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Some methodological issues in mortality projection, based on an analysis of the U.S. social security system

1. INTRODUCTION

Mortality decline and the resulting growth of elderly populations have critical implications for the pension plans of many countries. In the United States, the main source of public pension support is the Social Security system, which pays benefits to most retirees and disabled persons, and their dependents. The current financial status and expected future prospects of this system are summarized each year by its Board of Trustees[1] in an Annual Report (Board of Trustees, 2003).

In 2003 an expert group (referred to here as the "2003 Technical Panel," or "the Panel") was appointed by a separate agency of the federal government[2] and was charged with reviewing the official projections of the Social Security trust fund,[3] and with delivering recommendations to the Board of Trustees about the methods and assumptions used when making such calculations. Their final report included detailed discussions and specific recommendations regarding the various economic and demographic components of these projections (Technical Panel, 2003). A similar report by a different group of experts was published four years earlier (Technical Panel, 1999).

As a member of the 2003 Panel, I took primary responsibility for reviewing the methods and assumptions used for deriving expected future

[1] The Board of Trustees (of the Federal Old-Age and Survivors Insurance and Disability Insurance Trust Funds) consists of three Cabinet members (Secretaries of the Treasury, Labor, and Health & Human Services), the Commissioner and Deputy Commissioner of Social Security, plus two "public" trustees.

[2] The full name of the expert group was the "2003 Technical Panel on Assumptions and Methods." The Panel was appointed by the Social Security Advisory Board (SSAB), which is responsible for advising the President and Congress on matters related to Social Security. As an independent governmental agency, the SSAB is not part of the Social Security Administration or under the authority of Social Security's Board of Trustees.

[3] Technically, the Panel's charge was limited to reviewing official projections of the Old-Age and Survivors Insurance (OASI) and the Disability Insurance (DI) trust funds, known collectively as OASDI. Therefore, all comments here about the financial consequences of different projections refer to the combined OASDI trust fund (and thus do not include Medicare).

trends in fertility, mortality, and international migration. Changes in any of these demographic components could have major impacts on future program costs. In fact, of all the recommendations put forward by the Panel, the proposed changes regarding projected levels of international migration and mortality proved to be, by far, the most significant in financial terms.

The projections of the 2003 Trustees report foresaw an expected financial shortfall over the next 75 years that could be corrected by an immediate and permanent increase of 1.92 percentage points in the national payroll tax used to fund the system. However, the Panel concluded that the levels of international migration used when making these official projections were implausibly low and recommended an alternative set of assumptions. If the Panel's recommendations concerning international migration were adopted in place of the assumptions used in the 2003 Trustees report, the increase in the payroll tax needed to achieve fiscal solvency over the next 75 years would be lower by 0.25 percentage points (thus, a 1.67 percentage point increase, instead of 1.92).

On the other hand, the Panel also recommended a substantial increase in anticipated gains in future longevity, which would have the effect of increasing future pension costs. In fact, the effect of the reduction in expected financial obligations due to the recommendations concerning international migration was cancelled almost exactly by its recommendations with regard to mortality, which imply an increase in the projected 75-year actuarial imbalance equal to 0.24 percent of the national payroll.

The purpose of this paper is to review the methods and assumptions used for forecasting mortality as part of the official Social Security projections, and to discuss in detail the Panel's recommendations on this topic. Many issues discussed here may be relevant to other countries or populations, in situations where mortality forecasts are derived by means of a judicious extrapolation of past trends. Before addressing these general topics, let us begin with a brief overview of historical trends in U.S. mortality and longevity, as well as a short summary of the Trustees' mortality projections over the past two decades.

2. BACKGROUND

2.1 Historical trends in U.S. mortality and longevity

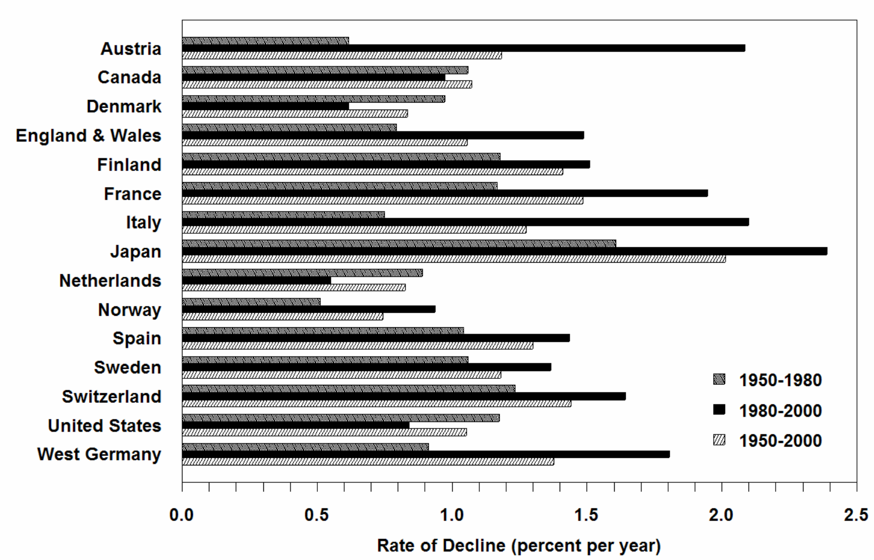
Mortality risks across the age range fell dramatically during the 20th century, leading to an unprecedented increase in life expectancy at birth (and at all ages) for both men and women in the United States (as in many other countries). For the total population, life expectancy at birth rose from 47.7 years in 1900 to 76.6 in 2000, a 60 percent increase over the century. However, most of this change (72 percent) occurred before 1950. Life expectancy at older ages presents a similar story overall, but there is one key difference. At age 65, for example, life expectancy rose from 11.7 years in 1900 to 21.2 in 2000, an 81 percent increase. However, most of this change (75 percent) occurred after 1950.

Part of the slowdown in the rise of life expectancy at birth occurred mechanically, due to the disproportionate influence of infant and child survival on the average life span of a population. Once childhood mortality became rare, there were few deaths left to eliminate in early life, making it more difficult to raise life expectancy at birth (Keyfitz, 1985; Wilmoth, 1998). In addition, there was a substantial reduction in rates of mortality decline among both children (ages 0-14) and adults of working age (15-64) between the first and second halves of the 20th century. In contrast, above age 65 the pace of mortality decline in the U.S. accelerated over the course of the 20th century, thanks to an unprecedented reduction in certain forms of old-age mortality (especially cardiovascular disease) beginning in the late 1960s.

Nevertheless, rates of mortality decline varied considerably from decade to decade. The 1940s and 1970s stand out as periods of very rapid improvement, while the last 20 years have been less favorable. The arrested decline above age 80 beginning in the 1980s – as well as increasing mortality above age 85 during the 1990s – must be considered when making decisions about how to project such trends into the future. The 1999 Panel had suggested that the unfavorable trends in old-age mortality during the 1980s and 1990s may reflect the delayed effects of increased levels of smoking among women, and a more recent article offers important empirical support for this explanation (Pampel, 2002).

In addition, it is important to note that the U.S. experience of slow mortality decline during the 1980s and 1990s was not typical of most industrialized nations. Figure 1 shows instead that most high income countries enjoyed an accelerated mortality decline at ages older than 65 years during these two decades. The U.S. is one of only four high-income countries (in this group of 15) that deviate from this general pattern (the others are Canada, Denmark, and the Netherlands).

Figure 1 - *Rates of decline in age-sex-adjusted death rates, ages 65 and over, 15 high-income countries, 1950-2000*



Notes: See discussion in text concerning age-sex-adjusted death rates.
Estimated rates of decline in age-sex-adjusted death rates for the U.S. are somewhat higher using HMD data compared to SSA data (for ages 65 and above). No explanation for this difference is available at this time. The time trend shown here is similar with either data source.
Available data series for all countries shown here begin in 1950 and end in 2000, with the following exceptions: Austria (1950-1999), Canada (1950-1996), England & Wales (1950-1998), Japan (1950-1999), the Netherlands (1950-1999), and West Germany (1956-1999).
Age-sex adjustment used the 1990 U.S. Census population as a standard.

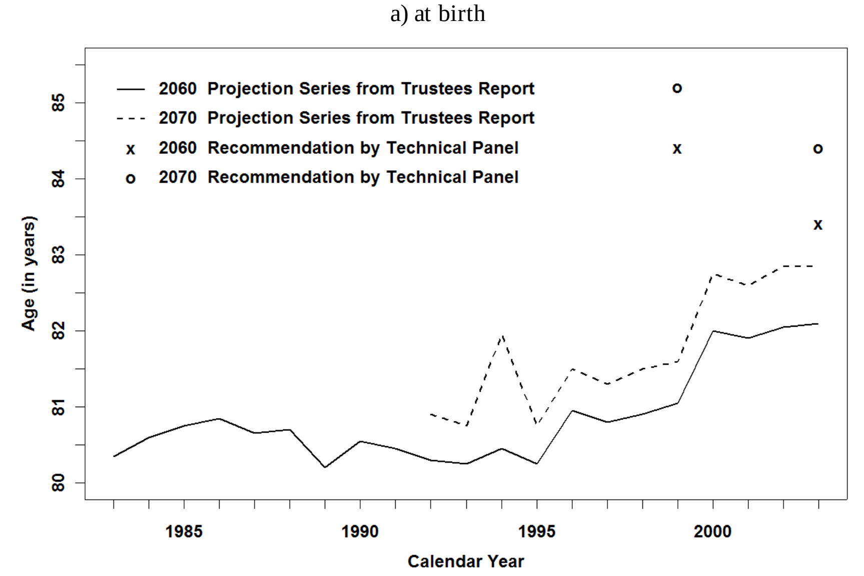
Source: Calculations by author using data from the Human Mortality Database, www.mortality.org.

2.2 Social Security mortality projections

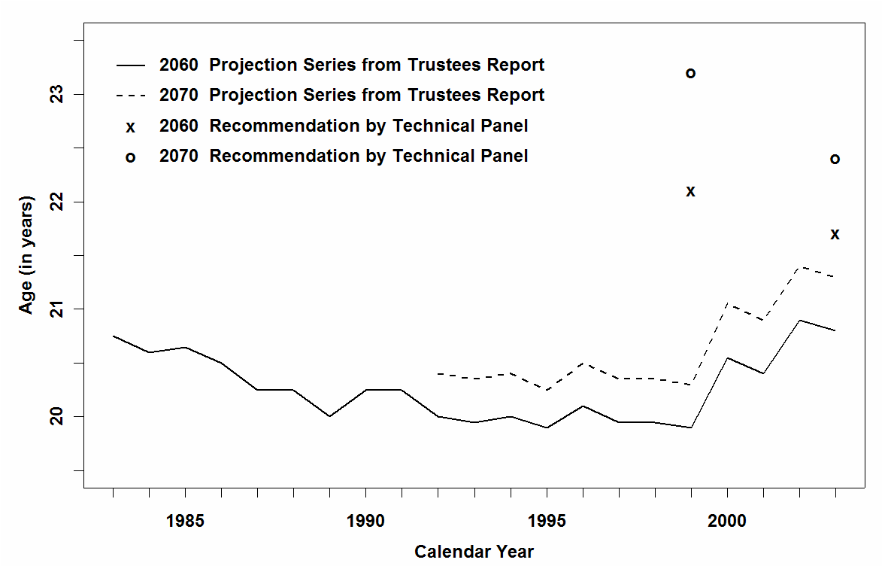
As shown here in Table 1 and Figure 2, future levels of life expectancy at birth implied by the mortality projections of the Trustees' annual financial evaluations of the Social Security trust fund changed little during the 1980s and early 1990s. Then, following the advice of an earlier technical panel that met during 1994-1995, this level was increased slightly in the late 1990s, and then again in 2000 following the publication of the report by the 1999 Panel. Despite these increases, the levels of life expectancy at birth used when projecting the trust fund still lie significantly below the recommendations of both the 1999 and 2003 Technical Panels.

Figure 2 – *Projected life expectancy in 2060 and 2070, U.S. total population, according to Trustees Reports from 1983 to 2003, and Technical Panels of 1999 and 2003 (intermediate scenario)*

a) at birth



b) at age 65



Notes: The horizontal axis of each graph depicts the calendar year when a Trustees Report was issued, or when a Technical Panel delivered its recommendations. See note b of Table 1.

Source: See sources for Table 1.

Table 1 – *Projected values of life expectancy in 2060 and 2070, at birth and at age 65, U.S. total population, according to Trustees Reports from 1983 to 2003, and Technical Panels of 1999 and 2003 (intermediate scenario)*

	2060		2070	
	At birth	At age 65	At birth	At age 65
Trustees Reports[a]:				
1983-1986	80.6	20.6	-	-
1987-1991	80.5	20.2	-	-
1992-1995	80.3	20.0	81.1	20.4
1996-1999	80.9	20.0	81.5	20.4
2000-2003	82.0	20.7	82.8	21.2
Technical Panels:				
1999[b]	84.4	22.1	85.3	23.2
2003	83.4	21.7	84.4	22.4

Notes: [a] The table shows average values of projected life expectancy from Trustees Reports for groups of calendar years. These time periods were chosen to match distinct phases in the trend by year (see Figure 2).
[b] TP1999 recommended a specific value for life expectancy at birth in 2070 and also specified a method for modifying the TR1998 projections in order to reproduce that single value. Other values of life expectancy associated here with TP1999 were computed by OCACT following this method.
Sources: Trustees Reports, 1983-2003; TP1999 and TP2003; Calculations by OCACT/SSA.

In recent years, the Trustees have specified their mortality assumptions in terms of rates of mortality decline by age, sex, and cause of death. In their 2003 Report, the complete set of assumptions consists of 70 numbers (5 age groups x 2 sexes x 7 cause categories). Technically, these are the underlying assumptions of the model, and all other summary statistics are results of the projection exercise. The Social Security Administration's Office of the Chief Actuary (OCACT/SSA) often summarizes these assumptions using the implied *ultimate* rates of decline (*i.e.*, during the last 50 years of the 75-year projection horizon) for all-cause mortality and for a limited number of broad age groups (e.g., 0-14, 15-64, and over 65), adjusted to remove the effects of changes in the distribution of the population by age and sex.

The assumed rates of mortality reduction in the future are based on trends between 1900 and 2000, and in particular from 1979 to 2000, for which information by cause of death is utilized as well. In general, it is assumed that mortality decline will slow down and then continue at a constant pace. In the Trustees' intermediate projection series, which is considered the most likely to occur, reductions in death rates are assumed to change rapidly from the average annual reductions (by age, sex, and cause of death) observed between 1979 and 2000, to the ultimate annual percentage reductions assumed for 2027 and later.

The Trustees' assumptions concerning cause-specific mortality imply a gradual deceleration in the pace of mortality decline throughout the projection interval, as seen here in Table 2 (or Figure 7, later in this report). During the ultimate period (from 25 to 75 years) and beyond, this deceleration is driven by the cause-of-death methodology: over time, categories that are assumed to decline the most slowly account for a increasing portion of deaths (Wilmoth, 1995). In addition to this built-in deceleration, there is also an explicit assumption of a pronounced slowdown in mortality decline below age 65 during the first 25 years of the projection period.

Below age 15 this deceleration is roughly twice as large as the historical slowdown that occurred between the first and second halves of the 20th century; for ages 15-64 it is about 1.5 times as large. For ages 65 and above, the Trustees' assumptions imply rates of mortality decline throughout the projection interval that lie below the historical average for 1950-2000. Furthermore, the implied rate of mortality decline above age 65 during 2027-2077 (0.68 percent per year) is below the historical average even for the 20th century as a whole (0.78 percent).

The 2003 Technical Panel recommended that the Trustees increase assumed rates of mortality decline by a significant amount, resulting in higher projected levels of life expectancy at birth compared to official projections. However, compared to the 1999 Technical Panel, it recommend slower rates of mortality decline at older ages and thus lower projected values of life expectancy at birth. In 1999, the Trustees' assumptions implied a life expectancy in 2070 of 81.4, compared to 82.9 in 2003. By comparison, the 1999 Panel's recommendations yield a life expectancy in 2070 of 85.2, whereas the 2003 Panel suggested a value of 84.4. Thus, although they differed in the magnitude of their recommendations, both Panels concurred in concluding that the Trustees' assumptions concerning future rates of mortality decline are implausibly low.

3. KEY CHOICES IN MORTALITY PROJECTION BY MEANS OF TREND EXTRAPOLATION

Most methods of projecting mortality, or life expectancy, into the future involve assumptions about rates of decline in age-specific mortality rates, which are used to extrapolate observed trends from the past and present into the future. Since the pace of mortality decline has varied enormously in the past as a function of age (typically, with much faster reductions at younger ages, and slow or no decline at very high ages), mortality trends are usually

Table 2 – *Rates of mortality decline*[a] *in age-sex-adjusted death rates, U.S., 1900-2000 (observed) and 2000-2077 (projected, 2003 Trustees Report, 2003 and 1999 Technical Panels, intermediate scenario)*

Age group	Observed			2003 Trustees		2003 Panel		1999 Panel[b,c]	
	1900-1950	1950-2000	1900-2000	2000-2027	2027-2077	2000-2027	2027-2077	1996-2023	2023-2073
0-14	3.56	2.90	3.26	1.97	1.57	2.40	2.29	3.15	2.23
15-64	1.52	1.22	1.44	0.96	0.80	1.12	1.11	1.47	1.13
65+	0.56	0.91	0.78	0.70	0.68	0.84	0.90	0.75	0.99
All ages	**1.13**	**1.05**	**1.14**	**0.78**	**0.72**	**0.93**	**0.96**	**0.94**	**1.03**

Notes: [a] Rates of mortality decline shown here equal the average of values derived using the slope and endpoint methods (see note 1 of Table 3 regarding slope and endpoint methods).
[b] Comparable time periods for 1999 Panel are 4 years earlier than for TR2003 and TP2003.
[c] Values for 1999 Panel only are an average of male and female rates of decline in age-adjusted death rates, rather than rates of decline in age-sex-adjusted death rates.
Age-sex adjustment used the 1990 U.S. Census population as a standard.

Sources: TP1999 and TP2003. Calculations by author using data from OCACT/SSA.

projected separately by age. Thus, there is not just one trend being extrapolated, but several, and these lead to projected values of death rates by age in future years.

Using standard demographic methods, a series of death rates by age for a given year (either observed or projected) can be converted into a life table, which includes values of life expectancy at various ages. These values represent the average number of remaining years of life that would be lived by a person of a given age, if the mortality risks of his/her future lifetime mimicked the risks implicit in age-specific death rates for the year in question. Thus, life expectancy at birth in 2003 represents how long babies born in that year would live, on average, if mortality conditions did not change over the next century or so.

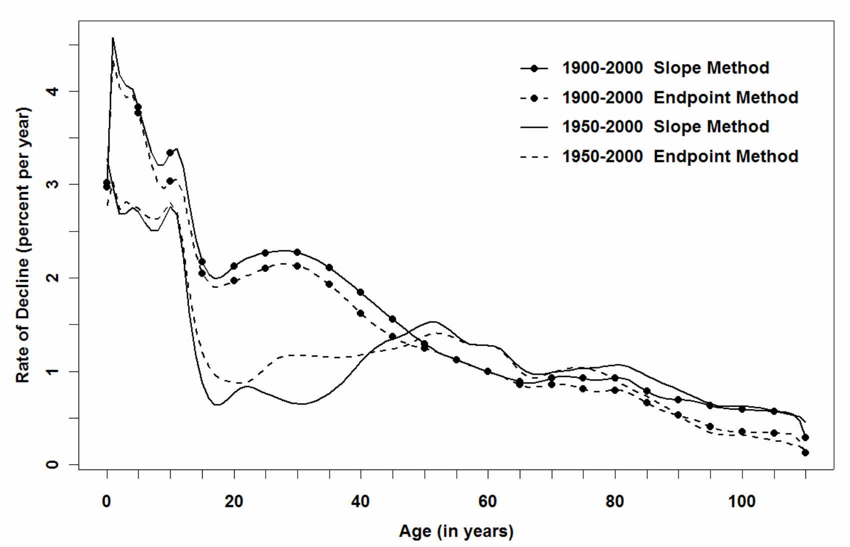
Although there is broad agreement on this general approach, there are many specific details that must be resolved. In practice, any mortality projection involves a series of choices about how to extrapolate historical trends in death rates by age. The following are five of the most important choices, which the Panel took into consideration when formulating its recommendations.

3.1 How to compute historical rates of change in age-specific death rates

The first issue is purely methodological and concerns the formulas used to compute rates of mortality decline by age. The Panel considered two approaches, which are referred to here as the *slope method* and the *endpoint method*. Briefly, the slope method consists of fitting a least-squares regression line to the logarithm of age-specific death rates; in this case, the rate of mortality decline is defined to equal the negative slope of the fitted regression line. By comparison, the endpoint method considers only two numbers, at the beginning and the end of the trend; in this case the rate of mortality decline equals, by definition, the complement (*i.e.*, negative value) of the logarithm of the ratio of the ending to the starting value, divided by the length of the time period. Equivalently, the endpoint method consists of drawing a line joining the first and last data points (plotted in a semi-logarithmic scale) and computing the slope of that line. As with the slope method, the rate of mortality decline is the negative slope of this trend.

Differences between the two methods are illustrated here in Figures 3-6 and Table 3. Figure 3 shows the age pattern of mortality decline for 1900-2000 and 1950-2000 by the two calculation methods. Both methods give the same overall picture of the pace of mortality decline by age. However, at very old ages there is an important divergence between the two methods, with the slope method producing consistently higher values than the endpoint method. In fact, above age 80, rates of decline depend more on the calculation method than on the time period considered. Differences between the two methods are also reflected in different values of age-sex-adjusted rates of mortality decline, especially at ages 65 and above (see Table 3).

Figure 3 – *Rates of mortality decline by age and method (slope and endpoint), United States, total population, 1900-2000 and 1950-2000*



Note: See note a of Table 3 regarding slope and endpoint methods.
Source: Calculations by author using data from OCACT/SSA.

Why do these two methods yield such different estimates of the rate of mortality decline? Figure 4 shows mortality trends from 1950 to 2000 for the affected age groups (mostly above age 80). It illustrates that the main cause of the difference between the two sets of estimates is the slow rate of mortality decline (and even slight increase) at very high ages during the 1990s. Since the endpoint method gives more weight to recent trends, it yields a rate of decline over the full interval that is slower than what is suggested by the slope method.

It is worth noting that the actuaries who prepare the official trust fund projections often use the slope method when computing rates of mortality decline for past trends. Therefore, since the slope method implies *faster* rates of mortality decline for the U.S. at older ages in recent decades (compared to the endpoint method), it may seem puzzling that the Trustees advocate a *slower* rate of mortality decline than what the Panel proposed. However, there is a simple explanation: although the Social Security actuaries employ

Table 3 – *Rates of mortality decline in age-sex-adjusted death rates by calculation method*[a]*, United States, total population, 1950-2000 and 1900-2000*

	1950-2000			1900-2000			
Age group	Slope	Endpoint	Average	Slope	Endpoint	Average	5-slope average[b]
0-14	3.07	2.73	2.90	3.30	3.22	3.26	3.30
15-64	1.20	1.24	1.22	1.48	1.41	1.44	1.42
65+	0.98	0.84	0.91	0.84	0.73	0.78	0.76

Notes: [a] The slope and endpoint methods are two means of computing the average annual rate of decline in age-specific mortality. For the slope method, a least-squares regression line is fit to the logarithm of death rates over time, and the negative slope of the fitted line is taken as the estimated rate of decline. For the endpoint method, the estimated rate of decline equals -1 times the natural logarithm of the ratio of ending to starting values (of an age-specific death rate), divided by the length of the time period.

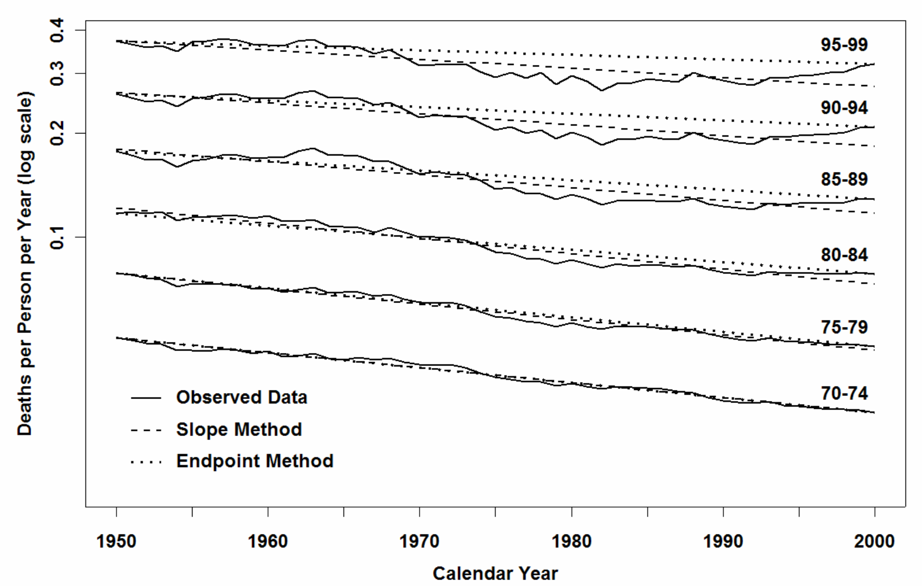
[b] The "5-slope average" method computes the weighted average rate of mortality decline over 5 selected time intervals (1900-1936, 1936-1954, 1954-1968, and 1982-2000), with weights proportional to the length of each interval.

Age-sex adjustment used the 1990 U.S. Census population as a standard.

Source: Calculations by author using data from OCACT/SSA.

the slope method for computing rates of mortality decline, they often apply it in a piecewise fashion, which in the end yields estimates that resemble the endpoint method more than the slope method. Let us consider this point further.

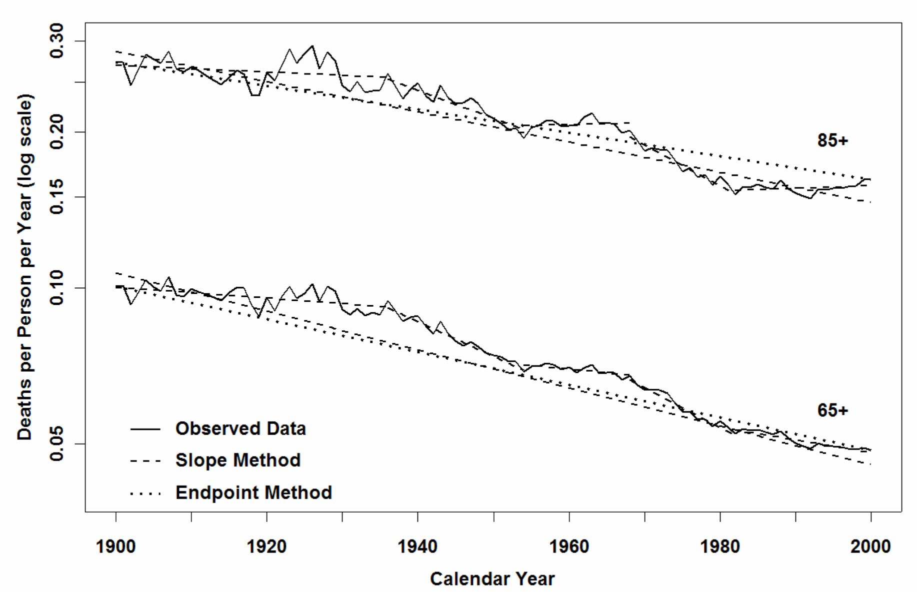
Figure 4 – *Mortality rates over time for ages 80-99, with trend lines corresponding to slope and endpoint methods, United States, total population, 1950-2000*



Notes: See note a of Table 3 regarding slope and endpoint methods.
Solid, dashed, and dotted lines have the same meanings for each age group.
Source: Calculations by author using data from OCACT/SSA.

One advantage of the endpoint method is that a trend can be broken up into pieces, such that the rate of decline for the full time interval exactly equals the weighted average of the values for the sub-intervals (with weights being equal to the length of each sub-interval). However, the same is not true of the slope method, where there is no obvious relationship linking the rate of decline for sub-intervals to the rate of decline for the entire time period. To illustrate this point, I have divided the last century (1900-2000) into sub-intervals and computed rates of mortality decline, using each of the two methods, for the entire time period and separately for each sub-interval. As shown here in Figure 5, the sub-intervals for this example were chosen so that each would have a relatively constant rate of mortality decline as reflected in their individual trends, which are nearly linear (in a logarithmic scale).

Figure 5 – *Age-sex-adjusted death rates for ages 65+ and 85+ over time, with linear trend for full century by method (slope and endpoint) and for 5 time periods (slope only), United States, total population, 1900-2000*



Notes: See discussion in text concerning age-sex-adjusted death rates.
The 5 time periods are 1900-1936, 1936-1954, 1954-1968, 1968-1982, and 1982-2000.
Age-sex adjustment used the 1990 U.S. Census population as a standard.

Source: Calculations by author using data from OCACT/SSA.

As expected, in this example the weighted average of the rates of decline for each sub-interval equals the rate of decline for the full interval when using the endpoint method. However, a weighted average of the various slope estimates (again, using weights equal to the length of each sub-interval) differs from the result obtained when the same method is applied to the full period and thus offers a third estimate of the rate of decline for the century as a whole. All three methods are illustrated in Figure 5, and their numerical values are compared in Table 3.

It may be surprising to note that the weighted average of sub-interval estimates based on the slope method implies a rate of mortality decline for ages 65+ during 1900-2000 (0.76 percent per year) that lies closer to the estimate offered by the full-century endpoint method than to the value given by the full-century slope method (0.73 versus 0.84, respectively). However, this result is fully comprehensible given that the slope and endpoint methods yield similar values within homogeneous sub-intervals (*i.e.*, relatively constant rates of decline within sub-intervals), and that the weighted average of the sub-interval values derived using the endpoint method equals the endpoint estimate of the rate of mortality decline for the full century.

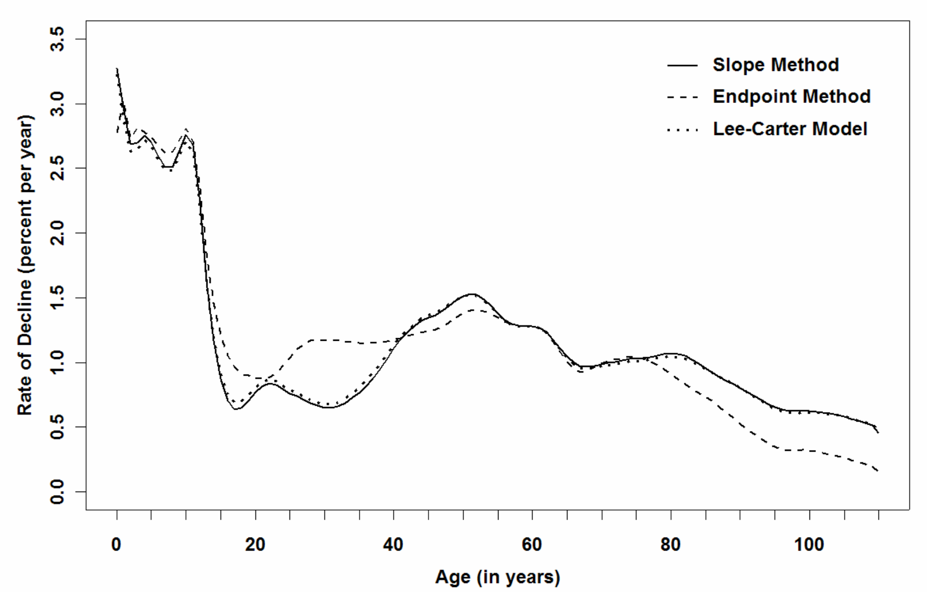
It is also worth comparing the rates of mortality decline implied by the slope and endpoint methods to comparable values implied by the parametric model of mortality change used in the Lee-Carter projection method, which served as the basis for the recommendations on mortality assumptions made by the 1999 Technical Panel. Figure 6 shows that the rates of decline implicit in the Lee-Carter procedure are largely similar to those found using the slope method. Thus, one important difference between the recommendations of the 1999 Technical Panel and the mortality assumptions of Trustees Reports in recent years lies in the method for computing mortality decline at older ages. Although neither is a simple slope or endpoint calculation, each is very close to one or the other of these two methods.

In summary, the endpoint method has the clear advantage of being able to join together sub-intervals in a natural way, such that the weighted average of their respective rates of decline equals the rate of decline for the full time period. However, this advantage is balanced by the fact that the slope method does a better job of capturing the long-term trend (based both on a visual inspection of graphs, such as Figures 4 and 5, and on the formal criterion of least squares), because it is not overly affected by recent fluctuations in a long-term trend. Although each method possesses certain advantages from a methodological point of view, differences between the two methods can be quite significant in certain cases, as shown here, affecting assumed rates of mortality decline derived from historical experience. In light of these facts, what is the "correct" rate of mortality decline for use in making mortality projections? In the absence of any clear theoretical or empirical justification for choosing one method over the other, the Panel's final analysis of this topic (and resulting recommendations) were based on a simple average of estimated rates of mortality decline derived using each method separately.

3.2 *Whether to consider various components of mortality separately* (i.e. *causes of death)*

In addition to computational methods, another complicating factor in making mortality projections is the possibility of incorporating information on causes of death. It is certainly possible to insert cause-specific morality into any projection method, but the standard approach for doing so suffers

Figure 6 – *Rates of mortality decline by age and calculation method (slope, endpoint, and Lee-Carter), United States, total population, 1950-2000*



Notes: See note a of Table 3 regarding slope and endpoint methods.
The Lee-Carter model, which specifies that the natural logarithm of the death rate at age *x* in year *t* equals $a_x+b_xk_t$ plus an error term, was fit by ordinary least squares. Constraining the slope of the line connecting the first and last values of k_t to equal -1, the fitted values of b_x provide an estimate of the annual rate of mortality decline.
Source: Calculations by author using data from OCACT/SSA.

from both theoretical and empirical weaknesses.

The main theoretical problem is how to build in interdependencies between causes of death. A common "finding" of cause-of-death mortality analyses concerns what would happen to life expectancy if a particular cause were eliminated. However, such calculations typically rely on the highly implausible assumption that the elimination of a given cause would have no impact on mortality risks due to other causes. Mortality projections by cause of death do not necessarily require such an untenable assumption, as the assumed rates of decline for the various components of total mortality include implicit assumptions about these interdependencies. Nevertheless, since we lack an appropriate model (both theoretically sound and empirically justified) about how such interdependencies operate, we have no good way of evaluating whether a mortality projection based on cause-of-death data is internally consistent and plausible.

One problem introduced by the cause-specific methodology used currently for Social Security trust fund projections is the complexity (and as a result, obscurity) of its underlying assumptions. Although discussions about the Trustees' mortality projections often focus on the rate of mortality decline (age- and sex-adjusted) for a few key age groups (e.g., ages 65 and above), the full projection model actually contains a total of 70 parameters, each referring to an assumed ultimate rate of mortality decline for some specific age-sex-cause combination (as noted already, there are 5 age groups, 2 sexes, and 7 cause-of-death categories, yielding 70 parameters in total). These 70 numbers are the only things that are fixed in this model during the ultimate period. Age-specific rates of decline in total mortality change gradually over this period due solely to the fact that the mix of causes of death is changing as well.

In general, for mortality projections by cause of death, the rate of mortality decline converges in the long run to the rate of decline assumed for the cause that is declining most slowly, which assumes an increasing share of total mortality. Thus, projecting mortality by cause of death effectively builds in an automatic deceleration in the rate of mortality decline over time (this deceleration can be observed here in Figure 7). In the end, the Panel concluded that it is indeed reasonable to assume a gradually diminishing rate of mortality decline in very long-term mortality projections, and this is one feature of the Panel's projected mortality series. Nevertheless, it would aid understanding (and thus facilitate constructive debate) if such an assumption were stated explicitly, in terms of age-specific rates of decline for total mortality.

Furthermore, the empirical basis for making cause-specific mortality projections is quite weak. It is very difficult to construct long time series of mortality data by cause of death, due to a lack of such data and/or changes in coding practices over the past century. The Trustees' 2003 projections are based on mortality data by cause for the U.S. that begin only in 1979. On the basis of trends over little more than two decades, they derive rates of mortality decline for seven cause-of-death categories for the next 100 years. For example, the assumed ultimate rate of decline for mortality due to cancer in the 65-84 age range is 0.5 percent per year (OCACT, 2002: Table 3). The source of this number is uncertain: it does not come from the historical data, since observed values in this case for 1979-1999 were -0.06 for men and -1.13 for women. A clear written explanation that might justify such detailed assumptions appears to be lacking, and it is difficult to imagine how such numbers could be derived in a reasonable fashion, either from historical data or from expert judgment.

It is important not to misunderstand the Panel's recommendation on the issue of cause-specific mortality forecasts. On the one hand, it is clearly desirable that the Social Security actuaries and Trustees should analyze information about historical trends in cause-specific mortality and use such data as part of their overall assessment of trends in life expectancy. On the other hand, a model formulated specifically in such terms seems to add unjustified complexity and to diminish the transparency of the overall projection method.

3.3 Whether to perform separate projections for sub-populations (by sex, race, etc.*)*

The value of complexity versus simplicity is a general issue in projecting mortality (and other quantities as well). When a mortality forecast relies on mortality data by cause of death, the projection model is stratified according to the outcome variable, mortality. However, the model can also be stratified according to other variables – like sex, race, educational attainment, marital status, *etc*. – that serve as predictors of mortality risks.

It is well known that mortality rates vary across sub-populations, and that such differences are sometimes as large as, or even larger than any reduction in death rates that may occur over a period of years. Clearly, the most important distinction is by sex, but it is also possible to analyze (and project) mortality differences by race, income, education, marital status, *etc*. Although separate projections for these various sub-groups may seem appealing, such an approach quickly encounters a familiar but annoying problem: separate extrapolations based on historical experience lead to an unending divergence of some groups, or to a convergence and eventual "crossover" of other groups (*i.e.*, the two groups change their relative positions with respect the quantity being projected, such as mortality).

Such problems are most easily avoided by assuming equivalent rates of change for all sub-populations, at least within some *ultimate* time horizon. For example, male and female mortality may continue to converge for one or two decades, and such an assumption can easily be a part of the projection model. However, it is advisable to assume parallel male-female trajectories afterwards, or else men's life expectancy would eventually move ahead of women's (based on recent trends), which seems highly implausible. There is probably a broad agreement amongst informed observers on this key point, especially within the context of an infinite time horizon. Indeed, the Trustees now assume very similar rates of mortality decline for both men and women, yet they retain separate assumptions by sex during the ultimate period.

Thus, the Panel recommended for various reasons that the Trustees' mortality projections be based on relatively simple assumptions, including no difference in *ultimate* rates of mortality decline by sex. In the series of mortality projections proposed by the Panel and documented here, there is no difference as well in rates of mortality change by sex during the *initial* period (2000-2002) and during the following ten years (when current rates of decline converge toward the assumptions for the ultimate period). However, perhaps the ideal solution would have been to assume a continuation of current differences in mortality change by sex during the initial period, and then convergence (in male-female rates of decline) by the start of the ultimate period.

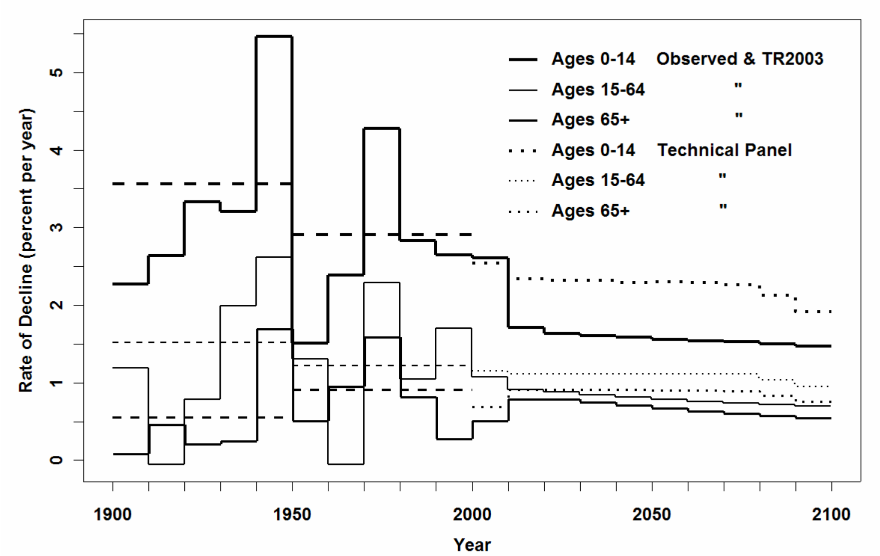
Despite differences in mortality levels between countries, international comparisons can also serve as a useful guide to future mortality trends. The United States differs from other wealthy countries in various ways that undoubtedly have an impact on the overall level of mortality (e.g., degree of income inequality, extent of social safety net, availability of firearms). Given the durability of such differences, the current gap between the U.S. and other wealthy countries in levels of mortality or life expectancy could remain for many years. However, it seems much less likely that the pace of mortality decline will be vastly different over the long term amongst this close-knit group of wealthy nations.

How much importance should be attached to the fact that the post-1980 slowdown in mortality reduction for the U.S. was not typical? Of course, it is important to analyze and understand the causes of such differences between countries with otherwise similar social and economic circumstances, if only for purpose of counteracting unfavorable trends in certain countries. When faced with the task of projecting mortality trends into the future, a plausible assumption is that this ongoing process of comparison and adjustment assures (not with certainty, but with a high degree of confidence) a similarity of long-term trends. By this logic, international trends since 1980 (see Figure 1) support the recommendation that official projections for the U.S. should anticipate a recovery from the recent period of slow mortality decline.

3.4 How to choose historical baseline period for deriving rates of decline

Another key issue concerns the specific quantitative values chosen as assumptions for describing future mortality trends. These depends to a large extent on the baseline time period used for deriving assumed rates of mortality decline across the age range. Although the pace of mortality decline at older ages is similar whether 1900-2000 or 1950-2000 is adopted as the baseline period (it was only slightly faster in the second half of the century compared to the first half), the same is not true at younger ages, which experienced a marked deceleration from 1900-1950 to 1950-2000. The pattern of mortality change is more complex when seen decade-by-decade. These points are illustrated here in Figure 7. Furthermore, although this graph presents the average results based on the two calculation methods mentioned earlier (*i.e.*, slope and endpoint), the general conclusions stated are the same for either calculation method.

Figure 7 – *Rates of decline in age-sex-adjusted death rates by age, for decades and selected 50-year periods, United States, total population, 1900-2000 (observed) and 2001-2100 (projected, TR2003 and technical panel, intermediate)*



Notes: Dashed lines depict average rates of decline within 50-year intervals (1900-1950 and 1950-2000).
Age-sex adjustment used the 1990 U.S. Census population as a standard.

Sources: Trustees Report, 2003; TP2003; Calculations by author using data from OCACT/SSA.

After considering various possibilities, the Panel proposed that the Trustees should use 1950-2000 as the baseline for their current mortality projections. One consideration is the quality of mortality data from the first half of the 20th century, which are known to be less complete and less reliable, especially at older ages. However, perhaps the main reason to prefer a baseline of 1950-2000 over 1900-2000 is that the second half of the century was characterized by a more even pace of mortality decline across the age range, and this pattern seems likely to prevail in the future as well.

The role of medical therapy (*i.e.*, what doctors do for people after they become sick) in the historical decline of mortality was probably much greater during the second half of the 20th century than in earlier times. As McKeown and colleagues argued so persuasively (McKeown *et al.*, 1975;

McKeown, 1979), therapeutic medicine probably had little positive effect on mortality decline before the 1930s and 1940s, when the role of medicine was altered dramatically by the introduction of anti-bacterial drugs (sulfanomides and, somewhat later, antibiotics). By this logic, one might propose a baseline of 1930-2000 instead of 1950-2000. However, including the 1930s and 1940s would have little effect on average rates of mortality decline over the full period (as can be seen by a close examination of Figure 7).

3.5 Whether to accelerate or decelerate rates of decline compared to historical baseline

It is reasonable to consider whether there will be future large changes in rates of mortality decline by age (not just random ups and downs, but long term trends toward higher or lower values). As seen in Figure 7, the pace of mortality decline decelerated from the first to the second half of the 20th century for ages below 65, but it accelerated at older ages. The Trustees assume a continuing deceleration at younger ages. However, they do not assume a further acceleration at older ages, nor even a continuation of the more rapid pace of decline observed during the second half of the century.

Compared to changes in rates of mortality decline that took place during the 20th century, the Trustees have been assuming a more rapid deceleration in future rates of mortality decline below age 65, and especially below age 15. Although a continued deceleration at younger ages seems plausible, the magnitude of that deceleration is uncertain. Obviously, this choice affects values of projected life expectancy at birth, but not at age 65, whereas most discussions about future mortality decline focus on trends at older ages. Nevertheless, trends at younger ages are important as well, as they affect the population age structure (like higher fertility, lower mortality at young ages acts to create a younger age structure, with favorable impacts on trust fund balances). Thus, although it is clearly a second-order issue compared to the assumed rate of mortality decline at older ages, the Panel concluded that the Trustees may have exaggerated the future deceleration in the pace of mortality decline at younger ages and recommended some modification in the assumptions about mortality decline at younger ages.

Although it is worth considering the possibility that the pace of mortality decline at older ages could continue to accelerate (as it did during the 20th century in the U.S.), the Panel did not choose to recommend such a trend for its intermediate scenario. Nevertheless, the most important recommended change in mortality assumptions is the suggestion that the Trustees should assume a continuation of the more rapid rate of mortality decline at older ages observed during the second half of the 20th century, thus dropping the deceleration at these ages implied by their current projections.

4. PANEL'S RECOMMENDATIONS

4.1 Assumptions

As noted already, the 2003 Technical Panel recommended using 1950-2000 as the historical baseline for deriving future trends in mortality for the United States. Using the full 20th century for this purpose is another possibility, but in that case the assumed pace of mortality decline at older ages would be somewhat slower (see either Figure 7 or Table 2). In contrast, mortality decline at younger ages was much slower on average during the second half of the century; therefore, assumed rates of decline at younger ages would be much higher with a baseline of 1900-2000 instead of 1950-2000.

Another point to be considered is what to do concerning the infinite time horizon, which the Trustees adopted in 2003 in addition to their traditional 75-year horizon. The Panel recommended a very simple solution, which consists of forcing rates of mortality decline back to zero at some date far out into the future. For their intermediate projection series, the Panel chose a date of 2200, but noted that any date around 200-300 years into the future would be equally well justified for this purpose. The reasoning behind this choice was that there is no firm basis for projecting mortality decline farther into the future than it has been observed in the past. Since most of the mortality decline observed in human history has occurred during the past 200-300 years, forcing rates of mortality decline to zero within a similar future time horizon seems sensible. However, further study is needed on this point. In particular, it would appropriate to perform more extensive sensitivity analyses about the effect of alternative choices of the date at which this convergence to zero occurs.

4.2 Methods

The Panel commended the Trustees and the Social Security actuaries for investigating past mortality trends separately by cause of death and for men and women. (Other breakdowns could be useful as well, for example, by race, ethnicity, income class, or nativity.) However, making separate assumptions about future rates of mortality decline by cause of death or for sub-populations adds complexity to the projection model without evidence of improved accuracy in forecasting. The Panel opted for simplicity, but this principle should apply only to projection methods, not to the analysis of historical trends.

The age range from 0 to around 110 can be broken up in an infinite number of ways. Fortunately, data availability constrains this choice somewhat (*i.e.*, vital statistics and census data usually come in 1-, 5-, or 10-year age intervals), but that fact does not eliminate this problem altogether. Ideally, one works with fairly narrow age groups (*i.e.*, 1-year or 5-year), because this strategy minimizes the effects of changing population age structure on observed rates of mortality change over time. That is, since mortality reduction has typically been much slower at older ages, population aging has the effect, on its own, of depressing the rate of mortality decline observed over time, if one works with broader age ranges (e.g., 20- or 30-year age intervals). This problem is often addressed by computing age-adjusted (or age-standardized) rates of decline, which represent the rate of decline that would be observed in a population with a constant age structure (the Social Security actuaries typically use the 1990 Census population as the "standard" for these calculations).

A similar problem arises due to changes in the distribution of the population by sex. Population aging has typically (but not always) been associated with increasing proportions of females, especially at older ages. This shift tends to exaggerate the magnitude of mortality decline, if one only makes calculations for the total population (*i.e.*, not broken down by sex). Therefore, trends in mortality for the total population are often age- and sex-adjusted in order to achieve comparability over time.

These sorts of calculations are useful as a means of summarizing past and future trends (as seen here, for example, in Figure 7). However, they are a poor means of deriving assumed rates of mortality decline for a projection, except in the case of observed rates of decline that are roughly constant across broad age ranges. This point may seem like a small detail, but it is important: one should not try to derive assumptions about future rates of mortality decline using historical values based on age- or age-sex-adjusted death rates, because these value depend on an arbitrary choice about the population used for standardization. Rather, it is better to examine the entire age profile of rates of mortality decline (preferably, in 1-year age groups) and to derive assumptions directly from there.

Regarding sub-populations, separate mortality projections based on different historical rates of decline lead either to continual divergence between groups, or to convergence and eventual crossover (*i.e.*, where groups change their relative positions). Both situations seem rather unlikely, at least for long-term projections. Although recent differential trends by sex could plausibly continue for another 10 to 20 years, the Panel recommended that ultimate rates of mortality decline be equal for men and women, derived from trends for the total population.

4.3 Derivation of Panel's mortality forecast

The derivation of the Panel's preferred mortality forecast is documented here in Figures 8-11 and in Table 4. Rates of mortality decline for an initial period, 2000-2002, were derived from historical values for 1980-2000. The level of the "plateau" assumption (the horizontal line between ages 20 and 75 in Figure 8) equals the average of slope and endpoint estimates of observed rates of decline for ages 20-74 during 1980-2000. The level for age 0 and for ages 95 and above are similar historical averages. In between, the values were merely connected by line segments.

In Figure 9, the "plateau" assumption for the ultimate period, 2012-2077 (intermediate scenario), was derived in a similar manner using the historical experience for 1950-2000. The level at age 0 was chosen to produce a one-fold deceleration in the rates of mortality decline below age 15 (*i.e.*, similar in magnitude to the decrease from 1900-1950 to 1950-2000, as can be seen in Table 2). The rate of decline converges to zero at age 122.5, which was the age at death of Jeanne Calment of France, the oldest documented age at death in human history. In short, the Panel reasoned, it is implausible (at least for an intermediate scenario) to assume positive rates of mortality decline for ages that have never been observed in human history, which led to the choice of this cut-off point.

Figure 10 shows how the Panel chose the "plateau" assumptions for its low- and high-cost scenarios. The low-cost plateau is the average of rates of decline for ages 20-74, using both the slope and endpoint methods, for the three periods of the 20^{th} century with relatively slow rates of mortality reduction (1900-1936, 1954-1968, and 1982-2000). For age 0 of the low-cost scenario, the Panel chose the rather high rate of decline for the full 20^{th} century (keeping in mind that a high rate of mortality decline at younger ages is "low-cost").

For the high-cost scenario, the Panel initially considered averaging the rates of decline for ages 50-109 during the 2 periods with relatively rapid mortality decline (1936-1954 and 1968-1982). However, the resulting value (the "very high-cost scenario" of Figure 10) is quite high, and it does not seem plausible that such a rapid pace of mortality reduction could be maintained over the next 50-100 years. Therefore, the Panel chose a high-cost assumption that would produce symmetry of the low- and high-cost plateaus around the intermediate assumption. In addition, for the high-cost

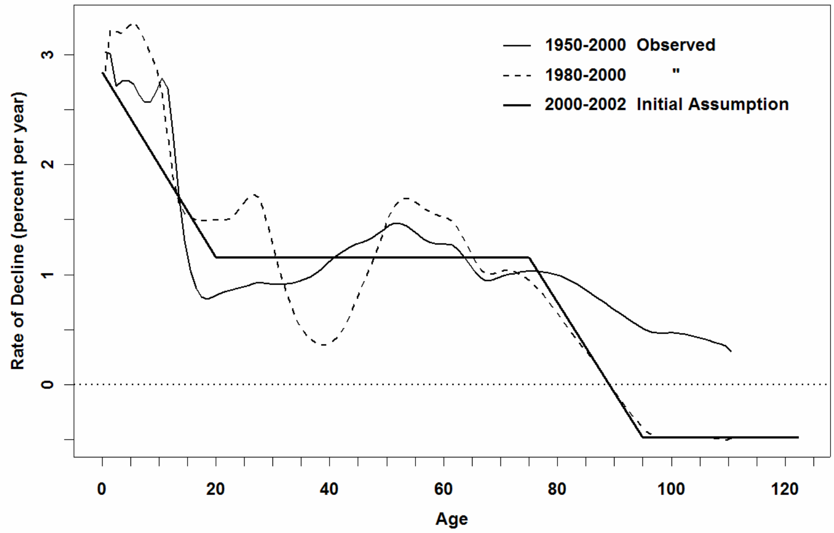
Table 4 – *Assumed rates of mortality decline for selected ages, Panel's projection series, United States, 2000-2002 (initial), 2012-2077 (4 ultimate), and 2200- (infinite)*

		Ultimate, 2012-2077			
Exact age	Initial, 2000-2002	Intermediate	Low-cost	High-cost	Infinite, 2200-
0	2.84	2.50	3.00	1.51	0.00
20	1.16	1.11	0.71	1.51	0.00
75	1.16	1.11	0.71	1.51	0.00
95	-0.48	0.64	0.41	1.51	0.00
122.5	-0.48	0.00	0.00	1.51	0.00

Note: Rates of mortality decline for the Panel's recommended series of projections are fully defined by the values in this table. Rates of decline over the full age range can be obtained by joining these points by line segments (see Figure 11).

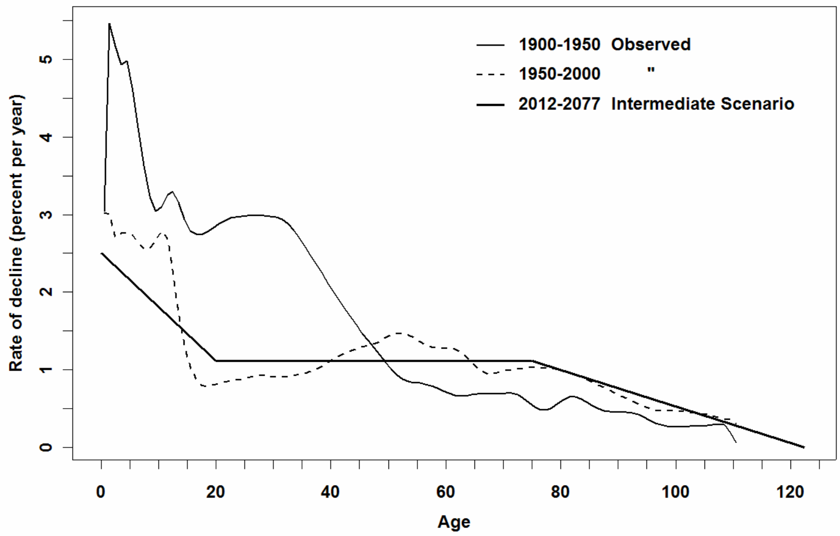
Source: TP2003.

Figure 8 – *Rates of mortality decline by age, United States, total population,1950-2000 and 1980-2000 (observed), and 2000-2002 (assumed, panel)*



Sources: TP2003; Calculations by author using data from OCACT/SSA.

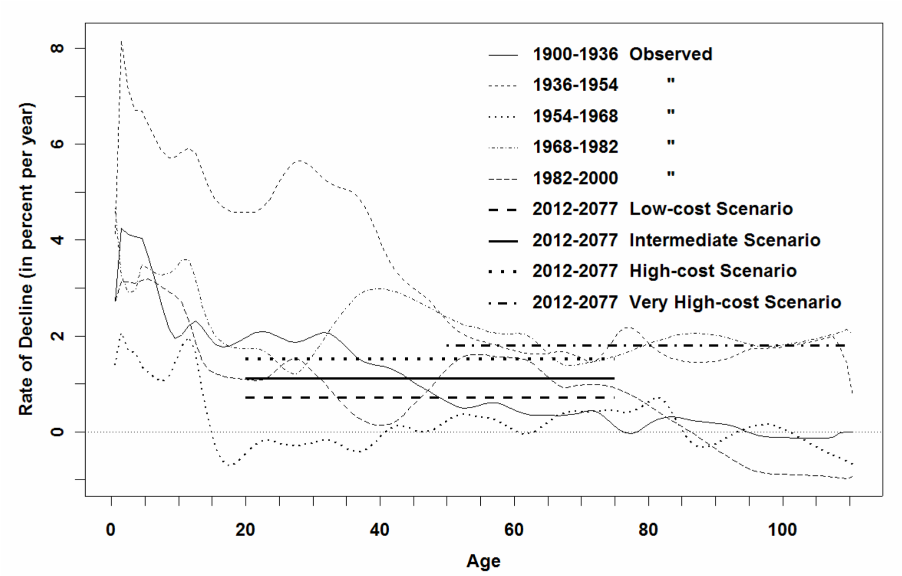
Figure 9 – *Rates of mortality decline by age, United States, total population, 1900-1950 and 1950-2000 (observed), and 2012-2077 (assumed, panel, intermediate scenario)*



Sources: TP2003; Calculations by author using data from OCACT/SSA.

scenarios, the Panel assumed a constant rate of mortality decline across the entire age range.

Figure 10 – *Rates of mortality decline by age, United States, total population, selected periods of 20th century, with plateau assumptions of panel's ultimate scenarios (2012-2077)*



Sources: TP2003; Calculations by author using data from OCACT/SSA.

All assumptions of the Panel's projection series are illustrated in Figure 11, with numerical values provided in Table 4 Projected values of life expectancy at birth and at age 65 are shown in Figure 12. It is also useful to refer back to Figure 7, which shows projected rates of mortality decline in age-sex-adjusted death rates. Numerical values of life expectancy for the 2003 Trustees Report are compared with the Panel's recommendations in Tables 5 and 6. Also, Table 2 compares rates of decline in age-sex-adjusted rates for the intermediate scenarios of these two projections.

5. COMPARISON OF MORTALITY PROJECTIONS

Perhaps the most important part of the analysis presented here is contained in Table 7. The notes to that table explain many of the details, so they will not be repeated here. Aside from the projections with specific names (*i.e.*, TR1999 and TR2003, for the Trustees Reports of 1999 and

Table 5 – *Life expectancy by sex and projection method, United States, 2000 (observed), and 2010, 2020, …, 2100 (projected, intermediate scenario, Trustees Report and Technical Panel of 2003)*

	Female		Male		**Total**	
	TR2003	Panel	TR2003	Panel	**TR2003**	**Panel**
			a) at birth			
2000	79.2	79.2	73.9	73.9	**76.5**	**76.5**
2010	80.0	80.3	75.2	75.2	**77.5**	**77.7**
2020	80.9	81.5	76.3	76.5	**78.5**	**79.0**
2030	81.8	82.5	77.3	77.8	**79.5**	**80.1**
2040	82.6	83.5	78.3	79.0	**80.4**	**81.3**
2050	83.4	84.5	79.2	80.1	**81.2**	**82.4**
2060	84.2	85.5	80.0	81.2	**82.0**	**83.4**
2070	84.8	86.4	80.8	82.3	**82.8**	**84.4**
2080	85.5	87.3	81.6	83.3	**83.5**	**85.4**
2090	86.1	88.1	82.3	84.2	**84.2**	**86.3**
2100	86.7	88.8	83.0	85.1	**84.8**	**87.0**
			b) at age 65			
2000	18.9	18.9	15.8	15.8	**17.4**	**17.4**
2010	19.3	19.5	16.4	16.5	**17.9**	**18.1**
2020	19.9	20.2	17.0	17.2	**18.5**	**18.8**
2030	20.5	20.9	17.6	18.0	**19.1**	**19.5**
2040	21.1	21.6	18.2	18.7	**19.7**	**20.3**
2050	21.6	22.4	18.8	19.4	**20.2**	**21.0**
2060	22.2	23.0	19.4	20.2	**20.8**	**21.7**
2070	22.7	23.7	19.9	20.9	**21.3**	**22.4**
2080	23.2	24.4	20.4	21.6	**21.8**	**23.1**
2090	23.7	25.0	20.9	22.3	**22.3**	**23.8**
2100	24.1	25.5	21.4	22.9	**22.7**	**24.4**

Sources: TR2003; Calculations by author using data from OCACT/SSA.

2003, and TP1999 and TP2003, for the reports by Technical Panels in those years), all of these values were derived simply by calculating the rate of mortality decline (in 1-year age groups) during a given time period using a particular method. Some of these scenarios are based on the maximum or minimum of such values from two time periods. In other cases, the trend has been accelerated or decelerated at older or younger ages, either one-fold or two-fold, relative to changes observed between the first and second halves of the 20th century. The age pattern of mortality decline chosen in this way was then applied to death rates in year 2000, which were projected forward to 2100.

Such calculations yield a range of estimates of mortality and life expectancy over the 21st century. Since the 1999 Panel used life expectancy

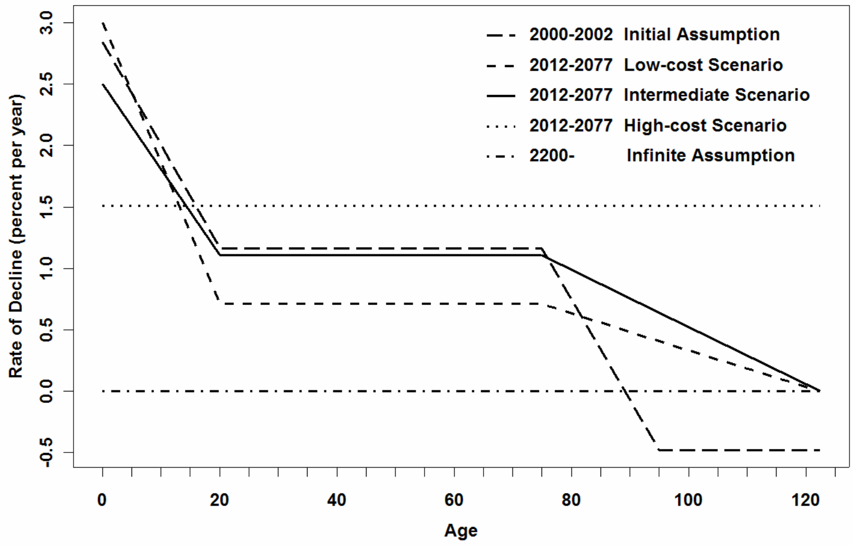
Table 6 – *Life expectancy by projection method and scenario, United States, total population, 2000 (observed), and 2010, 2020, …, 2100 (projected, Trustees Report and Technical Panel of 2003)*

	Intermediate		Low-cost		High-cost	
	TR2003	Panel	TR2003	Panel	TR2003	Panel
			a) at birth			
2000	76.5	76.5	76.5	76.5	76.5	76.5
2010	77.5	77.7	77.0	77.6	78.2	77.9
2020	78.5	79.0	77.5	78.5	79.8	79.6
2030	79.5	80.1	78.0	79.3	81.4	81.3
2040	80.4	81.3	78.5	80.1	82.9	83.0
2050	81.2	82.4	78.9	80.8	84.3	84.6
2060	82.0	83.4	79.3	81.5	85.6	86.3
2070	82.8	84.4	79.7	82.2	86.9	87.9
2080	83.5	85.4	80.1	82.9	88.0	89.6
2090	84.2	86.3	80.4	83.5	89.1	91.1
2100	84.8	87.0	80.8	84.1	90.1	92.4
			b) at age 65			
2000	17.4	17.4	17.4	17.4	17.4	17.4
2010	17.9	18.1	17.5	18.0	18.2	18.2
2020	18.5	18.8	17.7	18.4	19.3	19.3
2030	19.1	19.5	18.0	18.9	20.4	20.6
2040	19.7	20.3	18.2	19.4	21.5	21.8
2050	20.2	21.0	18.4	19.9	22.5	23.1
2060	20.8	21.7	18.7	20.3	23.4	24.4
2070	21.3	22.4	18.9	20.8	24.3	25.7
2080	21.8	23.1	19.1	21.3	25.2	27.0
2090	22.3	23.8	19.3	21.7	26.1	28.2
2100	22.7	24.4	19.5	22.1	26.9	29.4

Sources: TR2003; Calculations by author using data from OCACT/SSA.

at birth in 2070 as their point of reference, the results in Table 7 focus on that year as well (but include values for age 65 as well as age 0). The table illustrates that the only way to obtain a mortality projection similar to the intermediate scenario of the 2003 Trustees Report is by making pessimistic choices (*i.e.*, pessimistic with respect to longevity, although optimistic with respect to trust fund balances) at every turn. Although each individual choice is not unreasonable, taken together they produce a less plausible projection than what is obtained by a more balanced set of choices.

Figure 11 – *Assumed rates of mortality decline by age, Panel's projection series, United States, total population, 2000-2002 (initial), 2012-2077 (ultimate), and 2200- (infinite)*



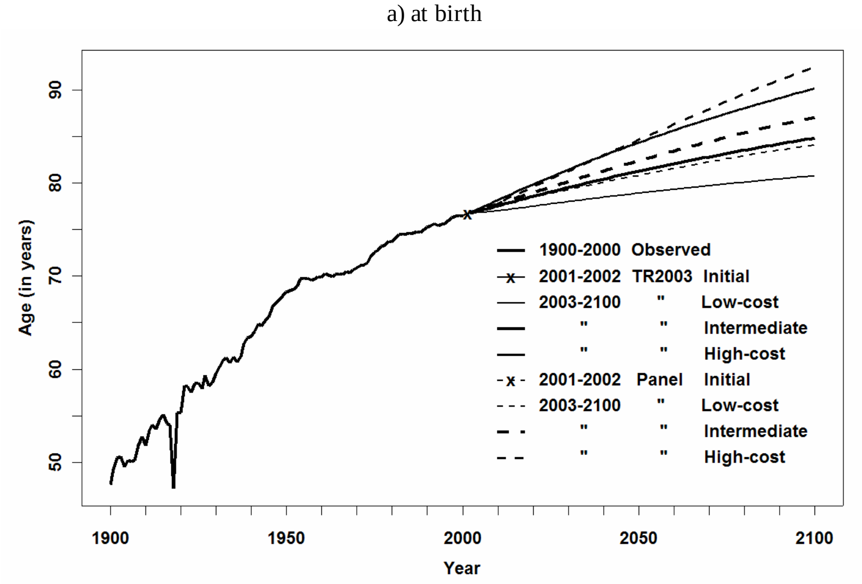
Sources: TP2003; Calculations by author using data from OCACT/SSA.

6. CONCLUSION

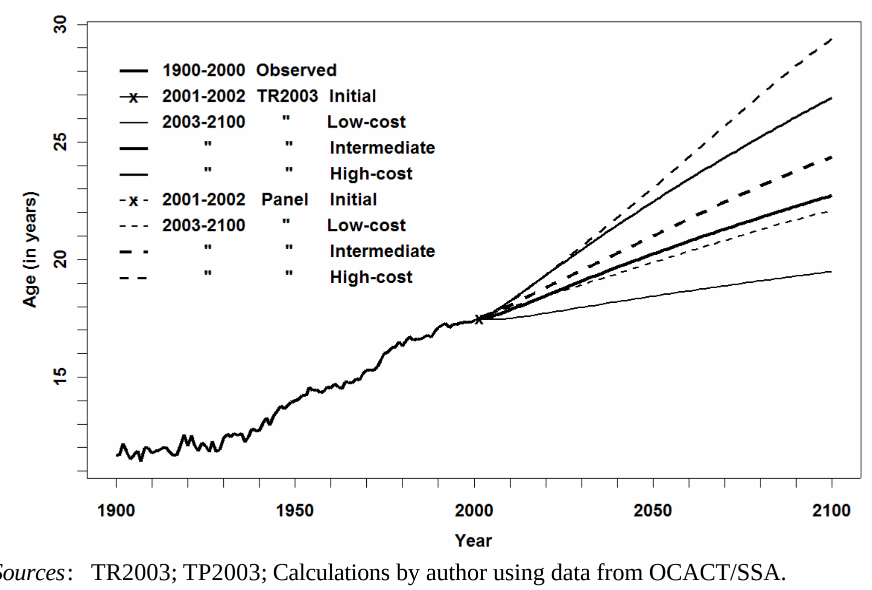
The Panel recommended that the Trustees increase assumed rates of mortality decline, while also simplifying the projection model by eliminating the breakdown by causes of death. The recommendation for an increase in assumed rates of mortality decline was grounded mostly in an analysis of historical trends for the United States alone, but it was supported as well by a review of the recent mortality experience of other high-income countries. The increase would result in higher projected levels of life expectancy at birth compared to official projections. In 2003, the Trustees adopted assumptions concerning rates of mortality decline separately for each cause of death. The Panel recommended eliminating such detail from the projection method, arguing that it was unlikely to produce more accurate results, and noting that there was little empirical basis for the assumptions being used.

Figure 12 – *Life expectancy by projection method (Trustees Report and Technical Panel of 2003), United States, total population, 1900-2000 (observed) and 2001-2100 (projected)*

a) at birth



b) at age 65



Sources: TR2003; TP2003; Calculations by author using data from OCACT/SSA.

Table 7 – *Projected life expectancy at birth and age 65 in 2070 using various methods and assumptions, United States, total population*

	Life expectancy in 2070	
	At birth	At age 65
Trustees Report 2003, Low	79.7	18.9
Trustees Report 1999, Intermediate	**81.4**	**20.3**
Technical Panel 2003, Low	82.2	20.8
min(1900-2000, 1950-2000), endpoint, 2x decal younger ages	82.3	21.4
Trustees Report 2003, Intermediate	**82.8**	**21.3**
1950-2000, endpoint, 2x decel. younger ages	83.1	21.9
min(1900-2000, 1950-2000), slope, 2x decel. younger ages	83.1	22.1
min(1900-2000, 1950-2000), endpoint	83.4	21.4
1950-2000, endpoint, 1x decel. younger ages	83.5	21.9
1900-2000, endpoint	83.8	21.4
1950-2000, slope, 2x decel. younger ages	83.9	22.7
min(1900-2000, 1950-2000), slope	84.0	22.1
1950-2000, endpoint	84.2	21.9
1950-2000, slope, 1x decel. younger ages	84.3	22.7
Technical Panel 2003, Intermediate	**84.4**	**22.4**
max(1900-2000, 1950-2000), endpoint	84.6	21.9
1900-2000, slope	84.6	22.1
1950-2000, slope	84.8	22.7
1950-2000, endpoint, 1x decel. younger ages, 1x accel. older ages	85.1	23.2
Technical Panel 1999, Intermediate	**85.2**	**23.2**
max(1900-2000, 1950-2000), slope	85.5	22.7
1950-2000, endpoint, 1x accel. older ages	85.7	23.2
max(1900-2000, 1950-2000), endpoint, 1x accel. older ages	86.2	23.3
Trustees Report 2003, High	86.9	24.3
Technical Panel 2003, High	87.9	25.7
Technical Panel 2003, Very high	90.0	27.3
1950-2000, slope, 1x decel. younger ages, 1x accel. older ages	90.3	28.2
1950-2000, slope, 1x accel. older ages	90.9	28.2
max(1900-2000, 1950-2000), slope, 1x accel. older ages	91.6	28.2

Notes: Projection scenarios are in order of increasing life expectancy at birth.

All projections, except TR1999 and TP1999, commence from observed data for year 2000.

Except for TR1999, TR2003, and TP2003, these projections do not include a transition period in which rates of mortality decline converge gradually from current to ultimate values (*i.e.*, in all other cases the same age-specific rates of decline are applied throughout the projection interval).

For scenarios described only in terms of a range of years and a calculation method (e.g., slope or endpoint), mortality rates were projected forward using age-specific rates of mortality decline for that time interval calculated according the specified method.

For scenarios based on the "max" or "min" for two time intervals, the projection was derived using age-specific maxima or minima of historical rates of mortality decline.

Some scenarios include assumptions about a continuation of historical trends in rates of mortality decline observed during the 20th century (*i.e.*, decelerated rates of decline at younger ages, or accelerated rates of decline at older ages). For example, the designation, "1x decel. younger ages," means that the ratio of age-specific rates of mortality decline at ages below 45 years in the projection to those observed for 1950-2000 is similar to the same ratio based on observed values for 1950-2000 compared to 1900-1950. Likewise, a "1x accel. older ages" implies that projected rates of mortality decline at ages above 45 years are higher than those in 1950-2000 by an amount that resembles their historical increase (in proportional terms) from 1900-1950 to 1950-2000. The magnitude of the projected acceleration or deceleration is variable (*i.e.*, 1x, 2x) and is based on historical average levels observed across broad age ranges. The breaking point in terms of age (between deceleration at younger ages and acceleration at older ages) depends on the calculation method (slope or endpoint) but is close to 45 years in either case.

Sources: TR1999 and TR2003; TP1999 and TP2003; Calculations by author using data from OCACT/SSA.

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