On Forecasting Mortality

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FORECASTS OF TRENDS IN POPULATION GROWTH ARE most often made by making assumptions as to how each of the components of population change—fertility, mortality, and migration—might change in the future. Demographers who have been making such forecasts throughout this century have met with varying degrees of success. For instance, forecasts made by Whelpton (1928) produced estimates of the 1940 population that were within 5 percent of the official decennial census count of the population for that year. Yet, population forecasts made by the same demographer for subsequent years severely underestimated population size because of his inability at the time to anticipate unforeseen changes in the components of population change, particularly postwar fertility. Since then, the U.S. Census Bureau and the Office of the Actuary at the Social Security Administration have been responsible for making the official forecasts of the components of population change for the United States.

Given the fact that errors in estimates of fertility have accounted for the majority of the error in past population forecasts, most of the attention regarding forecasting assumptions has thus been concentrated on modeling changes in fertility (Crimmins 1984; Siegel 1979). Recently, some effort has been made at estimating the contribution of migration to population growth (Bouvier 1981). Forecasts of mortality, however, have often been made under the assumption that mortality would decline for a short time in younger and middle-aged groups, but that

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mortality declines for older-aged groups would be minimal. This was based on the premise that observed-period life expectancy at birth, which was near 70 years by the early 1960s, was thought to be close to the upper bound of the human lifespan (National Center for Health Statistics 1964). As it turned out, the assumption that 70 years represented the upper bound to the lifespan of the population was about as inappropriate for forecasting mortality from the decade of the 1960s, as were forecasts of a continuation of low fertility rates for the postwar era based on fertility trends observed during the 1930s. Unanticipated events occurred that produced extremely rapid declines in mortality rates, much like the conditions of the postwar era where unanticipated increases in fertility rates made previous forecasts of fertility appear extremely low. In both cases it was not possible for *anyone* at the time to foresee the events that led to rapid changes in postwar fertility rates and post-1968 mortality rates. More recently, actuaries at the Social Security Administration have revised their assumptions about prospective mortality change to include a range of assumptions that was more consistent with recently observed rapid mortality declines for older-aged groups. This new set of mortality-forecasting assumptions represented a considerably more optimistic view about future levels of mortality by comparison to previous forecasts, one in which there was believed to be the potential for significantly greater mortality declines than had ever been previously thought possible. This optimism has subsequently been tempered by a concern over the potential adverse effects of such mortality declines on patterns of morbidity for the elderly population (Myers and Manton 1984; Schneider and Brody 1983; *Gerontologica Perspecta* 1987).

Why is it that within the past 15 years demographers and actuaries have been paying much greater attention to their assumptions about prospective mortality change, and why is it that they have suddenly directed considerable national attention to the demography of aging and the mortality patterns of the old and very old (House Select Committee on Aging 1977; Neugarten and Havighurst 1977)? There are several answers to this question. First, it has been known for some time that the postwar baby boom cohorts would begin to swell the upper end of the age structure by the second decade of the next century as they progress through the age pyramid (Siegel 1979). What was not apparent just 15 years ago, or at least didn't appear as pressing as other population-related issues, was the momentum for population aging that was built into the age structure, *and* the potential for the acceleration of this process caused by unanticipated declines in death rates from degenerative diseases for cohorts surviving to more advanced ages.

In addition, recent articles by both physicians and demographers have directed the attention of policy makers to the enormous social and economic implications of a rapidly aging society, and the uncertainties about health and morbidity that may accompany recent changes in old-age mortality (Brody, Brock, and Williams 1987; Fries 1980; Manton 1982; Manton 1986a; Rosenwaike 1985; Guralnik, Yanagishita, and Schneider 1988; Schneider and Brody 1983; *Milbank Memorial Fund Quarterly* 1985). Included among these concerns is the possibility that a reduction in the risk of death from some of the major degenerative diseases, such as heart disease and stroke, could expose the survivors to an increase in the number of years spent in a state of frail health—thereby increasing both the duration of individual frailty and aggregate morbidity for the population (Schneider and Guralnik 1988; Manton 1986a). Precipitating these concerns was an article published by Fries (1980) in which an extremely optimistic view of the relation between mortality and morbidity was presented, one in which it was assumed that declining mortality would naturally lead to a compression of morbidity into fewer years of the life span and a decline in the frailty that accompanies old age.

Finally, recent mortality transitions in the United States have remained largely unexplained, and they have not been experienced evenly across age, race, and gender groups. There are numerous unanswered questions here, including the questions of why mortality rates are declining the fastest for those who already have the lowest levels of mortality—white females (Manton 1982); what role the upper bound to the human life span may play in influencing the pace and extent of future mortality declines; and what the relative contributions of modern medical technology and improved lifestyles have made to declining mortality rates, and what their contributions might be in the future (U.S. Office of Technology Assessment 1985). While all of these issues will influence heavily the pace and extent of future mortality declines, we are still faced today with the difficult task of providing reasonable forecasts of mortality so that public health officials and policy makers can better prepare for the rapidly aging American population.

Today, mortality conditions in the United States are such that 75 percent of all deaths occur as a result of chronic degenerative diseases, with 69 percent of all deaths concentrated among the population aged 65 and over. (In this article the term *chronic degenerative diseases* refers to the summation of deaths attributable to all circulatory diseases (390–448), malignant neoplasms (140–209), and diabetes mellitus (250) based on cause-of-death codes from the 9th revision of the *International Classifications of Diseases, Adapted*.) Since those who will be aged 65 and over between 1985 and the year 2050 have already been born, estimates of the size and relative health status of future elderly cohorts are dependent largely on forecasts of the survival rates of the present population, and the patterns of morbidity and disability they will experience. This helps to simplify the task of forecasting the size and health status of future elderly cohorts as assumptions about fertility, which have been the major source of error in previous forecasts of overall population growth, need not be made. In this article we compare and contrast the methods used to forecast mortality, present their underlying assumptions, examine how these methods have been used in the past, and discuss the implications of mortality forecasts to policy issues associated with prospective trends in morbidity, disability, and aging.

Forecasting Models

While demographers have been forecasting mortality officially for more than 50 years, the methods and assumptions used to make such forecasts have varied considerably. In order to compare the relative advantages and disadvantages of these methods and clarify the differences between them, they will be categorized into two basic types of forecasting methods—conventional models which have been used extensively in official forecasts such as extrapolation and targeting models, and cause-delay models (to be discussed shortly) which are relatively new and have yet to be used to make official forecasts of mortality.

Conventional Models

Extrapolation. The most widely used method of forecasting mortality by demographers throughout this century has been to extrapolate into the future past trends in mortality, usually by age, sex, and underlying cause of death. With extrapolation models a given period of time during which mortality is observed to have changed is used as a frame of reference for estimating how mortality will change in the future. This is usually done by observing changes in mortality rates over a selected time frame and then extrapolating these mortality rates, or some other measure used to gauge changes in mortality, forward in time. Examples of commonly used measures include death rates by age, sex, and cause, percentage change in selected rates, the slope of the change in mortality rates, and others. The underlying premise is that the factors that caused the recently observed changes in mortality are likely to remain operational and bring forth comparable changes in mortality in the future.

One of the earliest formal uses of the extrapolation model was by Whelpton (1928), in which forecasts of death rates and overall population growth in the United States were made based on trends in mortality from all causes observed from 1900–1904 and 1920–1924. This approach was combined with a targeting model (which was more heavily relied upon) in which mortality schedules from New Zealand were used as targets toward which the United States would slowly approach. Extrapolation models were again used by Whelpton and his colleagues in subsequent forecasts (National Resources Committee 1938; Thompson and Whelpton 1943; Whelpton 1936; Whelpton, Eldridge, and Siegel 1947), and these methods and assumptions were, in turn, adopted by the Office of the Actuary in their initial forecasts of mortality (Myers 1937, 1948). The extrapolation method has been used in one form or another, or in combination with other methods, in almost all subsequent efforts by actuaries at the Social Security Administration and others to forecast mortality for the United States (Bayo, Shiman, and Sobus 1978; Bayo and McKay 1974; Faber and Wilkin 1981; Greville 1957; Myers and Rasor 1952; Rice et al. 1983; Wade 1984, 1985, 1986, 1987; Wilkin 1980a, 1980b).

While extrapolation models are particularly appealing for forecasting mortality because of their simplicity and logic, there are numerous problems that arise when using such methods. To begin with, unlike the extrapolation of the downward and upward trends in other types of variables, vital rates are subject to upper and lower bounds that are influenced by biological constraints. This means that, in the case of mortality, there are biologically determined upper limits to life that will eventually end the downward trend in mortality rates that has occurred throughout most of this century in the United States and, in particular, the latest wave of mortality declines since 1968. Without knowledge as to the exact age of this biological limit to life, it is not possible to determine whether any given trend in mortality, observed over a relatively short time period, indicates either that this limit has been approached, or that estimates of the biological limit to life have been incorrect.

For example, forecasts of mortality made by actuaries at the Social Security Administration in the early 1970s underestimated subsequent changes in mortality because they were based on the observation that there was a slowdown in mortality declines observed in the 1950s and early 1960s, thus indicating that perhaps the biological limit to life had already been closely approached (Bayo and McKay 1974; Bayo and Wilkin 1977). These forecasts and others made by the Office of the Actuary during this century, and the methods and underlying assumptions of each study, are recorded in table 1. These data indicate that some form of the extrapolation method has been used in every actuarial forecast since 1952 (see column 6). In the 1952 study the actuaries made their forecasts from overall mortality rates by age and sex without considering underlying cause. Since then mortality forecasts have been made at the disease-specific level for 10 separate disease categories that encompassed virtually all causes of death. It is interesting to note that until the 1974 study was published, it was implied that the mortality schedules forecast for the year 2000 represented the lower limits of mortality declines (e.g., ultimate mortality rates that were subject to no further improvement), and that mortality rates would remain constant past that year. With the latest two actuarial forecasts there is no longer any reference to "ultimate mortality rates" or lower limits to mortality declines. Instead, what has been referred to as "ultimate rates of mortality decline" were postulated. These ultimate rates of mortality decline represented the range of possible mortality change that was thought possible over the projection time frame while apparently leaving open the possibility that further mortality declines would be possible (although this was not stated explicitly). They were arrived at by considering how "such factors as the development and application of new diagnostic, surgical, and life-sustaining techniques, the presence of environmental pollutants, improvements in exercise and nutrition, the incidence of violence, . . . etc." might influence future trends in mortality. Just how these "factors" were evaluated and then translated into assumptions about how mortality for each age/sex/disease category would change has never been discussed, although the author's personal communication with Alice Wade from the Office of the Actuary revealed that there has never been a systematic method of arriving at these ultimate rates of mortality decline. Instead, they were arrived at by using the personal judgment of those responsible for the forecasts.

As an illustration of how forecasts of mortality have been made by the Office of the Actuary, consider the methods and assumptions used in their latest official forecast (Wade 1987, 10). In this case, average annual reductions in central death rates were presented by age (in 5-year age groups up to ages 90 to 94), sex, and ten separate disease categories from 1968 to 1983. Although not stated explicitly, it appears that these data were used in several of the actuarial studies as the rationale for the selection of the ultimate rates of mortality decline. Mortality schedules for 1984 were then estimated from provisional data provided by the National Center for Health Statistics, and 1985 mortality schedules were based on estimates of mortality change (from 1984) provided by Monthly Vital Statistics Reports (volume 34). Mortality rates in 1986 were arrived at by extrapolating to that year the average annual reductions observed from 1968 to 1983, and the range of forecasts for 1987 was obtained by taking 50 percent, 100 percent, and 150 percent of the average annual reductions observed from 1968 to 1983. From 1987 to 2010 a logarithmic formula was used gradually to transform the annual reductions used to obtain the 1987 mortality levels into "postulated ultimate annual reductions" by age, sex, and for each of 10 separate disease categories. From 2011 to 2080 a single overall "ultimate annual reduction" in mortality was assumed to apply equally to all age groups, by sex and cause of death. These "ultimate annual reductions," which are the basis for these forecasts, were arrived at by, to borrow a phrase from Preston (1974, 728), "projection by reference to the informed guesses of others."

While the Office of the Actuary's forecasts of life expectancy at birth and at age 65 by sex are recorded in columns 1 to 4 of table 1, a better illustration of these forecasts is presented in figures 1 to 4 where they are presented in relation to observed trends in life

TABLE 1

U.S. Office of the Actuary Forecasts of Life Expectancy at Birth and at Age 65 for the United States in the Year 2000, and Description of Forecasting Methods

Actuarial study no. (Reference)	Life expectancy at birth and at age 65, forecasted to the year 2000 (middle or average assumption): Males e_0 (1)	Males e_{65} (2)	Females e_0 (3)	Females e_{65} (4)	Forecast of gender gap in e_0 to the year 2000 (5)	Method used for forecasting mortality (6)	Comments (7)
No. 24 (Myers 1948)	—	—	—	—	—	Targeting based on expert opinion using past trends in mortality from years unspecified.	High and low mortality assumptions were made by calendar year and age for native white males in order to set target mortality schedules for the year 2000. Rates for intermediate years were interpolated with a simple logistic curve. Forecasts of rates for all other race/sex groups were obtained by allowing the mortality rates for each group to approach those forecasted for the native white males in the year 2000. Methods are described in detail in Thompson and Whelpton (1943). The high mortality assumption extended the mortality schedule of 1939–1941 to the year 2000. The low mortality assumption was based on opinions of percentage reductions in mortality for various age groups.
No. 33 (Myers and Rasor 1952)	71.41	13.98	75.54	15.86	Decrease	Extrapolation and targeting based on expert opinion using trends in overall mortality rates by age and sex observed from 1940 to 1948.	High and low mortality assumptions were made about age-specific mortality rates, by sex, from 1940 to 2000. Low mortality targets for the year 2000 (referred to as ultimate mortality rates) were obtained by extrapolating trends in the age-specific percentage reduction in mortality observed from 1940 to 1948, and then fitting a logistic curve to these rates so that they fall between the rates from the percentage reduction and those forecasted in actuarial study no. 24. The high mortality forecast was based on the assumption that the mortality schedule for the year 1975 under the low assumption would occur in the year 2000. Mortality rates for intermediate years were obtained by linear interpolation between 1950 and forecasts for the year 2000.

TABLE 1—*Continued*

Actuarial study no. (Reference)	Life expectancy at birth and at age 65, forecasted to the year 2000 (middle or average assumption)				Forecast of gender gap in e_0 to the year 2000 (5)	Method used for forecasting mortality (6)	Comments (7)
	Males		Females				
	e_0 (1)	e_{65} (2)	e_0 (3)	e_{65} (4)			
No. 46 (Greville 1957)	71.45	14.96	77.14	17.54	Decrease with middle and low assumption. Increase with high assumption	Methods unstated. It appears that mortality data from 1955 were used as the baseline, and data from 1949–1951 and 1953–1955 were used for the interpolation.	High and low mortality assumptions were made about each of ten separate disease categories, by age, sex, and calendar year from 1955 to 2050. Ultimate mortality rates were postulated for the year 2000, and intermediate rates were arrived at by interpolation. The forecasted percentage reductions were arrived at in consultation with statistical experts, although their methods were not presented. Mortality rates for the year 2000 and after were assumed to remain constant.
No. 62 (Bayo 1966)	70.51	14.28	76.42	16.68	Increase	Methods unstated. Mortality data from 1959–1961 were used as the baseline, and expert opinion was used to obtain the forecasted percentage declines.	High and low mortality assumptions were made about each of ten separate disease categories, by age, sex, and calendar year from 1960 to 2050. Ultimate mortality rates were postulated for the year 2000, and intermediate rates were arrived at by linear interpolation. The forecasted percentage reductions were arrived at in consultation with experts, although the data and methods used to arrive at the ultimate mortality rates were not stated. Mortality rates for the year 2000 and after were assumed to remain constant. The method used to calculate the ultimate mortality rates for the year 2000 was based on a cause-elimination strategy where a hypothetical cause was created which accounted for the postulated declines, and then the hypothetical cause was statistically eliminated.
No. 72 (Bayo and McKay 1974)	69.01	13.59	76.93	18.12	Increase	Extrapolation and targeting using expert opinion. While the time period used as the frame of ref-	One mortality assumption was made about each of 10 separate disease categories, by age, sex, and calendar year from 1972 to 2000. Ultimate mortality rates were postulated for the year 2000, and intermediate rates were obtained by geometric interpolation. The forecasted

						crease was not stated, data from 1968 were considered.	percentage reductions were arrived at in consultation with experts, and the experts relied on an evaluation of past trends in mortality and possible future changes. The data and methods used by the experts were not stated. Mortality rates for the year 2000 and after were assumed to remain constant.
No. 74 (Bayo and Wilkin 1977)	70.30	14.60	78.04	18.93	Increase	Targeting and expert opinion based on data from 1975 and other unspecified earlier years.	One mortality assumption was made about each of 10 separate disease categories, by age, sex, and calendar year from 1977 to 2050. Ultimate mortality rates were postulated for the year 2050, and rates for intermediate years were obtained by geometric interpolation. The precise methods used to arrive at the ultimate mortality rates for the year 2000 were not stated. It was not clear whether the ultimate mortality rates postulated for the year 2000 were subject to further improvement.
No. 77 (Bayo, Shiman, and Sobus 1978)	70.30	14.60	78.04	18.93	Increase	Extrapolation and targeting using expert opinion based on trends in mortality for 1975 and unspecified earlier years.	One mortality assumption was made about each of 10 separate disease categories, by age, sex, and calendar year from 1977 to 2050. Ultimate mortality rates were postulated for the year 2050. Forecasts for the intermediate years were obtained by geometric interpolation between observed rates in 1977 and the ultimate rates forecast for the year 2050. Although not stated explicitly, it was implied that mortality rates would not improve past the year 2050.
No. 82 (Wilkin 1980a; 1980b)	72.80	15.50	81.20	21.20	Increase	Extrapolation and targeting using expert opinion based on trends in age/sex cause-specific mortality rates observed from 1969 to 1977. Mortality rates from 1977 to 1985 were extrapolated from mortality rates observed from 1969 to 1977.	Three mortality assumptions were made about each of 10 separate disease categories, by age, sex, and calendar year from 1985 to 2080. Ultimate rates of mortality decline were postulated for the years 2000 to 2080. Forecasts for the years 1985 to 2000 were based on an average of the ultimate rates of mortality decline postulated for 2000 to 2080 and observed average annual declines for the years 1977 to 1985. It was not clear whether the target mortality rates for the year 2080 were subject to further improvement.
No. 85 (Faber and Wilkin 1981)	72.9	15.8	81.1	21.1	Increase	Extrapolation and targeting using expert opinion based on trends in age/sex cause-specific mortality rates observed from 1968 to 1978.	Three mortality assumptions were made about each of 10 separate disease categories, by age, sex, and calendar year from 1981 to 2080. Ultimate rates of mortality decline were postulated for the years 2005 to 2080. For the years 1981 to 2005 a logarithmic formula was used to transform gradually the average annual improvements from 1968 to 1978 into the postulated ultimate annual improvements. For the years

No. 95 (Wade 1985)	73.9	15.8	81.2	20.7	Decrease	Extrapolation and targeting using expert opinion based on trends in age/sex cause-specific mortality rates observed from 1968–1981.	Three mortality assumptions were made about each of 10 separate disease categories, by age, sex, and calendar year from 1984 to 2080. Ultimate rates of mortality decline were postulated for the years 2009 to 2080. For the years 1984 to 2008 a logarithmic formula was used to transform gradually the reductions applied to obtain the 1984 levels into the postulated ultimate annual reductions. The 1984 mortality levels were obtained by extrapolating mortality trends observed from 1968 to 1981. It was not clear whether the targeted ultimate mortality rates for the year 2080 were subject to further improvement.
No. 97 (Wade 1986)	73.9	15.6	81.0	20.5	Constant with assumptions I and II. Decrease with assumption III.	Extrapolation and targeting using expert opinion based on trends in age/sex cause-specific mortality observed from 1968 to 1982.	Three mortality assumptions were made about each of 10 separate disease categories, by age, sex, and calendar year from 1986 to 2080. Ultimate mortality rates were postulated for the year 2010, and forecasts for 1986 to 2009 were obtained by using a logarithmic formula to transform the range of mortality rates forecasted for the year 1986. The 1986 forecast was based on alternative assumptions about trends in mortality observed from 1968 to 1982. The ultimate mortality rates were assumed to apply from 2010 to 2080. It was not clear whether the targeted mortality rates for the year 2080 were subject to further improvement.
No. 99 (Wade 1987)	73.9	15.6	80.8	20.1	Decrease	Extrapolation and targeting using expert opinion based on trends in age/sex cause-specific mortality observed from 1968 to 1983.	Three mortality assumptions were made about each of 10 separate disease categories, by age, sex, and calendar year from 1987 to 2080. Ultimate rates of mortality decline were postulated for the years 2011 and after, and these were assumed to be the same each year for all age groups, although separate assumptions were made by sex and cause. While not stated explicitly, mortality declines after 2080 were considered possible.

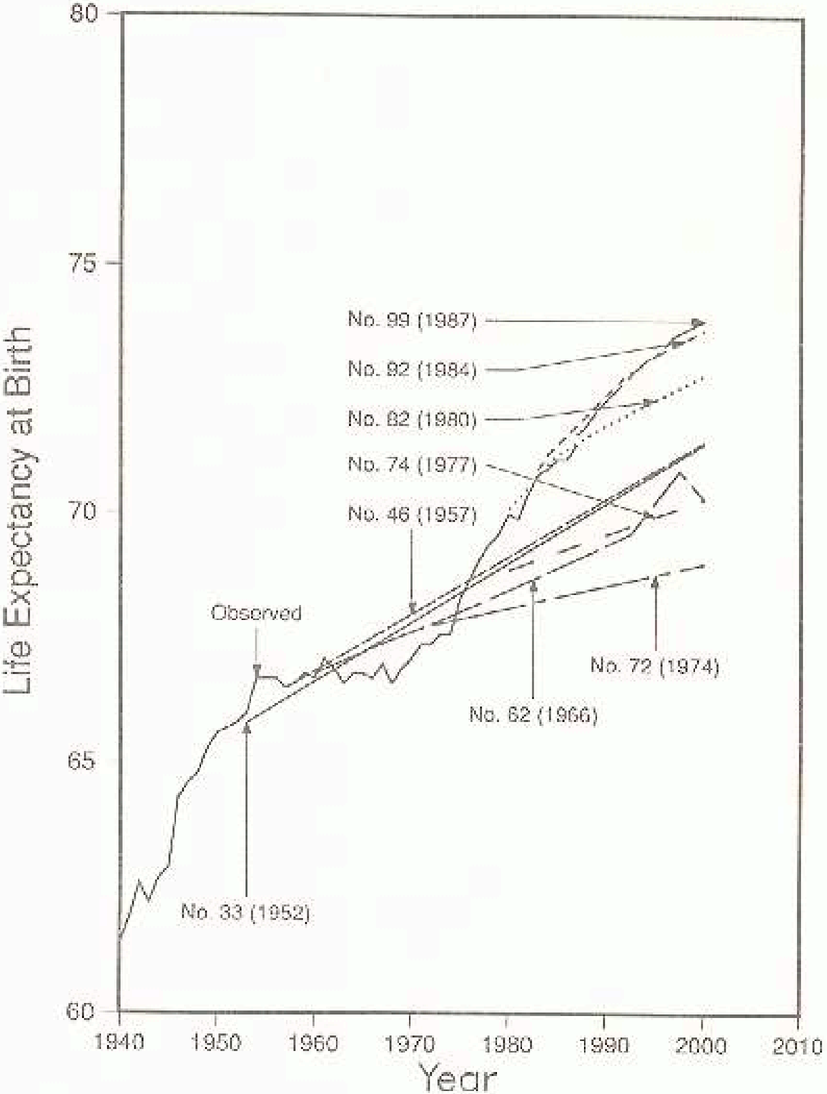

FIG. 1. Comparison of U.S. Office of the Actuary forecasts of life expectancy at birth for U.S. males to the year 2000 with observed changes from 1940 to 1986.

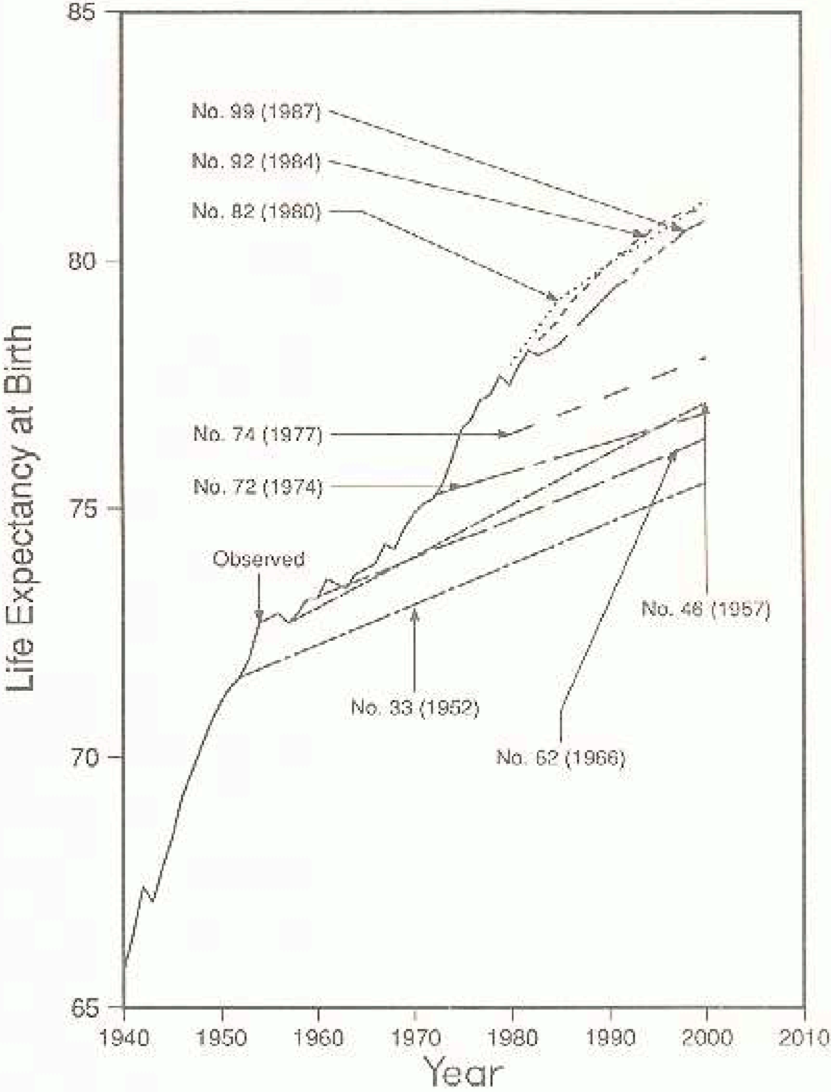

FIG. 2. Comparison of U.S. Office of the Actuary forecasts of life expectanc at birth for U.S. females to the year 2000 with observed changes from 194 to 1986.

expectancy at these ages. In figures 1 and 2, a sample of Office of the Actuary forecasts of life expectancy at birth (based on middle or average assumptions) for men and women in the United States, respectively, for each calendar year to the year 2000 are compared. These figures indicate that, at least for the three most recent studies listed, forecasts of life expectancy were dependent on the extrapolation of trends in mortality that were observed in the years just prior to the publication of each study (see column 6 in table 1 for additional details). In the earlier actuarial studies it is apparent that the forecasts of life expectancy did not follow exactly from the mortality trends that were observed in the years used as the frame of reference, and it was simply not anticipated that life expectancy would continue to increase at such a rapid pace. Of particular interest here is the substantial difference in assumptions between the 1974 and 1977 studies, both of which relied heavily on the observation that mortality rates had levelled off in the late 1950s and early 1960s, and subsequent forecasts in the 1980s which were considerably more optimistic. These differences are attributable mostly to the fact that the later forecasts were based on mortality trends observed after 1968 when mortality rates began their rapid declines while the earlier forecasts relied, in part, on pre-1968 data during which mortality declines experienced a temporary stagnation.

In figures 3 and 4, a sample of Office of the Actuary forecasts of life expectancy at age 65 (based on middle or average assumptions) for men and women in the United States with observed changes from 1940 to 1986 are compared. The data in figure 3 indicate that for males there was a levelling off of gains in life expectancy during the 1950s and 1960s, but rapid increases again occurred from about 1968. The 1952 and 1974 studies represented the most pessimistic forecasts of life expectancy for males in advanced ages, while the 1957 forecast was quite optimistic considering previous trends. The most recent studies were patterned closely after the changes in life expectancy observed from the late 1960s to the present.

The forecasts of life expectancy for females illustrated in figure 4 are even more interesting. It would appear from this figure that, in spite of rapid and near monotonic gains in life expectancy observed at age 65 from 1940 to 1986, the actuaries making each forecast simply could not believe that these gains would continue at that pace beyond the projection year. As a result, the gains in life expectancy

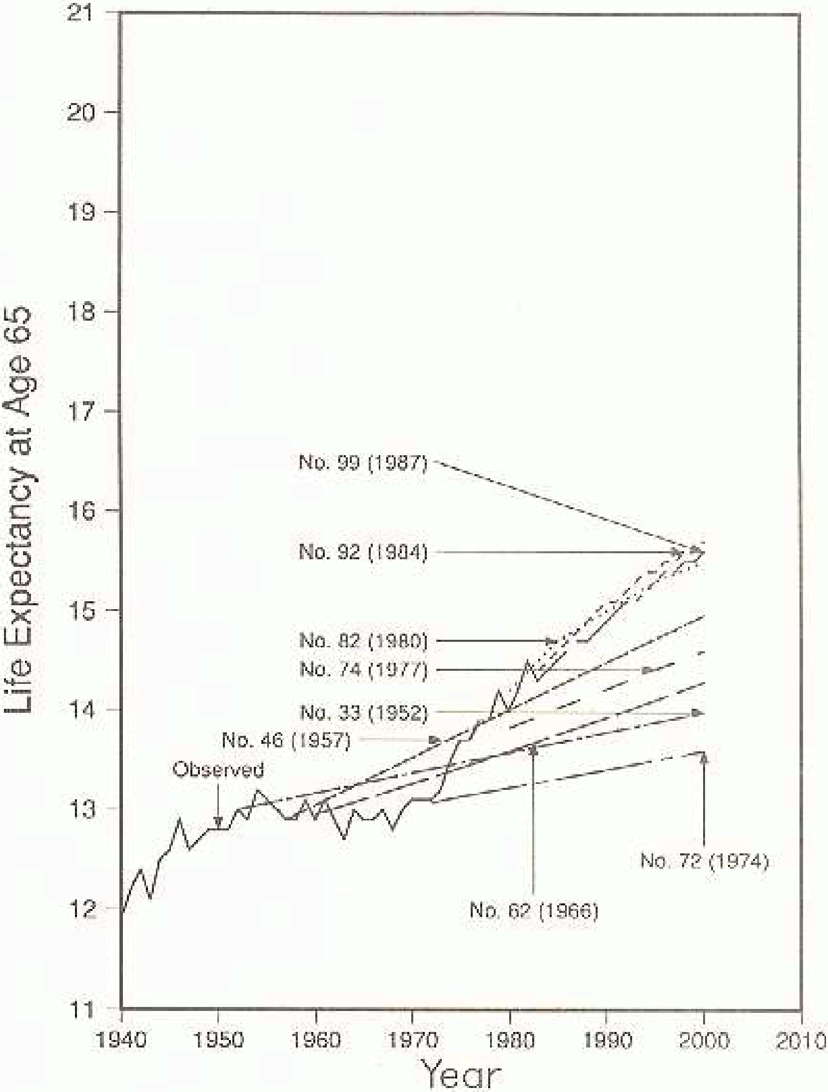

FIG. 3. Comparison of U.S. Office of the Actuary forecasts of life expectancy at age 65 for U.S. males to the year 2000 with observed changes from 1940 to 1986.

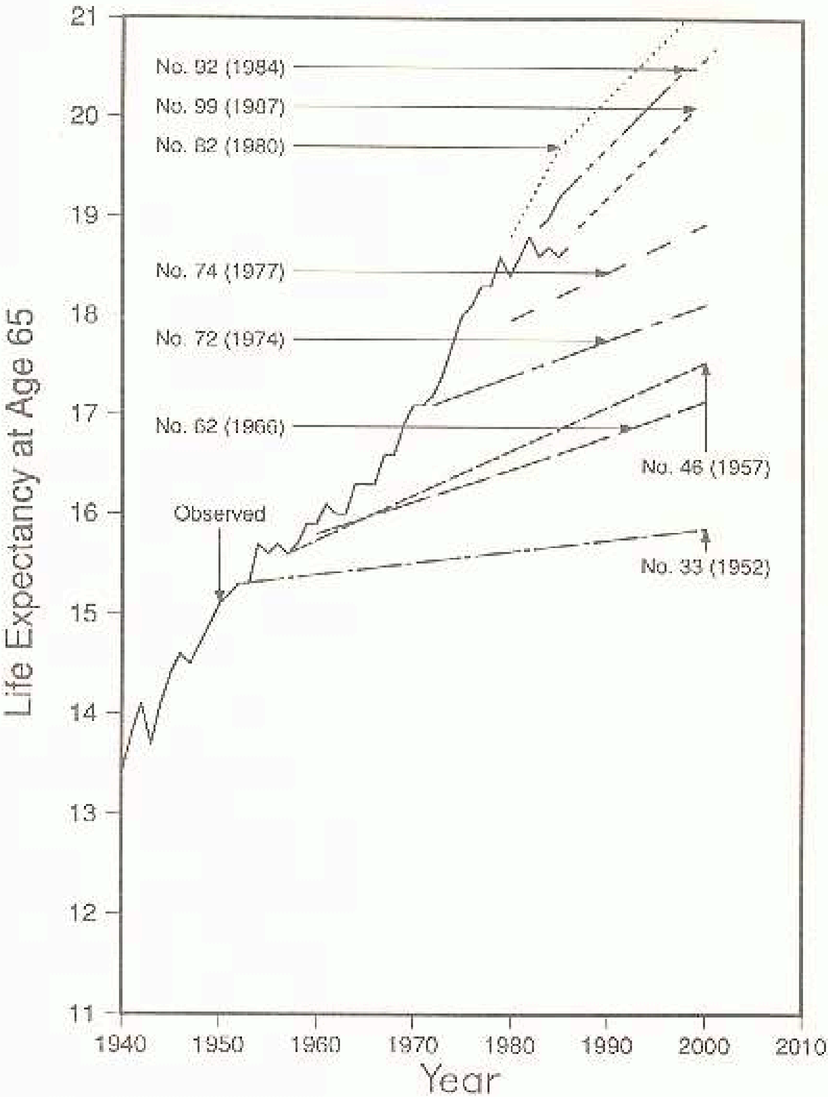

FIG. 4. Comparison of U.S. Office of the Actuary forecasts of life expectancy at age 65 for U.S. females to the year 2000 with observed changes from 1940 to 1986.

that were forecasted to occur by the year 2000 were actually achieved within just a few years following the publication of the forecasts, because the trend toward declining mortality in advanced ages continued. In contrast, the forecasts made during the 1980s have been quite optimistic, with each study extending the trend that had occurred just prior to the forecasts. In the latest official forecast by the Office of the Actuary (Wade 1987), a somewhat less optimistic view of gains in life expectancy for older age groups is presented for both men and women, by comparison to official forecasts made just three years earlier (Wade 1984). This less optimistic forecast was based on more recent mortality data for the United States in which it appeared that the mortality declines observed for older age groups had decelerated.

Another problem with the extrapolation of mortality is the questionable reliability of the rates that are being extrapolated. The underlying-cause-of-death statistic, for instance, is thought to represent a less meaningful and perhaps less accurate description of the clinical conditions that precede death because of the frequent coexistence of several life-threatening conditions in people who survive to more advanced ages. Additionally, the size of the population in more advanced ages is known to be overestimated because of age misstatement and because of inappropriate assumptions regarding the allocation of people of unknown ages (Spencer 1986), thus implying that mortality rates in older ages may be higher than current figures indicate. When both the numerators and the denominators of the rates that are used as the basis for extrapolating mortality are in question, then certainly forecasts based on these rates should be made with great caution, especially in the case of forecasts for the population in more advanced ages. It should also be noted that these concerns about data quality are not unique to extrapolation models, as other forecasting methods require the same data on cause-specific mortality for the population in advanced ages in order to forecast mortality for these age groups.

In short, while extrapolation models are the most frequently used method of forecasting both overall and cause-specific mortality rates, they have not been very reliable in the past. The accuracy of extrapolation will depend on the assumption that the factors that caused recently observed trends in mortality will continue. Given the uncertainty regarding (1) the exact cause of recent mortality transitions, (2) the heretofore unknown influence of the biological limit to life, (3) the likelihood that advances in medical technology will contribute significantly to mortality declines in advanced ages in the future, (4) the presence of increasingly more dangerous environmental risk factors that are unfavorable toward longevity, and (5) the questionable reliability of both the numerators and denominators of the mortality rates which are the basis for extrapolation models, there is reason to be concerned about the exclusive use of extrapolation models for forecasting mortality.

Targeting. The second most commonly used method of forecasting mortality is to use mortality rates or schedules that are observed for another population subgroup as a *target* toward which the population for which the forecasts are being made will approach with time. (The term "target" is used here to represent a mortality schedule that is believed to be realistically achievable for one population subgroup within a given time frame because it is already observed for another subgroup of the population. This should not be confused with an alternative interpretation of the term target in which a mortality schedule is viewed as a desirable goal and policy changes are set forth to achieve that goal.) With targeting models one uses as the target observed period mortality rates, or some measure of change in mortality from a selected subgroup of the population. Various statistical methods are used to forecast the reduction in the mortality rates observed between the base population and the target population, including simple percentage reductions and more complex curve-fitting procedures.

The use of the term *target* as a separate kind of forecasting methodology is distinguished in this analysis as a method that is qualitatively and quantitatively different from extrapolation methods, although it is easy to confuse the two. The reason for the confusion is that in the past demographers have used the term *targets* to refer to mortality schedules that were expected to occur at some selected time in the future. Although it was not always clear how the target mortality schedules were arrived at in the actuarial studies, it is apparent that sometimes they were *derived* from observations of past trends in overall or cause-specific mortality; at other times the opinions of experts were solicited (which were either based on observations of past trends in mortality or mortality schedules from other subgroups of the population), and at still other times observed mortality schedules from subgroups of the population with more favorable mortality schedules were used as targets. More recently the phrase "ultimate rates of mortality decline" has been adopted by the Office of the Actuary to define the targets to be approached (Wade 1984, 1987). The difficult

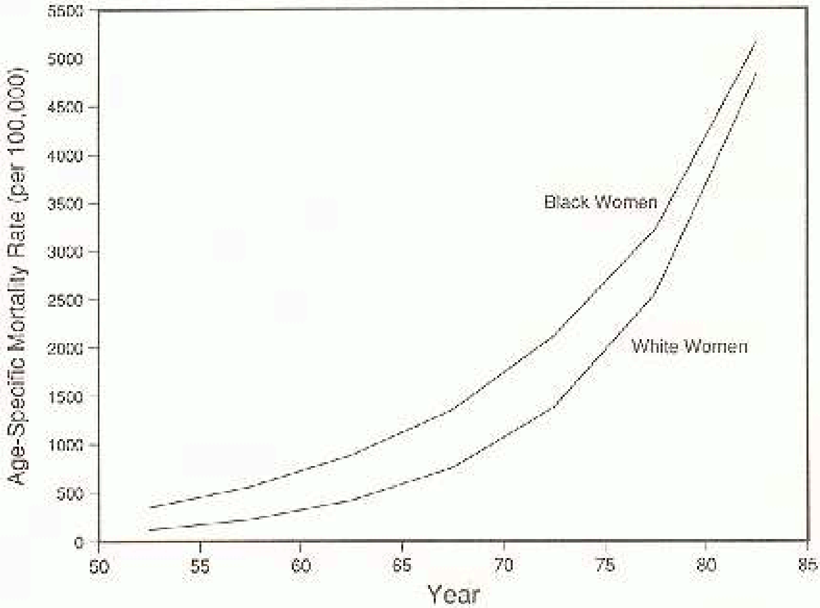

FIG. 5. Age-specific mortality rates from all circulatory diseases for white and black women aged 50 to 85 in the United States in 1980.

task was then to determine the rate at which the base mortality schedules would approach the targets.

In this article extrapolation models refer to forecasting methods in which a hypothetical mortality schedule of the future is mathematically *derived* either from trends in overall or cause-specific mortality rates observed in the past, or expert opinion (that is based on observations of past mortality) as to how mortality rates may change. Targeting models refer to the use of either period mortality rates observed for one population subgroup that are viewed as target mortality schedules toward which a different population subgroup of the same period may be expected to approach at some time in the future, or to expert opinion that is based on observations of period mortality rates from other subgroups of the population. The factor that distinguishes the extrapolation model from the targeting model is the method used to arrive at the target or ultimate mortality schedules.

As an illustration of a target, note in figure 5 how the mortality schedules from all circulatory diseases observed for white women in used data from other countries to gauge the prospects for further declines, and in the latter publication age-specific death rates of whites were used as targets for the black and foreign-born segments of the population. In later forecasts, Thompson and Whelpton (1943) again used mortality schedules from other countries that were lower than that of the United States as the rationale for an optimism that additional mortality reductions were possible, but forecasts of the white population were based largely on a form of extrapolation in which opinions about trends in cause-specific mortality rates were formulated (although a targeting approach was used to forecast mortality rates for blacks and the foreign-born population where mortality rates observed for whites were used as targets). Finally, Siegel (1976) used a targeting approach to estimate life expectancy for the United States. This was done by using the most favorable mortality schedule at the state level in the United States—in this case Hawaii—as the target for the rest of the country.

The underlying premise behind targeting models is that population subgroups differ in their risk of death because of varying lifelong exposure to exogenous hazards, and with time the population with higher mortality is expected to experience a drift in its mortality schedule toward a schedule currently observed for the target population where mortality rates are lower. Targeting models thus recognize the fact that subgroups of the population are heterogeneous with respect to survival chances, and that non-biological forces that are thought to contribute to heterogeneity are hypothesized to be lessened with time. Using population heterogeneity as the theoretical basis for forecasting mortality also has implications for improving forecasts of morbidity and disability. For example, with targeting models one considers the possibility that mortality declines will (a) allow less healthy individuals to survive, thus making the survived population more frail than before (Schoen 1986, Vaupel, Manton, and Stallard 1979), or (b) allow cohorts to survive into older ages with fewer accumulated risk factors. In any event, the consideration of heterogeneity for forecasting mortality may improve forecasts of morbidity and disability by taking into consideration the unique relation between mortality and morbidity and disability under conditions of declining mortality.

The targeting models are particularly appealing when forecasting mortality because they rely on the use of mortality schedules that are already observed for a given population subgroup. This eliminates the concern as to whether such mortality schedules are realistically achievable since they already exist. In effect, with the targeting method one assumes that there are mortality continuums that subgroups of the population pass through as they acquire more favorable survival conditions (or as they avoid more adverse risk factors), and that there is an orderly progression for shifts in mortality schedules. While this is an intriguing concept, it is reasonable to question whether population heterogeneity is always attributable to a common set of environmental constraints on longevity that influence equally all subgroups of the population. For example, it is quite possible that two separate population subgroups may experience comparable overall mortality schedules, but at the same time maintain quite different distributions of underlying causes of death. Although this would justify the use of targets at the cause-specific level, it is still possible for two separate population subgroups to experience comparable declines in mortality from a given cause for different reasons. For instance, declining mortality rates from ischemic heart disease may have occurred in Scandinavian countries largely because of improved living standards, while in the United States they may have declined as a result of modern medical technology reducing case-fatality rates and allowing the survivors to die from other causes.

If the causes of declining mortality rates vary considerably in the case of chronic degenerative diseases, then the prospects for additional declines may also be quite different. In order to determine whether targeting models may prove useful for forecasting mortality it is important to examine in greater detail the fundamental causes of cross-national trends in mortality as well as trends in mortality between population subgroups within a given nation (Preston 1974, 732).

Cause-delay Models

Complete or Partial Cause-Elimination. While the term "cause-delay" was first introduced by Manton and his colleagues in 1980 (Manton, Patrick, and Stallard 1980), the methods used for delaying or postponing death from a given disease *indefinitely* has been used by demographers for many years. This is commonly referred to as cause-elimination based on the analysis of competing risks (Chiang 1968). Cause-elimination models are life-table methods that are used to answer the question: How are mortality rates and life expectancy changed for a population in which part or all of one or more causes of death are hypothetically eliminated or postponed indefinitely? The idea of hypothetically eliminating diseases from the population is based on achievements that have been made within the last three centuries during which it was first learned that mortality could be altered, and later the realization that infectious and parasitic diseases could be reduced in importance to negligible levels (Bourgeois-Pichat 1978). As a result of the subsequent reduction to near zero of death rates from infectious and parasitic diseases, the saved population has survived throughout this century into increasingly older ages where they faced the elevated risk of dying from age-associated physiological impairments such as heart disease, stroke, and some types of cancer (Brody and Schneider 1986). In effect, degenerative diseases were substituted for infectious and parasitic diseases as the major causes of death for the population.

Taeuber (1976) was the first to discuss the implications of this substitution process in terms of what might occur if one or more of *today's* major killer diseases were somehow eradicated in a manner similar to that achieved with infectious and parasitic diseases. Taeuber's primary concern was focused on the diseases that would be replacing as causes of death, the disease that was eliminated, and the possible effects of this substitution on health care costs. The latter concern was based on the fact that today's major chronic degenerative diseases have associated with them quite varying levels and durations of pre-death frailty and cost to the health care system. Any substitution of diseases would then be expected to alter the prevalence and severity of population morbidity and disability—possibly in an undesirable direction. This substitution of degenerative diseases for those hypothetically eliminated, and subsequent concern about the possible substitution of varying levels of pre-death frailty, has been referred to as "Taeuber's paradox" (Keyfitz 1977). (It should be noted that Taeuber was not the first to raise the issue about the possible consequences of this substitution process. Whelpton (1928, 257) and Whelpton, Eldridge, and Siegel (1947, 9–10) also briefly discussed the importance of this issue.)

While the cause-elimination model has been used extensively in the literature (Greville, Bayo, and Foster 1975; Keyfitz 1977; Preston, Keyfitz, and Schoen 1972; Tsai, Lee, and Hardy 1978), it has not been used by official or unofficial sources for the purpose of making forecasts of mortality. This is the case because, as Siegel and Davidson (1984, 57) and Taeuber (1976) have noted, it is unreasonable to expect that major degenerative diseases are likely to be eliminated in the foreseeable future. Instead, such models are viewed as analytical tools that are more appropriate for assessing the relative contributions of single causes of death to overall mortality, and to provide a basis for dealing with policy questions regarding the allocation of health resources.

Partial cause-elimination models are basically the same as total elimination models except that only some portion, instead of all deaths from a given cause, are hypothetically eliminated—leaving the risk of death from all other causes unchanged (for example see Tsai, Lee, and Hardy 1978). The hypothetical partial elimination of a degenerative disease is appealing and appears more realistic than total cause elimination because the net effect of declining mortality rates from some degenerative diseases is a shift in the risk of death to older ages and other causes. While the number of deaths from other causes may increase as a result, this will not necessarily cause an increase in death rates from the substituted causes as the size of the population at risk also changes with lower death rates. This produces what appears on the surface to be an actual partial elimination of the disease, as the risk of death is shifted from one cause to another and some portion of the population does indeed die from other causes. The fact that the risks of death from major chronic degenerative diseases remain operational at the same time they are being postponed indefinitely into more advanced ages, however, represents one of the major concerns about the utility of this model for providing a realistic basis for forecasting mortality.

At issue are really several problems with the cause-elimination model, but the most important in this instance is the underlying assumption that diseases operate independent of each other in causing death. This is a tenuous assumption given the difficulty in observing and measuring the dependency between diseases. The basis for this assumption is that specific degenerative diseases tend to result in death over such short time periods that the probability of a second degenerative disease operating at the same time is thought to be small (Manton and Poss 1979, 314). As several authors have noted (Keyfitz 1977; Tsai, Lee, and Hardy 1978; Preston, Keyfitz, and Schoen 1972; Manton and Poss 1979; Siegel and Davidson 1984), death in more advanced ages tends to result from a number of age- and disease-associated degenerative conditions that often act interdependently to bring about death. Given the fact that degenerative diseases are also known to share common risk factors (Hamburg, Elliot, and Parron 1982), the assumption of independence in this case appears to be highly questionable. Additionally, the independence assumption is consistent with the standard nomenclature on death certificates where a single underlying cause is listed, and this is what is typically used to describe the one factor that is most responsible for causing an individual's death, and to follow general trends in mortality for the population. The questionable reliability of both the underlying-cause-of-death statistic and the assumption of independence have led to recent efforts to make use of all of the data on the death certificate to help understand more fully the relation between varying chronic degenerative diseases and their associated complications (Israel, Rosenberg, and Curtin 1986; Manton 1986b; Nam 1987).

A possible redeeming feature of the cause-elimination model as it might be used to forecast *overall mortality* is that today the advances in medical technology are occurring so rapidly that it is at least conceivable that some major chronic degenerative diseases may be eliminated in the future. If we are to extend our basic assumptions about future trends in mortality to consider the extreme in which major technological breakthroughs are achieved, then this model would prove useful. Thus, it is possible that the mortality schedules that would result from the hypothetical elimination of any given major degenerative disease may be comparable to what is projected under the assumption of, say, a more likely scenario in which there is a postponement of death from several degenerative diseases simultaneously (Olshansky 1985). Nevertheless, cause-elimination models are still viewed as inappropriate for forecasting mortality because of inherent problems with their underlying assumptions.

Simultaneous/Multiple Cause-delay. One of the criticisms of the extrapolation and targeting models as they have been used in the past is that, for the most part, they have been used as atheoretical statistical methods of extending past trends in mortality rates into the future with little or no concern given to the behavioral, medical, and social factors which contribute to mortality change (Olshansky 1987, 358). Cause-elimination models have been criticized because it is unrealistic to assume that the major chronic degenerative diseases of today—heart disease, stroke, and cancers—are amenable to elimination because these diseases appear to be inexorably linked to incremental age-associated physiological impairments. As is the case with any forecasting method, the accuracy of these methods is dependent on the justifiability and accuracy of the underlying assumptions. It is for this reason that several authors have argued that instead of hypothetically eliminating deaths or postponing them indefinitely as some have suggested, it would be more realistic at this time to estimate the effects of marginal improvements in cause-specific mortality, as in postponing some portion (instead of all) deaths from a given cause without reducing the risk of death from the cause(s) considered to zero (Keyfitz 1977, 411; Siegel and Davidson 1984, 57; Manton, Patrick, and Stallard 1980). This was suggested because the factors that appear to be causing declining death rates and which are likely to cause such declines in the future—medical technology and improved lifestyles—are believed to influence the risk of death by reducing or postponing mortality hazards rather than eliminating them. In effect, marginal improvements in mortality are thought to be represented more realistically by statistical models that allow for marginal *reductions* in the age-specific risk of death from any single cause, but which also maintains the existence of the risk of death from prevailing causes rather than eliminating them entirely.

There are several reasons why it is important to preserve the interdependent relations, both theoretically and methodologically, between the risks of death from *different* degenerative diseases. With the cause-elimination model, for example, the entire population is removed from any risk of dying from a selected disease. With a partial cause-elimination model the risk of death from a given cause is reduced by, say, 10 percent. This is an unrealistic assumption given that few if any individuals are ever at zero risk of dying from any major chronic degenerative disease. It is much more likely that perhaps some portion of the population are saved from dying from one or more major degenerative diseases as a result of, for example, preventive health care programs (hypertension control), disease-specific interventions (coronary bypass), or a healthy lifestyle, each of which may postpone (but not reduce to zero) the risk of experiencing symptoms of a disease into later years. If one or more of these factors serve to postpone death long enough so that death eventually results from a different cause, it would then *appear* that postponing death is equivalent to eliminating the risk of death for that disease (Manton, Patrick, and Stallard 1980, 580). Yet, in fact the risk of death from that disease is not reduced to zero; it is simply reduced for a sufficiently long enough time to allow another disease to cause death. The importance of this distinction is that chronic degenerative diseases often act interdependently in the body, and the presence of some risk factors, even in the absence of physical symptoms associated with any single disease, may precipitate the progression of other diseases. The justification for using a cause-delay model over a cause-elimination model is, therefore, based on the premise that the risk of death from degenerative causes at any given age are present; the risk tends to increase with age; and their presence is known to influence the risk of death from other causes, even when cause-specific mortality rates are declining.

Based on this understanding of the underlying assumptions for cause-elimination models, Manton, Patrick, and Stallard (1980) developed a method of estimating the changes in mortality that result from the hypothetical postponement of death from a single underlying cause. The methodology for this model was based on the assumption that observed age-specific mortality rates for a single time period could be used to estimate the effects of a delay in the risk of death for a given age group. Hypothetical delays in mortality for a given age group are calculated by assuming that the risk of death from a selected cause is shifted toward adjacent younger age groups. A five-year delay in mortality rates from heart disease, for example, would thus be approximately equal to shifting the observed age-specific mortality schedule for heart disease toward younger ages by 5 years.

The Manton, Patrick, and Stallard (1980) single cause-delay methodology was subsequently extended to allow for the simultaneous delay of more than one disease at a time (Olshansky 1987). This extension to a multiple cause-delay model was believed to portray more realistically the effects on mortality of the presence of more favorable risk factors at the population level. For instance, the advances in medical technology and improved lifestyles that have become more prevalent in the United States, and are known to reduce the risk of death from degenerative diseases, are also likely to reduce the risk of death from more than one degenerative disease at a time—given that major degenerative diseases are known to share common risk factors (Hamburg, Elliot, and Parron 1982). Any improvement in a single major risk factor—for example, a reduction in smoking—would then be expected to reduce the risk of death from all of the diseases smoking is known to influence (e.g., circulatory diseases, certain types of cancer, etc.). If it is these kinds of favorable improvements in major risk factors at the population scale that are driving down mortality rates, and there is reason to believe this is the case, then the introduction of separate delay assumptions that are made by cause of death, age, race, and sex (and given a time frame for the delays to occur) appears to be a most promising method of forecasting mortality for the population in more advanced ages where the majority of deaths are attributable to chronic degenerative diseases. It is at these more advanced ages where the majority of the recent mortality declines have occurred, and where they may be expected to occur in the future if the risks of death from degenerative diseases are to be reduced by healthier lifestyles and modern medical technology.

The cause-delay methodology developed by Manton, Patrick, and Stallard (1980) and the extension by Olshansky (1987) may also be viewed, in a sense, as a form of targeting. In this case, however, instead of using as targets mortality schedules from other subgroups of the population, mortality rates from age groups *within* a population subgroup are used as the targets toward which cohorts surviving to older ages in the future are forecasted to approach with time. In effect, the delay model explores as a tool for forecasting mortality the use of varying risks of mortality that occur as a function of age and across time, or cohort heterogeneity. Delay models are dependent on the assumption that each generation will accumulate fewer lifetime hazards at any age, by comparison to previous cohorts that passed through the same ages. The effect of this delayed or slower accumulation of mortality hazards for successive generations is a reduction in the risk of death for a given age range to approximately the risk of death currently observed for a younger age range. This results in continuous mortality declines that are concentrated in increasingly more advanced ages as long as each new birth cohort accumulates fewer risk factors throughout their lives as compared with previous cohorts. The question that remains is how long successive birth cohorts can continue to enjoy more favorable life conditions.

Microanalytic Cause-delay Models. Another version of the cause-delay model is one in which the level of analysis is changed from the cause-specific level to the more detailed direct relation between specific risk factors and their effects on mortality, morbidity, and disability (Manton 1986a). This is done by first modeling the relation between specific risk-factor interventions and their effects on overall survival, and then analytical models are developed to assess the condition-specific probabilities of disability and functional change by age and sex. If the relation between risk factors and mortality is combined with knowledge of the probabilities of disability associated with specific causes, then it is possible to forecast mortality, morbidity, and disability *together*, given various assumptions about how risk factors might change in the future.

The advantage of this method is that it models directly the delay process for degenerative diseases as successive cohorts may be expected to acquire fewer lifetime risk factors from these diseases by comparison to previous cohorts. This methodology is currently in the development stage with respect to its use as a forecasting methodology, however, although it certainly appears to be the next logical extension of the cause-delay methodology originally developed by Manton, Patrick, and Stallard (1980).

Implications for an Aging World

The demography of aging and the mortality and morbidity patterns of the elderly and oldest old have received a considerable amount of attention by the scientific community in recent years because of the importance of these issues to national social programs that are linked to the size and health status of the elderly population. Estimates of the fiscal viability of the nation's Social Security program, for instance, are heavily dependent on forecasts of the size of the population expected to survive to more advanced ages in the coming decades. The future economic viability of other age-entitlement programs such as Medicare are also dependent on forecasts of both the size and relative health status of future elderly cohorts. Yet, official forecasts of mortality that have been made throughout this century have consistently underestimated subsequent mortality declines, thus implying that the estimated cost of social programs that have been linked to population projections made less than just 5 years ago are likely to be underestimates. Moreover, efforts at forecasting population morbidity, or what has been referred to as active life expectancy, have used very simple static component models in which morbidity rates are held constant and applied to forecasts of the population. This raises the question of whether it is reasonable to assume that morbidity and disability rates will remain constant at the same time mortality rates for the major chronic degenerative causes of death are declining rapidly. In this section the implications of the methods and assumptions used to forecast mortality and morbidity are discussed in relation to how social programs that are linked to the size and health status of the elderly population might be influenced by prospective trends in these variables.

Forecasting Mortality

Forecasts of mortality generated by the U.S. Census Bureau and the Office of the Actuary have most often been made at the disease-specific level where separate assumptions were developed for each of ten separate disease categories. The mortality rates forecasted for each disease category were then summed to produce mortality schedules by age and sex, and these were combined with forecasts of fertility and migration for the purpose of forecasting population growth and structure for the United States. The reason given in each study for making forecasts at the disease-specific level was simply that past trends in mortality have been observed to vary considerably by cause of death (for example, see Wade 1987, 8). It was, therefore, presumed that the greatest accuracy could be obtained with the level of aggregation at the disease-specific level, as assumptions about prospective trends in each disease category could then be more closely aligned with recently observed trends in mortality from that cause (or group of causes). Given that trends in mortality rates for the major disease categories have historically changed at different rates in the United States—and frequently these changes have occurred in opposite directions—it would appear reasonable to forecast mortality at the disease-specific level.

What needs to be considered carefully is the reason why forecasts of mortality are made in the first place. With both the U.S. Census Bureau and the Office of the Actuary, the primary reason for forecasting mortality has been to provide the most reasonable estimates of future levels of *overall* mortality that could then be used to forecast population growth and survival, and to generate life tables for the purpose of estimating prospective trends in life expectancy. The goal in making such forecasts has not been based on any particular interest in trends in the health status of the population—the real interest was to generate mortality schedules from all causes of death that when combined with other data could then be used for other purposes—such as forecasting population growth. In retrospect, then, it is possible that forecasts of mortality at less detailed levels of aggregation could have been at least as accurate for forecasting overall mortality rates, if not more accurate, than forecasts made at the disease-specific level (Alho and Spencer 1988).

It is critical to note, however, that forecasts of mortality at a less detailed level of aggregation—say, at the age-specific level from all causes combined—fails to reveal the two aspects of mortality transitions that we are most interested in today from a health care and public policy perspective—changes in the relative distribution of causes of death for the population, and prospective trends in the number of deaths by cause. Regarding the distribution of death, mortality transitions that have occurred in the United States and other developed countries throughout this century have resulted in a redistribution of death from the young to the old. This substitution of causes of death and the ages at which they occur has had an enormous impact on the structure of the health care industry in the developed world, and it has contributed to the economic burdens that are imposed by the presence of chronic degenerative diseases and nonlife-threatening but disabling conditions that often make the last years of life both expensive and unpleasant to live through (Roos, Montgomery, and Roos 1987; McCall 1984). It is the incidence and prevalence of these conditions that will increase rapidly in the coming decades as the population ages, even in light of rapid declines in mortality rates (Greunberg 1977; Kramer 1980). Additionally, forecasts of mortality at the cause-specific level also allow one to estimate prospective trends in morbidity and disability when data are available to make such linkages. Thus, efforts at forecasting mortality today emphasize the disease-specific approach not only because it is a reasonable assumption to make when trends in mortality vary by cause of death, but also because it supplies estimates of other components of mortality and aging that are critical for tracking and forecasting the general health status of the population.

To illustrate the disease-specific approach to forecasting mortality, and to compare forecasting methods, figure 6 provides a comparison of observed (1968–1978) and forecasted (1980–2000) mortality rates from all circulatory diseases (ICDA 390–448) for nonwhite men in the United States for two selected age ranges. With each method, assumptions were made that are believed to be consistent with recently

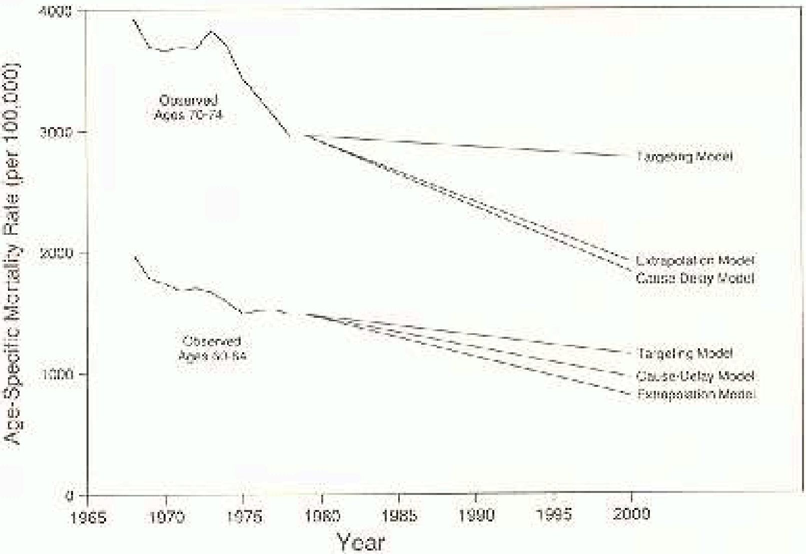

FIG. 6. Observed (1968–1978) mortality rates from all circulatory diseases for nonwhite men in selected age ranges in the U.S. and forecasts to the year 2000 using three different models. Targeting model: Assumes that the mortality rates observed for white men in 1978 will be achieved by nonwhite men by the year 2000. Extrapolation model: Assumes a linear extrapolation of annual average changes in mortality observed from 1968 to 1978. Cause-delay model: Assumes a 5-year delay in mortality.

observed trends in mortality from that cause. This simple comparison of forecasting methods and assumptions illustrates some of the reasons why it is difficult to forecast mortality. First, note that for the group aged 70 to 74 there was a rapid decline in mortality observed from 1968 to 1978, but these declines were interrupted briefly by an increase in mortality from 1970 to 1973. The extrapolation and cause-delay models produced quite similar forecasts in spite of the fact that only the former method actually took into account this period of increased mortality. The targeting model produced results that were much less optimistic by comparison to the other two models, and this leads one to question the appropriateness of the choice of the target population, the assumption about the time frame for the forecasted mortality rates to occur, or the assumptions behind the other two models.

For the group aged 60 to 64 the slope of the mortality declines was less steep than that observed for the older age group, and each forecasting method and related assumptions produced results that were fairly comparable. In this case how does one decide which method and set of assumptions to use? Even a minor variation in one or more of the assumptions for any of the three methods would result in virtually identical mortality forecasts. It should be noted that in the forecasts presented in figure 6 it was assumed that the forecasted mortality rates would be achieved in the year 2000 and that intermediate rates were linearly interpolated. Herein lies the basic problem that all forecasters must face—deciding upon the underlying assumptions.

Given that one has already decided to forecast by age, race, sex, and cause of death, a number of other decisions must also be made with each method. First, a common assumption for all three methods is the decision as to when the forecasted mortality rates will be achieved. That is, how long will it take to arrive at a given target, in what year will a 5-year delay be achieved, and for how long into the future should mortality rates be extrapolated? With extrapolation models decisions are required about which measure of mortality change to use, should the extrapolation be linear or nonlinear, and what should be used as the time frame to extrapolate from. With targeting models one must decide upon which target will be used and in what manner the target will be approached, and with cause-delay models one must decide how long it will take for a given delay to occur. Given that these decisions should be made separately by race, sex, age, and for each cause of death considered, it is easy to envision the likelihood of error regardless of which method is used.

Population Aging

Forecasts of the numbers and proportions of the population aged 65 and over have been revised with each new study made by the U.S. Census Bureau and the Office of the Actuary as assumptions about prospective trends in mortality have been changed. In spite of the fact that assumptions about future trends in mortality are not likely to influence significantly forecasts of the *proportion* of the population which is elderly (Siegel 1979, 19; Crimmins 1986, 193), forecasts of the *size* (or absolute numbers) of the elderly population are very sensitive to assumptions about mortality (for example, see Rice et al. 1983). It is these absolute numbers of survivors to more advanced ages that are used by health care planners and others to forecast population morbidity and disability and to forecast trends in health care usage and expenditures. While forecasts of the proportion of the total population that is elderly have been used to determine what the relative demands will be on the working-age population to support age-entitlement programs such as Social Security and Medicare, even these forecasts are sensitive to changing estimates of mortality and survival. This is an important factor to consider today given the magnitude of recent changes in assumptions about prospective trends in mortality (Rice and Feldman 1983), and the fact that forecasts of the proportion of the older population which is the oldest old (aged 85 and older) *are* quite sensitive to varying mortality assumptions.

Guralnik et al. (1988) illustrated the importance of assumptions about both fertility and mortality to forecasts of population growth by comparing selected U.S. Census Bureau forecasts of the 1980 population made from 1937 to 1975 with actual census counts of the population for that year. It was determined that while assumptions about fertility accounted for the majority of forecasting errors in the studies published before 1970, in subsequent studies the forecasts of mortality were considerably higher than what was actually observed. This produced an underestimate of the total 1980 population, about 20 percent of which was attributable to an underestimation of the population aged 65 and over. It was concluded that there are vast differences in forecasts of the size of the elderly population based on varying assumptions about mortality alone, and that if present trends in mortality continue it is possible that "the needs for increased health care for our older population will be enormous and could overwhelm future health care resources" (Guralnik et al. 1988, 25).

Population forecasts made by the U.S. Office of the Actuary have also been subject to these same kinds of forecasting errors. For example, table 2 provides a comparison of forecasts to the year 2000 of the total United States population and the population aged 65 and over made at different times by the U.S. Office of the Actuary. It is interesting to note first the wide variation in such estimates not just between studies, but also within studies as high or low estimates were provided in each case, except 1974. In the 1957 study, for example, the range between the high and low estimates of the population aged 65 and over for the year 2000 was 5.7 million persons (see column 5). This range was reduced to zero in the 1977 study because only one mortality assumption was adopted, but with the publication of the 1980 study the range increased to as much as 4.6 million persons

TABLE 2
Comparison of U.S. Office of the Actuary Forecasts of the Total Population and the Population Aged 65 and Over for the United States to the Year 2000

Actuarial study no. (Reference)	Forecasts to the year 2000 (in thousands)					
	Total population			Population aged 65+		
	High (1)	Medium (2)	Low (3)	High (4)	Medium (5)	Low (6)
No. 24 (Myers 1948)	124,201	—	241,049	19,025	—	29,308
No. 33 (Myers and Rasor 1952)	254,456	—	210,197	25,829	—	27,979
No. 46 (Greville 1957)	388,444	—	262,516	29,490	—	35,198
No. 62 (Bayo 1966)	323,438	—	301,251	29,577	—	31,756
No. 72 (Bayo and McKay 1974)	—	271,082	—	—	31,033	—
No. 74 (Bayo and Wilkin 1977)	273,975	268,759	258,337	—	32,960	—
No. 77 (Bayo, Shiman, and Sobus 1978)	273,977	268,760	258,339	—	32,960	—
No. 82 (Wilkin 1980a)	279,024	272,985	264,766	34,436	35,998	39,056
No. 84 (Wilkin 1980b)	—	272,989	—	—	35,999	—
No. 85 (Faber and Wilkin 1981)	276,127	273,947	272,327	34,651	36,251	39,409
No. 88 (Wilkin 1983)	280,028	277,353	272,923	34,610	36,338	38,001
No. 92 (Wade 1984)	281,356	277,451	271,901	34,695	36,184	37,599
No. 95 (Wade 1985)	282,716	277,142	270,023	35,235	36,445	37,573
No. 97 (Wade 1986)	282,016	277,479	271,755	34,844	35,884	36,809
No. 99 (Wade 1987)	279,408	275,493	270,593	34,773	35,626	36,415

as alternative assumptions about mortality were again included. In the last four actuarial studies the range of the forecasts of the elderly population declined considerably, because these studies were based on more recent mortality trends in which mortality declines in older ages appear to have slowed down.

While planners may feel comfortable using medium-range forecasts of the population made in any single study as the basis for forecasting nursing home beds, health care expenditures, and other related costs, the variation in forecasts of the elderly population between studies has also been quite large and is a reason for concern. In 1974, for example, the forecast of the population aged 65 and over for the United States in the year 2000 was 31.03 million persons. Within 3 years this was increased to 32.96 million, and in the subsequent two studies in 1980 and 1984 the medium-range forecasts were 36.0 and 36.18 million persons, respectively. This means that within a 10-year time period, from 1974 to 1984, the medium-range forecast of the population aged 65 and over in the United States for the year 2000 was increased by 5.15 million persons, a 16.6 percent increase. Over the same time period the forecast of the total population was revised upward by 6.37 million, thus indicating that about 80 percent of the difference between the two forecasts of the total population was attributable to revised assumptions about survival to more advanced ages (see column 2). This is the case because those who will be aged 65 and over in the year 2000 are already alive, and estimates of the number of people in this age group rely largely on assumptions about survival (although some portion of this difference may be attributable to varying assumptions about migration). In their latest forecast, the U.S. Office of the Actuary once again revised their assumptions—although this time the medium-range assumption for the population aged 65 and over in the year 2000 was 558 thousand less than had been forecasted just three years earlier (Wade 1987). Again, this occurred because the latest study used more recent data on mortality where it appears that mortality declines in older ages may have decelerated.

Given the magnitude of the differences in recently published official forecasts of mortality and survival, and the fact that major revisions in assumptions have occurred over such short time periods (see figures 3 and 4), forecasts of related economic variables that are dependent on baseline population estimates must be changed accordingly. As an illustration of this point, Rice and Feldman (1983) estimated that if age-specific rates of activity and limitation remained constant at 1980 levels, health care costs for the population aged 65 and over would increase from 64.5 billion dollars in 1980 to 90.3 billion (constant 1980) dollars by the year 2000, a 25.8-billion-dollar increase in just 20 years. If the baseline population forecasts for the year 2000 used by Rice and Feldman (1983, 372) are adjusted upward by (1) the percentage difference between the middle-series baseline population forecasts of the population aged 65 and over made by the U.S. Office of the Actuary between 1974 and 1984 (16.6 percent), or (2) the percentage difference between the middle and high series forecasts of the population aged 65 and over for the year 2000 from the 1980 U.S. Office of the Actuary study (8.5 percent), total health care costs forecasted for the year 2000 would be increased to about 105.3 and 98.0 billion dollars, respectively, from the current forecast of 90.3 billion dollars. These represent differences of 7.7 and 15 billion dollars in estimates of health care costs that arise in less than 20 years almost exclusively from different assumptions about prospective trends in mortality and survival.

In a different study, Roos, Montgomery, and Roos (1987) found that forecasts of health care utilization are heavily dependent on forecasts of the size of the elderly population. Using a measure of total health care usage that included hospitalization, nursing home use, and physician services, it was determined that for a sample of the Canadian population the forces of population aging and the postponement of death into more advanced ages from declining death rates will result in a significantly increased burden on the Canadian health care industry over present levels by the year 2000. This is expected to occur primarily because increased proportions of elderly cohorts are forecasted to survive long enough to require the services of nursing homes that are known to be considerably more costly than other types of care for the elderly. These trends in health care costs were extrapolated into the future by assuming that morbidity and disability rates by age and sex would remain constant at present levels (this is referred to as a static component model), and then these rates were applied to forecasts of the population made by Statistics Canada. Given that (1) the population aged 85 and over is one of the fastest-growing segments of the population in Canada and other developed countries, (2) people in this age group are more likely to utilize more expensive long-term care facilities than the rest of the population, and (3) mortality rates have been declining rapidly in these age groups, then even minor errors in forecasts of mortality would, therefore, influence both the forecasts of the size of the population at risk of surviving to older ages and estimates of health care expenditures that are dependent on such forecasts.

The importance of minor changes in assumptions about mortality and survival to forecasts of the size of the elderly population and the calculation of related morbidity, disability, and health care costs, should, therefore, not be underestimated.

Forecasting Morbidity and Disability

Forecasts of morbidity and disability require the consideration of how the incidence and prevalence *and* incidence rates and prevalence rates of the measures of interest might change in the future. The methods and assumptions used to forecast morbidity and disability rates are not the same as those used to forecast the overall incidence and prevalence of morbidity and disability. In order to forecast the incidence and prevalence of measures of morbidity and disability, it is necessary to make assumptions about what the rates of morbidity and disability will look like in the future, and these rates are in turn multiplied by forecasts of the population at risk. This means that such forecasts are dependent on two separate and unrelated sets of assumptions about the future course of trends in population growth *and* public health. To forecast *rates*, one requires either data on trends in morbidity and disability rates to extrapolate from, or a justifiable reason to believe that such rates will change in a given direction in the future. This is equivalent to forecasting the *probability* that morbidity and disability will occur at a given level at a selected moment in time in the future, and it requires knowledge about prospective trends in the health status of the population.

To date the methods used to forecast morbidity and disability are considerably less sophisticated than those used to forecast mortality—for a number of reasons. First, measures of morbidity and disability are highly subjective and amenable to a broad range of interpretation, thus making such measures both difficult to obtain and interpret. In the absence of reliable period or cohort data on morbidity and disability for the United States, there are no sufficient data on trends in these variables that may be used to extrapolate from. Given these two problems, studies that require rates for forecasting the incidence and prevalence of morbidity and disability have, therefore, used static component models in which rates are held constant at present levels and applied to forecasts of the population (Brody 1987; Crimmins 1986; Liu and Manton 1987; Manton and Soldo 1985; Rice et al. 1983; Rice and Feldman 1983; Roos, Montgomery, and Roos 1987). The rationale for this assumption is that at this time there appears to be no sufficient justification for assuming morbidity and disability rates will change in either direction in the near term or far term. In this sense, methods of forecasting morbidity and disability rates have, until recently, never really been developed. Recent research by Manton (1986a) and Liu and Manton (1987), however, have made the first steps in this direction by modeling the complex relation between morbidity and disability, and prospective trends in mortality, and by developing alternative assumptions regarding how rates may change in the future.

While there are insufficient data at this time to justify alternative assumptions about the incidence and prevalence rates of morbidity and disability, there is certainly reason to question the use of static component models. For instance, how reasonable it is to assume that age-specific morbidity and disability rates will hold constant during a time in which age-specific mortality rates are declining rapidly. This concern is particularly important now considering that recent mortality declines have occurred for the population in more advanced ages where morbidity and disability rates are the highest, and for some of the major chronic degenerative diseases that are commonly linked to high morbidity. The key factor here is the linkage between mortality, morbidity, and disability. If mortality rates are observed to decline from a given cause of death that is known to be preceded often by high morbidity, then it appears questionable to assume that morbidity rates from this cause will remain constant. Much depends on why mortality rates from that cause have declined, what the remaining years of life are like for the saved population, and what the relation is between the risk of death from that cause and the risk of morbidity, disability, and death from other causes. The same questions arise for each chronic degenerative disease. Additionally, some of the major causes of morbidity or disability in the population, such as dementia, arthritis, blindness, osteoporosis, etc., are not always life-threatening conditions and have not yet been linked in any systematic way to specific causes of death.

As an illustration of this point, consider the case of cerebrovascular disease (stroke), which has been declining as a cause of death and which has also been linked to high levels of predeath frailty (Manton 1986a). If mortality rates from stroke declined as a result of cohorts surviving to more advanced ages with fewer lifetime accumulated risk factors for that cause, then stroke deaths are either being postponed into more advanced ages, or people at risk of dying from stroke are surviving long enough to die from some other cause. Deaths attributable to stroke may also be declining because of improved survival chances following a stroke (i.e., lower case-fatality rates). In either case it is not possible at this time to determine whether the probability of stroke-related morbidity and disability would increase or decrease with declines in the risk of death from that disease. While it might appear reasonable to assume that a reduction in the risk of death from stroke (or any other degenerative disease) will postpone morbidity and disability into later years and compress it into a shorter time span before death occurs (Fries 1980), it is still not known whether the *duration* of time spent above a disability threshold will also decline (even if morbidity compression occurs), nor is it known how such a process might influence the risk of morbidity and disability from other causes. This is further complicated by the fact that declines in the risk of death from other chronic degenerative diseases, regardless of whether or not they are associated with high predeath frailty, are likely to be associated in a complex fashion with the risk of stroke-related mortality, morbidity, and disability.

If this substitution process were occurring for only one cause of death leaving constant the relation between mortality, morbidity, and disability from other causes, then it might be possible to determine what effects changes in the risk of death from that cause might be for the population. Given that the risk of death from most major chronic degenerative diseases has been declining rapidly in recent decades, however, and that there is uncertainty as to why this is occurring and how it might influence the complex relation between mortality, morbidity, and disability, the task of forecasting these variables at the population level is one that few are willing to tackle. These questions and concerns are the very issues that Taeuber (1976) raised with respect to the hypothetical elimination of degenerative diseases and the substitution of causes of death that would follow, although they are equally valid issues to raise with respect to the *postponement* of death from these same diseases.

While static component models have been widely used in the literature to forecast the incidence and prevalence of morbidity and disability, it is possible to develop somewhat more sophisticated methods of forecasting morbidity and disability rates based on the development of linkages between these variables and mortality. For instance, consider that static component models rely on two basic assumptions. One is that morbidity and disability rates will remain constant at all ages across time, and the second is that these rates will also hold constant within specific disease categories to which such rates may be linked. This assumes implicitly that the relative distribution of causes of death will not change with time, even in light of mortality rates changing at a different pace for each degenerative disease. In other words, prevailing rates of morbidity and disability are applied to forecasts of the population in order to make forecasts of their incidence and prevalence, in spite of the fact that we know that the relative distribution of causes of death is changing rapidly with declining mortality rates. If there is a strong linkage between predeath frailty and subsequent underlying cause of death, then shifts in the distribution of death by cause will alter the morbidity and disability profile of the population. This makes the use of static component assumptions appear to be highly unrealistic for forecasting morbidity and disability.

It is possible to refine forecasts of morbidity and disability by using knowledge about the prevailing linkages between morbidity and disability, and mortality, and apply these to forecasts of the number of deaths from these causes. To do this one would forecast the number of deaths attributable to the major chronic degenerative diseases and causes of death most commonly associated with high predeath frailty, and then apply the risk of morbidity and disability associated with those causes (when available) to forecasts of the number of deaths from each cause. Although this procedure would still make forecasts dependent on the assumption that the disease-specific risks of morbidity and disability from each cause remain constant, it would at least make such forecasts sensitive to the changing distribution of causes of death. If these forecasts were then combined with some of the recent work by Manton (1986a), in which the relation between risk-factor interventions and the risks of mortality, morbidity, and disability is further developed, it would then be possible to make forecasts that are sensitive to both the changing distribution of causes of death and the changing disease-specific risks of morbidity and disability that result from changes in the mortality profile of the population.

Conclusion

Recent interest in the demography of aging and the mortality patterns of the old and very old occurred with the realization that an impending shift in the age composition will create an enormous burden on, among other factors, the funding of age-entitlement programs and health care costs. The recent acceleration of this problem of population aging that has been caused by unexpected and rapid declines in mortality rates from degenerative diseases for the population in more advanced ages has heightened interest in the methods and assumptions used to forecast mortality.

Official forecasts of mortality rates made by the U.S. Office of the Actuary during this century relied heavily on expert judgment and the extrapolation of past trends in age/sex cause-specific mortality rates as their forecasting methods. Data presented here indicate that these extrapolation methods, or at least the assumptions that underlie the use of extrapolation methods, have not been very successful in forecasting observed changes in mortality. The presence of other methods such as targeting and cause-delay appear to be quite promising as alternative methods of forecasting mortality because they are based on mortality transitions that have been observed recently in the United States.

The importance of forecasts of mortality to the future status of social programs that are linked to the size and health status of the elderly population, such as Social Security, Medicare, and forecasts of morbidity, disability, and demand for long-term care facilities, is evident. Recent forecasts of population growth by the U.S. Office of the Actuary have been made after making significant changes in assumptions about mortality and survival with each study. These revised assumptions about mortality were based on the observation that recently observed mortality declines have been much greater than anticipated. The effect of these revised assumptions about mortality has been an increase of the forecast of the population aged 65 and over for the year 2000 of 5.15 million persons between forecasts made in 1974 and 1984, a 16.6 percent increase. Given that morbidity, disability, health care costs, and other related variables tend to increase rapidly with advancing age, an upward adjustment of the population aged 65 and over of 5.15 million persons tends to produce dramatic increases in forecasts of these related expenses.

Regardless of which methods are used to forecast mortality, morbidity, and disability, the aging of the population and the acceleration of this aging process caused by declining mortality in advanced ages, will result in a substantial burden on this nation's health care system, in particular, and other programs related to the size and health status of the elderly population. Similar concerns are valid for other developed and developing countries as well. In spite of claims made by some that morbidity will decline in the future, the complex relation between mortality, morbidity, and disability is just beginning to unfold, and it is too early to tell what the health and economic impacts of recent trends in these variables will be for both the United States and the rapidly aging global population.

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