 percent. The impact is much less significant on females, as smoking is less prevalent among women and there is less room for improvement.

Olshansky et al.

Olshansky et al. (2005) found that if recent trends in childhood and adult-onset obesity are not reversed in the United States, it is possible the life expectancy of some subgroups of the population could fall within the next few decades.

To illustrate the impact of obesity, the authors construct a scenario where everyone who is currently obese would lose weight to obtain a body-mass index (BMI) in the healthy range of 24. The results are summarized in Table 16 below.

**Table 16. Improvement in life expectancy in years when BMI changes to 24**

<b>Original BMI</b>	<b>30</b>	<b>35</b>
White males	0.33	0.93
White females	0.30	0.81
Black males	0.30	1.08
Black females	0.21	0.73

Neil Mehta and Virginia Chang

Mehta and Chang (2009) compare the results from two studies regarding the impact of obesity on life expectancy: Flegal et al. (2005) and Mokdad et al. (2004). Flegal et al. estimated that only about 26,000 adult deaths in the United States in the year 2000 were attributable to obesity. Mokdad et al., on the other hand, found that 350,000 deaths were attributable to obesity.

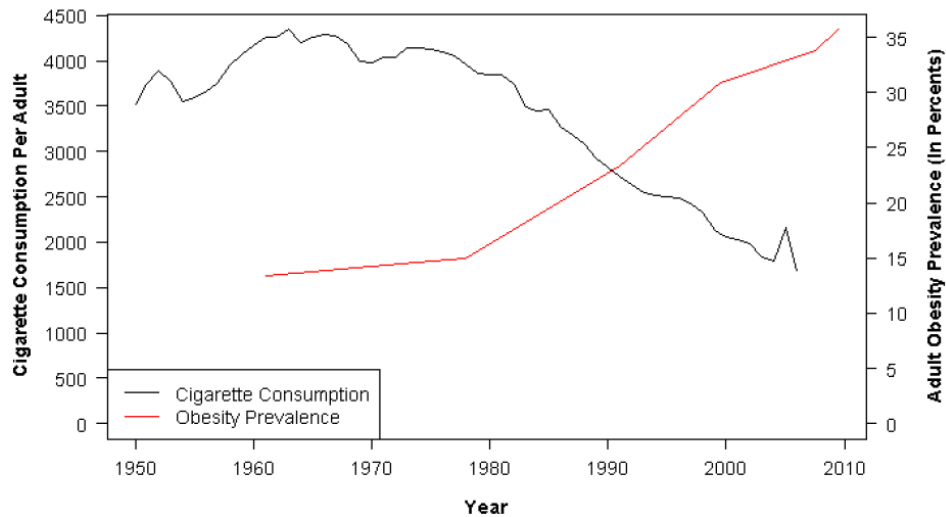
Mehta and Chang find the wide disparity in results stems from a lack of reliability in the source data, the National Health and Nutrition Examination Survey. By using data from the Health and Retirement Study, they found significantly higher mortality risks associated with a BMI greater than 35 (class II/III obesity), but not for a BMI between 25 and 34.9 (overweight/class I obesity). The authors' final result is similar to the results from Flegal et al. showing a reduced number of deaths attributable to obesity.

Preston et al.

Preston et al. (2012) found that smoking and obesity effects may not be independent from each other. The trend lines of prevalence of smoking and obesity have had an inverse relationship in the United States, as shown in Figure 22 below.

**Figure 22. Smoking and obesity trends in the United States**

**Source: U.S. Department of Agriculture, October 2007. Reprinted with permission.**



The authors therefore analyze the joint impact of smoking and obesity and estimate the aggregate future impact on mortality improvement rates. The results are shown in

Table 17 below.

**Table 17. Change in life expectancy at age 40 resulting from changes in smoking and obesity**

	Changes in obesity		Changes in smoking		Changes in smoking and obesity	
	Male	Female	Male	Female	Male	Female
2020	-0.259	-0.191	0.529	0.038	0.273	-0.147
2030	-0.453	-0.422	1.035	0.322	0.597	-0.074
2040	-0.614	-0.642	1.515	0.848	0.923	0.259

The authors conclude that the reduction in smoking will outweigh the penalty from obesity.

Willets et al.

Willets et al. (2004) identified the changes in smoking prevalence as a key force behind recent changes in U.K. mortality. They observed that the change in cigarette consumption has been responsible for between a quarter and a third of the reduction in heart disease mortality since the 1970s.

The authors acknowledge that the effects over long periods of time and across age groups are difficult to judge. In addition, the adverse impact of smoking increases substantially with the duration for which that person has been smoking. The authors suggest we may see cohort patterns within the lung cancer mortality data, with a key driver being the prevalence of cigarette smoking as each generation passes through their 20s.

**VIII.C. Summary considerations of other factors affecting mortality improvement**

In reviewing available literature and the research performed, we found that several studies support the view that socioeconomic factors such as wealth, income level and attained level of education have an impact on mortality and mortality improvement experience. The better educated and wealthier populations exhibit lower levels of mortality and also appear to have experienced higher levels of mortality improvement compared to the general population. This is particularly relevant to the pension population since it tends to be focused at the higher education and income levels. Research shows that individuals in higher socioeconomic groups (identified by level of education achieved) may experience mortality improvements between 0.5

and 1 percent per year greater than the general population (Purushotham, Valdez and Wu 2011).

Obesity is commonly cited as a potential source of future mortality deterioration, particularly for the U.S. population. Research shows that lack of reliability in source data makes it difficult to quantify the long-term impact in mortality improvement (Mehta and Chang 2009). Period effects are expected to appear as a result of health campaigns impacting obesity levels at all ages in the coming decades.

The reduction in the percentage of smokers in the United States since 1970 has been a contributing factor to improvements seen in general population mortality. Research shows that mortality improvement levels for nonsmokers are distinctively greater than improvement levels for smokers. Researchers also expect cohort effects to appear as a result of changing smoking behavior (Preston and Wang 2005).

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