CHAPTER 27

The Demography of Population Health

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Demographic regimes of low fertility and low mortality in developed nations have been in place for over half a century (Hayward and Zhang 2001). The result is populations with advanced age structures and slow or even negative growth rates. Italy, Greece, Sweden, and Japan, for example, are fast approaching a situation where approximately one in five persons will be 65 years of age or older, and these countries will continue to age (Kinsella and Velkoff 2001). Already, Greece, Italy, and Sweden have populations where there are more elderly than youth aged 0 to 14.

Below-replacement levels of fertility and declining mortality over an extended period of time have led some European and American demographers to warn of impending population declines (Davis, Bernstam, and Ricardo-Campbell 1987), and this prediction has come to fruition. Population declines have occurred recently in Italy and Greece as well as Eastern European nations such as Estonia, Latvia, Hungary, Romania, Russia, and Belarus. Projections by the United Nations predict that the populations of most of Europe and Japan will decline in size over the next five decades (United Nations 1996a, 1996b, 2000a, 2000b). The historical trend toward population aging in developed nations is being echoed in less developed nations, and United Nations projections point to a global convergence in 50 years (Hayward and Zhang 2001; Kinsella 2000; Kinsella and Velkoff 2001; United Nations 1996a, 1996b). Population aging is a worldwide demographic phenomenon.

The aging of populations' age structures, particularly because of dramatic declines in mortality at older ages, has influenced demographers' investigations of recent trends in population health—particularly the linkages between mortality, morbidity, and

disability at older ages (Manton 1990). A key question has been whether declining mortality rates in the older population also signal declining morbidity and disability rates. The answer to this question has substantial implications for whether the sizeable gains in *life expectancy* at older ages are accompanied by an increase in *healthy life expectancy*, i.e., the expected number of years in good health. Investigations of the linkages between mortality, morbidity, and disability lie at the heart of anticipating an aging population's demands on health care systems and health care costs (Manton, Stallard, and Corder 1995, 1998; Murray and Lopez 1996; Robine and Romieu 1998; Waidmann and Manton 2000; World Health Organization 2000). Health expectancies provide information that allows the development of health policies targeted at improving the quality of life rather than simply improvements in the overall length of life. Health expectancies also are useful policy tools in monitoring trends in population health, evaluating disparities across major subgroups within a population, targeting health care policies where they are most needed, and identifying the effects of major interventions and policy changes on both the length and quality of life (Crimmins 2002).

Demographic research on the linkages between mortality, morbidity, and disability has led to new ways of modeling the interaction of these processes and new ways of conceptualizing population health. This research makes clear that while disability, morbidity, and mortality are related, they are not isomorphic concepts. Moreover, changes in these individual-level processes sometimes combine in complex ways to generate changes in population health. Understanding population health necessarily involves understanding the interaction of these major health processes.

Our purpose in this chapter is to provide a conceptual overview of the demographic framework used to examine the linkages between mortality, morbidity, and disability (i.e., the healthy life expectancy framework) and to describe the measures and methods used in modeling these linkages—and, implicitly, population health.[1] We emphasize conceptual underpinnings to better evaluate the major gaps in current knowledge as well as current and *potential* complementarities across key lines of research. We show how demographic models of healthy life expectancy are powerful tools in understanding population health, and we discuss how demographic models might inform individual-level analyses of health disparities within a population. We begin by reviewing the conceptual issues underlying research on the association between mortality change and population health.

IMPLICATIONS OF MORTALITY DECLINES FOR POPULATION HEALTH

Between 1950 and 1955 and 1990 to 1995, the world experienced dramatic improvements in mortality rates (Hayward and Zhang 2001). The infant mortality rate fell from 156.0 to 62.0. Life expectancy improved from 45.1 to 62.2 years for males and 47.8 to 66.5 years for females. Mortality declines were most dramatic in less developed regions of the world due to the high levels of mortality observed from 1950 to 1955.

[1] A number of recent reviews are available elsewhere that provide in-depth summaries of health expectancy research findings and methods (Crimmins 1996, 1998; Hayward and Zhang 2001; Kinsella 2000; Kinsella and Velkoff 2001; Laditka and Hayward 2003; Waidmann and Manton 2000).

Improvements in mortality rates, particularly in developed nations, have spawned a range of scientific activities designed to gauge the implications of mortality declines for the health and functioning of the surviving populations. The United Nations recognized the importance of this issue in its *Principles for Older Persons*, stating that the goal of scientific advancement must be "to add life in the years that have been added to life" (United Nations 1991). Does declining mortality over a lengthy historical period signify that the members of a population are living longer, healthier lives, i.e., is morbidity being compressed in the life span (Fries 1983)? Or, do mortality rate improvements lead to the lengthening of poor health prior to death?

These questions are at the center of an ongoing debate since the 1980s, in part fueled by contradictory empirical evidence. During the 1970s and into the early 1980s in the United States, reported disability prevalence increased at the same time that mortality rates declined (Crimmins, Saito, and Ingegneri 1989; Verbrugge 1984). An exception to this overall pattern was for persons aged 75 years and older, for whom disability prevalence was relatively stable. Evidence based on the National Long-Term Care Survey for the 1980s and 1990s, however, pointed to an overall decline in disability prevalence for the U.S. population aged 65 years and older (Manton, Corder, and Stallard 1993; Manton, Stallard, and Corder 1995, 1998). Although overall disability prevalence declined during the 1980s and early 1990s, the NLTCS data also showed that changes in specific types of disability prevalence were not consistent (Crimmins, Saito, and Reynolds 1997). Patterns of disability onset and improvement in the 1980s, the transition forces determining disability prevalence, were also inconsistent, clouding whether the changes reflected a historical trend toward improving health (Crimmins, Saito, and Reynolds 1997).

Building on Manton's work using the National Long-Term Care Survey, Crimmins, Saito, and Reynolds (1997) analyzed data from the Longitudinal Study on Aging and the National Health Interview Survey from 1982 to 1993 for persons 70 years of age and older. Their work provided additional evidence of declining disability prevalence in the 1980s, although they found less support for the idea that this was part of an overall trend toward improved health. Schoeni, Freedman, and Wallace (2001) extended Crimmins' analysis of the NHIS data to 1996. They reported declines in disability prevalence between 1982 and 1986 but did not observe additional improvements between 1986 and 1992. Disability prevalence then fell slightly between 1992 and 1996. Schoeni and his colleagues (2001) also noted that disability prevalence improvements, when observed, occurred for people needing help with routine care activities (mild disability) rather than people needing help with personal care, an indicator of more severe disability. Moreover, much of the improvement in disability was concentrated among well-educated persons.

An important confound in this debate is the lack of consistent, high quality, and nationally representative data for a lengthy time period (Hayward and Zhang 2001). The National Health Interview Survey for the United States is the longest available time series of morbidity and disability data. However, design and measurement changes make it challenging to use the NHIS data to make strong inferences about historical trends in disability and morbidity. Comparable time series data sets documenting trends are not available outside the United States. United States–based longitudinal panel studies such as the Longitudinal Study of Aging, the National Long-Term Care Survey, the Survey of Income and Program Participation, and the Health and Retirement Survey have also been used to assess recent changes in morbidity and disability. Survey

differences in measurement and design again frustrate researchers who try to reconcile differences in results. A recent study by Freedman, Martin, and Schoeni (2002) presented an evaluation of the quality of eight American data sources used in recent studies of population-level trends in disability. Based on a variety of criteria, the surveys were rated as good (2), fair (4) and poor or mixed (2) for assessing trends. Based only on those surveys rated fair or good, the surveys varied substantially in their estimates of the percentage declines in disability. For example, when disability was defined using self-reported activities of daily living, estimates of disability change ranged from -1.38% to $+1.53\%$ per year.

While methodological challenges make it difficult to ascertain trends in population health, this is only one source of confusion. Conceptually, the association between mortality changes and health changes in the surviving population is not as straightforward as one might think (Crimmins 1996; Crimmins, Hayward, and Saito 1994), and this partially accounts for the lack of clarity in the research literature. If mortality improvements occur primarily among persons already beset by health problems, a greater number of people will survive in poor health. This will lead to higher rates of prevalence of a health problem in a population (e.g., disability), and it will lengthen the years of life with the health condition. However, if mortality rate improvements occur because of delays in the onset of diseases and functional problems, then population health will improve. Thus, prevalence rates and life expectancy with a health condition will decline.

The mixture of fatal and nonfatal conditions in the population adds additional complexity to this relationship. For example, a substantial portion of functional problems in the older population is due to arthritis, a nonfatal condition, while cardiovascular diseases are also an important precursor of functional problems (Verbrugge and Patrick 1995). Improvements in cardiovascular mortality would potentially reduce related functional problems but would have little direct impact on functional problems due to arthritis (Hayward, Crimmins, and Saito 1998). Understanding how mortality change is likely to influence population health thus necessitates knowledge of where in a major disease process health improvements are occurring, as well as the changing mix of fatal and nonfatal disease conditions in the population. Further, progress in fighting some diseases may be more advanced than for others. Indeed, this is to be expected given national health care and research priorities and uneven scientific advances across the range of disease conditions. These factors, in addition to changes in the social and economic characteristics of populations, contribute to uneven changes in disease and disability prevalence—change that need not be uniformly downward (Bonneux et al. 1994; Crimmins 1996; Hayward, Crimmins, and Zhang, in Press). As Crimmins (1996: S224) argues, when mortality rate improvements occur, an increase in disability prevalence is an:

> expected epidemiological stage that can occur when increases in life expectancy are greater than reductions in the incidence of health problems. In addition, at any one time we are likely to see improvements in some indicators of health and not others, and improvements in some age groups and not others.

A Conceptual Framework of Population Health

Under the auspices of the World Health Organization, a conceptual framework of population health was proposed that integrates the concepts of morbidity, disability,

and mortality (Manton and Soldo 1985; World Health Organization 1984). The framework is based on a life table survival model where the overall survivorship in a life table cohort is decomposed into the proportion of a cohort that survives without one of three basic health events occurring—morbidity, disability, or death. Figure 27.1 shows the life table framework for a hypothetical population.

The vertical axis in Figure 27.1 identifies the probability of surviving (expressed in terms of a standard population) to a given age without one of the three basic health problems occurring. The areas in the figure refer to the average probability of being in a given health state at a given age. For example, the area beneath the morbidity curve (A) represents the probability of being free of morbidity at each age. By definition, the areas also describe the person-years spent in each health state by a life table cohort. Area C, for example, represents the person-years spent disabled while the combined areas of A and B represent disability-free person-years. Areas B and C combined represent the person-years lived with a chronic condition (morbidity and disability), while area A represents disease-free person years.

Using this life table model, demographers have developed a general summary measure of population health (i.e., healthy life expectancy) that explicitly integrates the mortality and disability (or morbidity) experiences of the population. Conceptually, the measure refers to the length of time that an average individual can expect to be healthy (according to some set of criteria) or unhealthy over the life cycle. This measure captures the *life cycle* burden of a health condition for a population (or population subgroup), i.e., the health-related quality of life for the average person in a population in relation to the overall length of life. In the context of the model shown in Figure 27.1, three indicators make up a family of population health indicators: total life expectancy, disease-free life expectancy, and disability-free life expectancy. The indicators can be interpreted independently of each other, e.g., how disease-free life expectancy or disability-free life expectancy is changing in the population. This type of interpretation responds, for example, to questions about the implications of public health policies or new medical interventions for enhancing specific aspects of population health. The measures can also be interpreted together, e.g., how disease-free life expectancy and disability-free life expectancy change as total life expectancy grows. In this way, investigators can assess whether declines in mortality rates lead to the compression of morbidity and disability

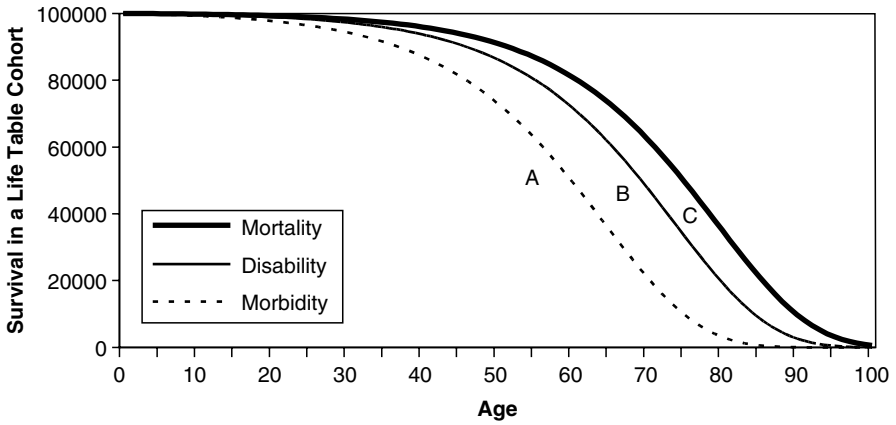

FIGURE 27.1.

during particular time periods and whether different population groups have similar overall survival but differ in terms of life cycle morbidity and disability experiences.

This conceptual framework offers a number of advantages for examining trends in population health, particularly in comparison to examining trends in disability prevalence as described above. Descriptively, the life table approach provides a means to compare population groups' health while controlling for differences in age composition. The framework also provides the means to explicitly address the question of whether declining mortality results in the expansion or compression of the period of life with disability and morbidity. Overall survival curves can be compared across historical periods, as can changes in the person-years of morbidity and disability. By extension, researchers can compare population groups' trends in health and identify the demographic conditions and trends underlying those changes.

The life table measure of healthy (and unhealthy) life expectancy differs from a prevalence rate of health conditions that captures the percentage of a population experiencing a health problem at a point in time. Prevalence reflects not only current experience but also captures health experiences at younger ages that have left their mark on the surviving population (Freeman and Hutchinson 1980; Hayward et al. 2000a; Schoen 1988). For example, blacks' higher prevalence of hypertension during middle age compared to whites' prevalence indicates a higher rate of onset among blacks prior to middle age (Hayward et al. 2000). Prevalence rates also benchmark the *societal* (or a group's) burden of disease at a particular time point, because prevalence rates are inherently properties of groups and not individuals.[2]

MEASURING THE HEALTH OF THE POPULATION

Health is a complex concept denoting compromised well-being stemming from disability and disease, and mental, physical, and emotional problems (Murray and Chen 1992). The main ways in which demographers measure health in the life table model of population health are primarily based on concepts from the World Health Organization's 1980 *International Classification of Impairments, Disabilities, and Handicaps* (ICIDH) (World Health Organization 1980) and Nagi's schemes (1989; 1991; Verbrugge and Jette 1994), adopted by the Institute of Medicine.[3] Conceptually, the WHO and Nagi schemes overlap significantly (Verbrugge and Jette 1994). The ICIDH and Nagi

[2] The individual analogue of a prevalence rate is whether a person has a health condition. Associations between the presence of a health condition and a predictor variable by definition summarize the historical relationship between some predictor variable (e.g., socioeconomic status) and the presence of a health condition prior to the time of observation.

[3] The World Health Organization introduced the *International Classification of Functioning, Disability, and Health* (ICF) in 2001 (World Health Organization 2001). The ICF's changes in terminology make it difficult to explicitly compare to Nagi's scheme and Verbrugge and Jette's disablement process, although the ICF's conceptual framework embraces Verbrugge and Jette's ideas of how extra- and intraindividual factors influence environmental demands and individuals' capabilities. The ICF uses two umbrella terms, functioning and disability. Functioning encompasses body functions, activities executed by the individual, and participation in a life situation. Disability refers to the impairment of physiological functions, organ systems, activity limitation, and participation restriction. Because demographers have relied almost exclusively on the earlier classification schemes, our discussion focuses on these health concepts.

schemes are the basis of Verbrugge and Jette's (1994: 3) framework of disablement which shows:

> the impacts that chronic and acute conditions have on the functioning of specific body systems and on people's abilities to act in necessary, usual, expected and personally desired ways in their society.

Roughly hierarchical, disablement typically begins with the onset of a chronic disease that may have a cascading effect so that a loss of physical or mental function occurs (e.g., impaired mobility, restrictions in body actions that involve various motions or strength, the loss of short-term memory). If functional problems make it difficult or impossible to perform normal social activities, then disability results. At the individual level, this pathway is neither unidirectional or deterministic. Changes in the family, social, community, and health care environments can alter the disablement experience. Persons with a chronic disease, for example, might regain functional abilities through medical treatment. Disabled persons could become nondisabled through the introduction of devices that provide assistance. Conversely, persons with a functional problem might experience hastened disability through the loss of their spouse—the spouse may have made it possible for a person with a functional problem to perform normal social activities.

This conceptualization corresponds roughly to the idea in the gerontological literature that individual aging refers to changes in structure and function. An important feature of this conceptualization is the lack of direct correspondence between disablement and mortality. Mortality *reflects* the aging process of "changes in structure and function" but it does not *define* the aging process. One way to think about the lack of direct correspondence is the sensitivity of mortality to temporal and environmental conditions versus aging processes. For example, how long persons with heart disease live is highly contingent on temporal and proximate conditions such as the availability of emergency services, scientific innovation in the treatment of heart disease, and the differential application of medical procedures, say, across race or sex groups.

Demographers' use of the ICIDH or disablement framework has resulted in a class of measures describing the health of the population.[4] *Disease-free life expectancy* is the expected number of years the average person in a population would expect to live free of disease (or a specific disease depending on the model) if current patterns of morbidity and mortality were to continue over time. Peeters and colleagues (2002), for example, calculated the number of years of life free of coronary heart disease (and with the disease) for the Framingham Heart Study cohort. Calculations for heart disease life expectancy show that life with heart disease can be quite lengthy—about six [D1]years for men aged 50. Other applications of this population health measure include the expected number of years lived with dementia in the Dutch population (Witthaus et al. 1999) and lung cancer expectancies for the U.S. population (Manton and Stallard 1988).

Disability-free life expectancy is the expected number of years of life free of a chronic health condition that limits the normal social activities of life. A number of studies focus on disability defined in terms of household management (measured by instrumental activities of daily living or IADLs) and the ability to provide self-care (measured by activities of daily living or ADLs) (Crimmins, Hayward, and Saito

[4] European demographers use a slightly different classification scheme, but the terminology is similar.

1994; Katz 1983; Katz et al. 1983).[5] IADLs refer to problems such as managing money, using the telephone, preparing one's own meals, and doing light housework. ADLs refer to self-care problems such as toileting, bathing, dressing, eating, and getting in and out of bed. Although item wording varies across survey instruments, ADLs and IADLs are among the main ways that health surveys measure disability. Disability-free life expectancies have been calculated for the United States elderly population (Crimmins, Hayward, and Saito 1994; Rogers, Rogers and Branch 1989; Rogers, Rogers, and Belanger 1989), as well as for key population subgroups defined by race, sex, and education (Crimmins, Hayward, and Saito 1996; Hayward, Crimmins, and Saito 1998).

Other studies reference disability in terms of the ability to perform major social roles (e.g., work and school) or normal activities. These measures have been used to document disability-free life expectancy for a number of countries around the world (Robine and Romieu 1998; Robine et al. 1995; Robine, Romieu, and Jee 1998), trends in disability-free life expectancy in the United States (Crimmins and Saito 2001; Crimmins, Saito, and Ingegneri 1997) and OECD countries (Robine, Romieu, and Jee 1998), race/ethnic, educational and gender differences in disability-free life for the U.S. population (Crimmins and Saito 2001; Hayward and Heron 1999), and social inequality in disability-free life for France (Cambois, Robine, and Hayward 2001), to name only a few studies. Crimmins and Cambois (2002) recently reviewed a range of studies that addressed socioeconomic differentials in healthy life expectancy in European countries, Canada, and the United States. A common finding was that socioeconomic differentials in healthy life expectancy exceeded differentials in total life expectancy.

Health Adjusted Life Expectancy measures health by adjusting life expectancy according to weights assigned to particular health states (Mathers, Robine, and Wilkins 1994; Wolfson 1996). The measure is intended to identify the gap between life in perfect health and life where individuals are beset by ill health. Weights for health states typically range from zero (dead) to one (perfect health). Weighting systems are frequently controversial (Barendregt, Bonneux, and Van der Maas 1996; Mathers, Robine, and Wilkins 1994; Waidmann and Manton 2000). What does perfect health mean? Who judges the assignment of values to particular health problems? Do the values reflect a theoretical premise, empirical evidence, or expert opinion? Given these questions, health-adjusted life expectancies have been less frequently examined in the scientific literature.

This class of measures, however, has become a useful policy tool in evaluating the burden of disease internationally. For example, health-adjusted life expectancies have been used to gauge the burden of illness consequences of eliminating particular diseases from the population (Manuel et al. 2003; Manuel and Schultz 2004; Nolte and McKee 2003). For example, what are the expected years of life if diabetes was eliminated as a health problem? The World Health Organization's Global Programme for Evidence on health policy estimates disability-adjusted life expectancy (DALE) to identify a country's expected years of healthy life. The DALE is calculated by weighting the years of ill health according to severity and then subtracting this figure from the total expected life expectancy. The difference is the equivalent years of healthy life. The World Health Organization ranks countries based on these measures, showing, for example, that the years lost to disability are substantially higher in poorer countries rather than developed

[5] Studies that define disability in terms of IADLs and ADLs often refer to disability-free life expectancy as active life expectancy (Crimmins, Hayward, and Saito 1994; Crimmins, Hayward and Saito 1996; Hayward, Crimmins, and Saito 1998). Some researchers reserve the term disability-free life expectancy for health problems that curtail activities in major social roles such as work and school.

countries. This pattern is due to the fact that limitations such as injury, blindness, paralysis, and the functional consequences of tropical diseases such as malaria affect children and young adults. A recent study reported that people in developed parts of the world lose only about 8% of their lives to disability compared to 18% for persons living in the poorest countries (Mathers et al. 2001).

MEASUREMENT AND METHODOLOGICAL ISSUES IN MODELING HEALTHY LIFE EXPECTANCY

Systematic comparisons of health expectancies across studies are challenged by the quality of the health measures and study designs (Freedman et al. 2002; Hayward and Zhang 2001), the operational definitions of the health measures (Crimmins 1996), and the various methods used to calculate health expectancies (Laditka and Hayward 2003). Not surprisingly, this makes it difficult to obtain consistent estimates of the expected years of healthy (and unhealthy) life in a population.

Because estimates of healthy life expectancy reflect assumptions about measurement and modeling, they should be treated as *indicators* of population health rather than an accurate accounting of health experience. As noted earlier, a life table *model* generates health expectancies and thus the expectancies are subject to the model's constraints and assumptions. This makes it difficult to compare exact numerical estimates of healthy life expectancy across studies. Frequently, researchers focus on the relative proportion of life that is healthy (or unhealthy) or the consistency of group (e.g., sex, race, or period) differences in healthy life expectancy.

Efforts to harmonize measures and methods have been promoted by the International Network on Healthy Life Expectancy (known by its French acronym of REVES—Réseau Espérance de Vie en Santé). Recognized by the World Health Organization, REVES is a grassroots scientific organization dedicated to promoting international consistency in the design, measurement, and calculation of health expectancy measures used in monitoring population health (http://www.prw.le.ac.uk/reves/). Illustrative of these efforts is the REVES project begun in 1997 under the auspices of the European Health Monitoring Programme and supported by the European Commission. The project's aim has been to set up a coherent set of instruments to measure health expectancies for the European Union. Seven research teams representing six countries and many academic disciplines have been involved in this effort (Robine, Jagger, and Egidi 2000). The project teams have made preliminary recommendations on 10 instruments documenting chronic morbidity, functional limitations (physical, sensory, and cognitive), disability, self-perceived health, and mental health. The REVES report is under review for comment by European policymakers.

Efforts such as those by REVES and the World Health Organization's Global Burden of Disease project (Mathers et al. 2002; Murray and Lopez 1996) are particularly important for the ongoing monitoring of population health. Cross-sectional surveys fielded repeatedly over some period typically provide the monitoring data. The National Health Interview Survey for the United States, for example, provides annual health data for the population since 1969. Similarly, the National Long-Term Care Survey provides information about the health of Medicare-enrolled Americans aged 65 years and older for 1982, 1984, 1989, 1994, and 1999.

Increasingly, however, researchers are utilizing longitudinal panel data to develop healthy life expectancy measures reflecting the complexity of age-related *changes* in health. Longitudinal panel data reveal that as persons age, they not only experience the onset of disability but they also recover from disability (Crimmins, Hayward, and Saito 1994; Land, Guralnik, and Blazer 1994; Rogers et al. 1989).[6] Onset and recovery are typically inferred from respondents' reports of current disability measured at multiple times in the course of the panel study. For example, a respondent may report being disabled at the time of a baseline interview but then report being nondisabled at a subsequent interview—and perhaps being disabled again at some future date.

An issue not well addressed in the literature is that some of the traditional health measures, particularly measures of disability (e.g., ADLs, IADLs, and work and domestic disability), do not translate well in a conceptual sense to a longitudinal design or longitudinal analysis (Crimmins 1996; Crimmins and Hayward 1997). At any particular survey wave, for example, reported disability is not exclusively the outcome of a biomedical process, but it is also an outcome of dysfunction (organ system or bodily function) *and* the environmental demands on functioning. Changes in a person's reports of disability across interview waves may reflect differences in the level of social and environmental support as well as changes in physical or mental functioning. For example, marital status changes or the addition of technology can result in changes in individuals reporting that they need or get less help with tasks without improvements in the underlying biomedical process.

This uncertainty points to the importance of differentiating functional changes from environmental changes in longitudinal health surveys in order to understand how changes in healthy life expectancy occur (Crimmins and Hayward 1997). For example, a decline in the years of disabled life could be a consequence of reductions in disabling diseases such as cardiovascular diseases and arthritis. Declines might also be attributable to the reduction of environmental challenges and the introduction of new technologies and medications. In the latter case, reductions in the expected years with disability are not a reflection of changes in health as we typically think of them. Rather, such declining disability reflects changes in the ability to cope with poor health.

Another factor contributing to difficulties in making cross-study comparisons of healthy life expectancy is the types of life table approaches used in modeling healthy life (see Laditka and Hayward [2003] for a review of the life table approaches' underlying assumptions, data requirements, and comparative advantages). A large number of studies of trends in healthy life expectancy rely on a prevalence-based life table method, often referred to as the Sullivan method (Sullivan 1966, 1971). Much of the impetus for using the Sullivan method to monitor trends in population health stems from its relatively straightforward data requirements—prevalence rates of health conditions and mortality rates for the population. Mortality rates are typically obtained from a country's statistical agency charged with providing information about the vital statistics of the population. Prevalence rates of health conditions are usually obtained from cross-sectional health surveys. These surveys are increasingly common around the world, and they are relatively inexpensive to field (compared to longitudinal panel surveys). The sample sizes of these surveys also yield highly reliable prevalence estimates. Robine and

[6] This has led to the use of multistate life table methods in calculating healthy life expectancy, because this approach explicitly allows for age-related declines and improvements in health (Laditka and Hayward 2003).

collaborators (1995) report that a growing number of countries are using the Sullivan method to monitor changes in population health.

However, a potential problem using the Sullivan method for examining changes in population health is its insensitivity to dramatic swings in disability and mortality. During periods of rapidly improving survival, for example, the Sullivan method underestimates improvements in healthy life expectancy (Barendregt, Bonneux, and Van der Maas 1994) relative to overall gains in survivorship. However, when changes in health and mortality are relatively smooth, a situation that is characteristic of more recent shifts in population health, the Sullivan method appears to provide realistic scenarios of long-term trends (Mathers and Robine 1997).

With the increased availability of longitudinal data on health changes, researchers have begun to use multistate life tables (and most recently microsimulations) to model the interactions of morbidity, disability, and mortality (Crimmins, Hayward, and Saito 1994; Laditka and Wolf 1998; Land, Guralnick, and Blazer 1994; Rogers, Rogers, and Branch 1989; Rogers, Rogers, and Belanger 1989). Estimates of healthy life calculated by the Sullivan method and the multistate model are difficult to compare directly because of the models' assumptions and the fact that they often use different sources of data (e.g., cross-sectional surveys compared panel studies). An advantage of the multistate model, however, is that it can be used to better assess the underlying causes of changes in healthy life expectancy and the prevalence of health conditions in the population. For example, Crimmins, Hayward, and Saito (1994) used a multistate life table model to demonstrate how healthy life expectancy (defined in terms of ADL and IADL disability) and prevalence respond to changes in the incidence rates governing declines and improvements in health, as well as changes in health-specific mortality. Hayward, Crimmins and Saito (1998) used a similar approach to show how healthy life expectancy is affected by the elimination of several major causes of death.

Although the multistate model has many desirable properties compared to the Sullivan method (Laditka and Hayward 2003), a potential drawback of the multistate method for monitoring trends in population health is its reliance on longitudinal data as inputs to the life table. The limited amount of longitudinal data for lengthy historical periods has clearly inhibited the use of the multistate method to investigate population health trends. Even if such data were available, however, potential methodological problems warrant serious consideration. For example, because longitudinal data are typically obtained from panel surveys, the reliability of the incidence rates of health change—the inputs for the multistate model—are potentially problematic because of the sparse numbers of health events at certain ages and for some population subgroups. The implications of sample attrition for incidence rates are also poorly understood, especially given that attrition may be related to largely unmeasured biomedical processes. Additional methodological research is needed to understand the sensitivity of the multistate model to design and measurement limitations of longitudinal panel surveys.

SOME IMPORTANT LESSONS OF DEMOGRAPHIC MODELS OF POPULATION HEALTH

An important outcome of demographers' investigations of population health has been the understanding that mortality, morbidity, and disability are related but not iso-

morphic concepts. An individual may contract a fatal disease condition, for example, but need not die from that cause (Manton and Stallard 1988). Moreover, for some diseases such as heart disease, individuals may live with the disease for many years before death (Peeters et al. 2002). Disability is not necessarily a permanent condition nor is it a condition that inevitably precedes death in the older population (Crimmins, Hayward, and Saito 1994, 1996; Rogers, Rogers, and Branch 1989a; Rogers, Rogers, and Belanger 1989b). Moreover, disability is associated with both fatal and nonfatal chronic conditions, so severe disability is not necessarily the final stage of poor health prior to death (Crimmins, Hayward, and Saito 1994; Verbrugge and Patrick 1995). The key point is that death is not always the outcome of an evolutionary process wherein individuals contract a fatal condition, the condition induces functional problems and disability, and when advanced, the condition results in death. The process can be fairly complex and is not obvious.

This complexity carries over to population subgroup differences in the processes defining population health. Crimmins et al. (1996) showed, for example, that men aged 70 years and older were more likely than women to die across the full range of functioning problems (although high levels of chronic health problems attenuated the sex effect somewhat). Men were also more likely to recover from functioning problems than were women. Women, however, experienced drastically higher rates of functional decline than did men. Sex appears to affect mortality and disability in the opposite directions in that women live longer than men, but they also live more years with functional problems.

At present, attention to subgroup differences in population health processes is restricted largely to race and sex groups. A handful of studies have also documented educational differences in population health processes (Crimmins, Hayward, and Saito 1996; Hayward, Crimmins, and Zhang, in Press; Land, Guralnick, and Blazer 1994; Zimmer et al. 1998). Generally, poorly educated persons appear to have higher rates of disability onset, as well as higher rates of death among persons without functioning problems. Once functioning problems occur, however, there is less evidence of an educational effect on mortality. The consequences of education's effects on the transitions making up the process are that education is associated with an increase of both total life and disability-free life and a compression of the period of life with functional problems.

In many ways, demographic models of population health are important starting points for explanatory analyses of health and mortality (e.g., see the demography of health chapter 26, "Health Demography," chapter 10, "Adult Mortality," in this *Handbook*). At a basic level, demographic models illustrate the difficulties confronting cross-sectional studies of health in making strong inferences about causal associations. For example, the association between education and respondents' reports of disability in a cross-sectional survey could reflect (prior) educational differences in the onset of disability, recovery from disability, and survival with (and without) disability that have left their mark on the surviving population (Hayward et al. 2000). Without understanding how education is associated with each of the transitions constituting the underlying process, interpretation of the cross-sectional association is ambiguous by definition.

This problem points to the need for longitudinal panel [D2]studies of health that take into account the underlying processes generating the observed health measure. Ideally, researchers should directly model the associations between explanatory variables and each of the transitions, but data limitations (the lack of longitudinal data, sparse data problems) necessarily limit the feasibility of this argument—hence the frequent reliance on cross-sectional data. In the face of data limitations, a more careful

conceptualization of the health process is called for to aid in interpreting the cross-sectional associations between predictor measures and the health outcome.

Despite the difficulty of approaching population health via individual-level health processes, a growing number of individual-level studies are examining health transitions. However, these studies are typically restricted to subsets of transitions (e.g., the onset of a health condition) (Freedman and Martin 1999; Hayward et al. 2000) and rarely focus on the full set of transitions defining the interplay between morbidity, disability and mortality (a recent exception is Zimmer et al. [1998]). A number of individual-level explanatory studies of health transitions have focused on the ultimate health event—mortality. Morbidity is not considered explicitly, and the assumption of isomorphism between morbidity and mortality is implicit. This results in potentially ambiguous interpretations of how explanatory variables are associated with the process leading to death. For example, as noted above, demographers have documented that education is negatively associated with the onset of functional problems and negatively associated with recovery but does not appear to have a strong association with mortality among persons with functioning problems. This suggests that education's frequently documented association with mortality largely reflects its association with the onset of health problems but has less to do with the mitigation of the fatal consequences of a health problem.

Demographic models of population health, therefore, are an important first step in laying the groundwork for explanatory models of health. Demographic models are useful in identifying health trajectories that are made up of morbidity, disability, and mortal events. These models also are important in evaluating key subgroup differences in population health and how specific morbidity, disability, and mortality experiences give rise to overall differences. The demographic models, in turn, help to ground the development of theoretical models and explanatory analyses that closely articulate with the interplay of morbidity, disability, and mortality.

CONCLUSIONS

Demographic models of population health combining morbidity, disability, and mortality are a scientific response to post-World War II trends in population aging in developed nations. Population aging has brought about greater demands for health care and old age Social Security as proportionately larger numbers of older persons make up the population. Not surprisingly, concerns about whether longer life signals better or worse health have led to population health monitoring systems and an ever expanding body of research.

Sullivan (1971) provided the first calculations of healthy life expectancy in 1971. Since that time, health expectancies have been calculated for numerous countries—both developed and developing—and the methods, and measures, as well as the associated scientific debates, have become increasingly sophisticated. Recently, the International Network on Healthy Life Expectancy (REVES) published a book, *Determining Health Expectancies* (Robine et al. 2003), which provides a detailed look at how health expectancy research and methods have evolved in the scientific community.

Health expectancy research has contributed significantly to the current understanding of the recent trends in population health. For example, this research has clarified that different components of morbidity—disease, disability, and self-perceived health—need not move in the same direction at the same time (Crimmins, Saito, and Reynolds 1997; Freedman and Martin 1998; Manton, Corder, and Stallard 1993). As Crimmins

(1996) notes, some of these indicators may rise during periods of falling mortality, a natural (although not necessarily inevitable) part of the epidemiological transition. Rising disability is not necessarily a signal of the failure of policies aimed at enhancing population health. Rather, this trend may be a sign of success. Although the evidence must still be verified, health expectancy research suggests a shift in the United States in the distribution of disability levels toward the less severe problems that accompanied the decline in old age mortality in recent decades.

Furthermore, health expectancy research has begun to clarify how major population subgroups differ in their morbidity, disability, and mortality experiences. Frequently population subgroups' health experiences differ in unexpected ways and may be masked by using prevalence rates of health and mortality rates as benchmarks. Demographic models' superior descriptions of how health problems unfold in population subgroups are particularly useful in helping refine theoretical arguments underlying health disparities. Health expectancy research points to the importance of carefully delineating the fundamental transitions defining population health, evaluating where in a given process groups differ, and then bringing multivariate techniques to bear in analyzing these transitions to understand the causal factors involved. This articulation between demographic models and individual-level explanatory models holds considerable promise for a more sophisticated understanding of the fundamental causes of population-level health disparities.

Health expectancy research has considerable scientific momentum. Globally, policymakers and researchers are engaged in new partnerships aimed at monitoring population health. This has led to an increase in the number of countries fielding health surveys and a sustained commitment within countries to field health surveys over time to monitor health trends. Within the scientific community, demographers and other health scientists are engaged in informative scientific debates over health expectancy methods and measures, investigating how different facets of morbidity interact and change over time, and assessing disparities in the health experiences of their nation's population. These activities are frequently collaborative, involving teams of researchers from multiple disciplines and from multiple countries.

Health expectancy research has come a long way since Sullivan first calculated an index of population health in which morbidity and mortality were integrated. Clearly, however, the scientific fervor surrounding substantive and methodological debates points to additional future advances in understanding the sources of change in population health and the extent to which these changes are shared within a population. This research will take place against a demographic backdrop of global population aging, scientific and technological improvements in combating disease, improvements in educational attainment, and the social capacity for good health in populations—factors that are likely to make population health a moving target. Thus, the epidemiological transition associated with population aging is far from complete, making it difficult to anticipate future changes in the burden of disease.

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