Long-Term Trends in Life Expectancy and Active Life Expectancy in the United States

KENNETH G. MANTON
XILIANG GU
VICKI L. LAMB

THREE IMPORTANT FEDERAL health policy issues being debated in the United States are: (1) the long-term stability of the Social Security Old-Age and Survivors and Disability Insurance (OASDI) program; (2) the costs of the expansion of Medicare mandated by the Medicare Modernization Act (MMA) of 2003 to include an outpatient prescription drug benefit starting in 2006 (i.e., Medicare Part D) and efforts to improve the health outcomes of Medicare-reimbursed health care (Miller 2005); and (3) recent and projected rapid increases in Medicaid expenditures due to the growth of the US population aged 85 and older, many of whom require long-term care. Demographic factors underlying these debates include: increases in life expectancy at later ages in the US population owing to continuing declines in heart disease, stroke, and, more recently, cancer mortality; the growth of the US elderly and oldest-old populations; and the large size of the post–World War II baby boom cohorts that become eligible for Social Security and Medicare starting in 2011.

Medicare is a health insurance program for people aged 65 and older, people under age 65 with certain disabilities, and people of all ages with end-stage renal disease. Medicaid is the health care insurer of last resort for those persons with significant (and often long-term) health care needs whose social and economic resources have been exhausted. Clearly, demographic and health conditions in the United States have changed dramatically since the Social Security system was instituted in 1935 and the Medicare and Medicaid systems were instituted in 1965. Yet many health policy analysts fail to take into account long-term changes in the health and functional status of the beneficiary population in analyses of both sets of programs. Equally they fail to directly link the effects of improved health and func-

tioning generated by Medicare and Medicaid program investments with their effects on the socioeconomic status and life expectancy of elderly Social Security Administration (SSA) beneficiaries (Manton 2005b). This is problematic given the significant improvements in both the health and functional status of the US elderly population (Manton and Gu 2001) and the expectation of continued increases in life expectancy in the US elderly and oldest-old population (e.g., Oeppen and Vaupel 2002).

It is unfortunate that the performance and stability of these federal programs continue to be discussed and analyzed separately without recognizing the linkages of their various inputs and outputs. Policies explicitly coordinating changes in program benefits might help mitigate some of the long-term fiscal problems intrinsic to each program. Significant health and life expectancy improvements were not anticipated when these programs were initiated. Because of increases in cardiovascular disease (CVD) mortality rates, male life expectancy had not improved during 1954–68. Projections based on mortality trends over the early period of the Social Security program suggested life expectancy would reach a quasi-biological maximum of roughly 77 years around 1977 and then increase no further (Myers 1981). Questions about changes in the health and functional status of the US elderly population were raised in 1982 when Congress and the Greenspan Commission first seriously debated the long-term fiscal stability of the Social Security Trust Fund. By then male life expectancy had increased rapidly owing to the initiation of declines in male CVD mortality that began in 1969 and have continued to the present day.

It now seems clear that the performance and stability of the three federal programs should be projected using models in which Medicare and Medicaid program investment in health improvements produce physical health inputs to SSA's life expectancy forecasts. Those forecasts, in turn, should be sufficiently detailed to represent the determinants of health status and human capital, with assigned propensities for persons to continue working. This approach is further justified by recent efforts at implementing the 2003 MMA initiative of "payment for performance" where reimbursements are adjusted to motivate improvements either in the delivery of health care or in actual health outcomes (Miller 2005). It will be necessary, for example, to determine the short- and long-term consequences of this quality initiative on Social Security, Medicare, and Medicaid taken as a group of health-related programs. A failure to do so leaves the independent assessment of each program subject to being misspecified because of the failure to recognize the existence of interactions.

The argument that accurate life expectancy forecasts for the SSA program are not needed if one has a self-adjusting system is not credible if Social Security benefit adjustments (mainly reductions) are needed to "catch up" with observed life expectancy increases. The current shortfall of the Social Security system would not exist if the trajectory of life expectancy

changes had been better forecast in 1935 or even subsequently. Even though differences between projected and observed life expectancy trends may appear small at a point in time, the accumulation of such differences means that an adjustment, when it is eventually made, will have a large effect on overall program liability. It will thus be pertinent to future SSA beneficiaries who have to absorb the benefit reductions. Thus, waiting 10 to 20 years to make an adjustment for a continuing trend of life expectancy increases leaves a significant problem in funding—if not for the system itself, then for individual beneficiaries, with attendant aggregate consequences for consumption patterns and subsequent economic growth.

In 1981 the National Commission on Social Security and the Social Security Administration decided not to explicitly consider the effects of health changes related to life expectancy increases because of insufficient data on trends in health and functional status (Feldman 1983). Some argued for a correlation linking increases in life expectancy to increases in the proportion of persons with serious morbidity and disability at later ages (Gruenberg 1977; Kramer 1980). This argument was embodied in the theory of the epidemiologic transition in which modern industrial societies were viewed as enhancing the risk of many chronic diseases, due, for example, to increased environmental pollution (Omran 1971). Such arguments have reemerged as concerns are being expressed about the effects of recent increases in body mass index in the United States on life expectancy (Olshansky et al. 2005), health trends (Lakdawalla et al. 2004), and Medicare expenditures. For example, Bhattacharya et al. (2004) suggested that the effects of recent medical innovations may have served to disproportionately prolong survival among persons with chronic diseases and poor quality of life.

Given the lack of detailed data on the nature of health improvements during the period 1969 to 1982, a modest one-time partial fix was recommended by the National Commission on Social Security Reform (the Greenspan Commission) in 1983 for Social Security normal retirement age with a two-year extension, to age 67, to be gradually introduced between 2000 and 2022. This change necessarily had to be conservative because direct measures of population health and functioning were not then available.

This decision had several implications. It continued the artificial separation of the effects of Medicare and Medicaid expenditures on population health from the Social Security entitlement for the US elderly population and its increasing life expectancy. Thus, as life expectancy (LE) and, more directly, active life expectancy (ALE) (i.e., years of life spent in a healthy or nondisabled state, Robine et al. 2003a) grew, the fiscal stress of Social Security entitlements on the US economy also grew. In effect, as LE and ALE increased and the period of life spent disabled decreased, the effects of positive health and mortality trends were to increase real benefits (i.e., growth in the number of person-years expected to be lived post-retirement for which Social Security OASI payments would be responsible) (1) without recognizing the potential

stimulating benefits such growth in human capital could realize in the US economy (Tolley et al. 2005); and (2) without factoring in, when assessing the return on investment to Medicare health benefits, the social and economic benefits the Medicare program generated by producing more human capital. Thus, the total social and economic benefits of Medicare and Medicaid program spending are not being accurately and fully calculated.

To clarify the implications of current assumptions and actuarial forecasts for the SSA and Medicare trust funds, Figure 1 presents a chart that relates Social Security, Medicare, and Medicaid costs to one another, as a percent of gross domestic product (GDP) through 2080. Medicare expenditures are projected to begin to exceed OASDI payments in 2024 with costs climbing to almost 14 percent of GDP by 2080. OASDI payments become relatively stable beginning about 2030, at roughly 6 percent of GDP, with a slow increase thereafter due to assumed modest life expectancy increases. Medicaid expenditures also grow consistently, passing SSA expenditures about 2045 and approaching 10 percent of GDP by 2080. Thus, growth in the Medicare and Medicaid programs, not Social Security, is the critical long-term problem for the US economy. Medicare and Medicaid combined are projected to grow to almost 24 percent of GDP by 2080. This projected growth is based on various assumptions, including increased health expenditures resulting from greater use of biomedical and medical technology and the future impact of the Medicare Part D prescription drug benefit.

FIGURE 1   Social Security, Medicare, and Medicaid costs as a percent of GDP, 2000–80
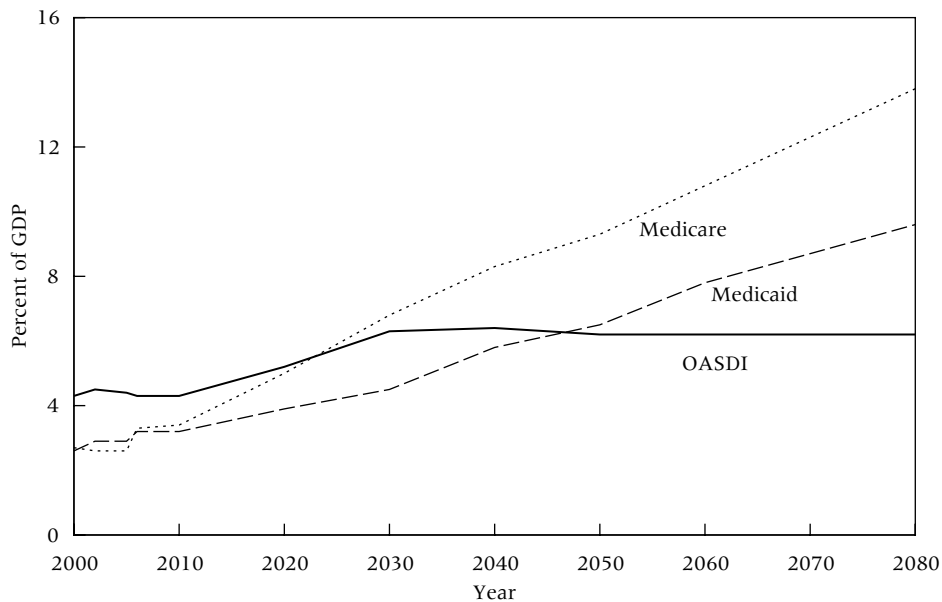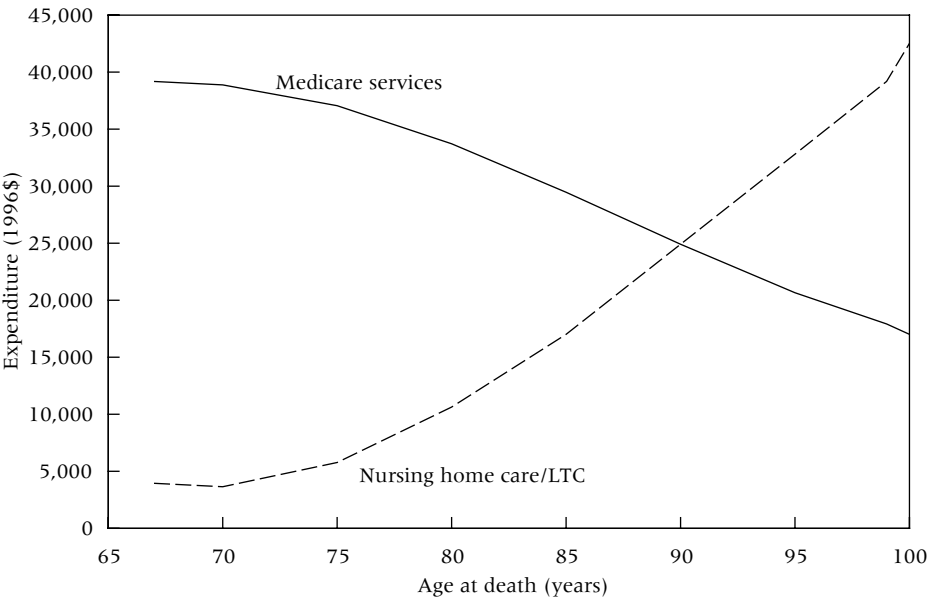

SOURCES: Social Security Administration (2005); Government Accountability Office (2005).

These projections are in fact unlikely to be realized for a number of reasons. First, one might expect that growth in one of the three programs would mitigate growth in the other two. This expectation depends on the economic status of the elderly population, which will be determined by how well Social Security income is preserved over time and thus by how many of the elderly will become eligible also for Medicaid contributions toward care not funded by Medicare. Second, depending on how Medicare and Medicaid funds are expended and how much they affect the health and functioning of the elderly population, the rate of growth of GDP could be sufficiently stimulated by that spending to alter projections of the proportion of GDP demanded for health care.

To illustrate how Medicare and Medicaid expenditures could be correlated over age and time, Figure 2 shows the proportion of health expenditures at each age at one point in time during the two years before death, attributable to Medicare for acute and postacute care and to Medicaid for institutional and long-term care (LTC) (Spillman and Lubitz 2000).

The figure shows that Medicare expenditures in the last two years of life are highest for the young-old, who mainly require acute and postacute health care. This is likely the type of health care most affected by recent

FIGURE 2   Per person health care expenditures in the last two years of life for Medicare and nursing home services according to age at death

biomedical research and therapy advances. At advanced ages, for example above age 90, long-term care dominates end-of-life costs, with the proportion of health care paid by Medicaid increasing with age. LTC is often highly labor intensive, and health outcomes and expenditures are less responsive to technological innovation.

It is also clear that the age at crossover of the liability of each program will be affected by the relative rates of increase of life expectancy and active life expectancy. As disability prevalence declines at later ages, and if LE and ALE become more similar, then innovations in medical technology are likely to have greater impact on health costs. Such impact may more closely approximate the price–production–technology innovation relations found in other economic areas, reducing the overall LTC burden and Medicaid costs. There is strong evidence for the latter effect from both the National Long Term Care Survey (Manton and Gu 2005) and the Medicare Current Beneficiary Survey (Lubitz et al. 2003), in which nondisabled persons aged 70 had health care expenditures similar to those of disabled persons of the same age, but with nondisabled persons having a significantly longer life expectancy. Thus, on an individual basis the same costs are spread over more years of nondisabled life, lowering their per capita and per annum expenditures and increasing the health return on investment and productivity of Medicare/Medicaid investments. The investments in the Medicare/Medicaid programs will, in turn, be enhanced by advances in medical therapy produced by investments in basic medical and biological research at the National Institutes of Health and the National Science Foundation—especially if these advances contribute to elevating the age at crossover in Figure 2.

The special role of Medicaid programs in responding to the most vulnerable at-risk subpopulations must be realized and examined in more detail (Manton 2004). Given the severity and mix of health problems in the Medicaid population, Medicare potentially may be the program most affected by changes in medicine that reduce chronic health problems, disability, and the need for long-term care.

Consequently, the projected expenditure dynamics in Figure 1 do not accurately reflect the data we present below on the observed and projected trends in the linkage of life expectancy and active life expectancy. Nor do they reflect the linkage of disability declines to reduced per person, per annum, inflation-adjusted Medicare costs and reduced LTC needs (Manton and Gu 2005; Manton et al. 2005b). This latter linkage might emerge as the age at crossover of Medicare and LTC expenditures in Figure 2 is elevated to even more advanced ages as more effective biomedical therapies delay the onset of disability. This delayed onset in turn will delay the age at which LTC is needed and, depending on the relative rate of change in ALE and LE, will alter the average amount of LTC required. Program linkages must also be represented in the forecasts because it is implausible that the govern-

ment would allow Medicare and Medicaid costs (as a proportion of GDP) to grow at the projected rate to 2080 with so little return in terms of survival, especially survival in an active state. Indeed, given the likely linkage of morbidity, disability, and mortality (Manton 1989a, 1989b, 1991; Fries 1980, 2003), reductions in disability might drive future life expectancy increases resulting in most of the person-years gained in potentially socially and economically active states.

In addition to reductions in per capita, per annum Medicare costs among the healthy elderly population aged 65 to 84 (Manton and Gu 2001; Manton and Lamb 2005a), the production of human capital at later ages may permit further increases in the normal retirement age (possibly keeping the OASDI portion of GDP below the projected 6 to 7 percent) and more rapid expansion of the general economy. In this case GDP could grow at a faster rate and the proportion of GDP projected to be consumed by Medicare and Medicaid could be kept significantly below that in Figure 1. If the recent short-term (17-year, 1982–99) disability reductions of 1.7 percent per annum (Manton and Gu 2001) continue, the rate of increase in Medicare expenditures could begin to level off around 2025–35 as predicted by Singer and Manton (1998), even though the financial impact of much of the baby boom cohort would also be felt in these years. Thus, evaluation of the fiscal solvency trajectory of the Medicare, Medicaid, and Social Security programs could be fundamentally changed by the modulation of long-term health dynamics by the health effects of Medicare and Medicaid service expenditures, especially if those services are enhanced by recent increased investment in biomedical research (Pardes et al. 1999).

Sources

For this study we conduct a coupled analysis of life expectancy and active life expectancy using data from three sources. The first source is analyses of data on Civil War Union Army veterans conducted by Fogel and Costa (Costa 2000, 2002, 2004; Fogel 1994, 2004; Fogel and Costa 1997). They estimated declines in chronic disability and disease from 1910 to the 1990s. The 1900–10 health measurements were based on detailed assessments by physicians of roughly 6,100 Union Civil War veterans applying for pensions for war-related service (Costa 2002). The health characteristics of the 1910 Civil War veterans were compared in different analyses to the physical status of World War II veterans assessed in the 1985–88 National Health Interview Survey (NHIS) (Fogel 1994; Fogel and Costa 1997) and noninstitutionalized white men assessed in the 1988–94 National Health and Nutrition Examination Survey (NHANES) and the 1994–95 NHIS (Costa 2002). These results have recently been supported and expanded using more detailed data from the Gould (1869) study of Union Civil War military recruits (Costa 2004). In the Gould

sample, measures were made of vital capacity, strength, and body composition in addition to body mass index (BMI). Costa compared those measures to those of US Army male recruits in 1988. Those analyses show that the long-term slow increases in BMI observed in military recruits up to 1988 were associated with improvements in measures of body composition (e.g., less abdominal fat) and function (e.g., increased vital capacity and strength).

These findings were supportive of the theory of technophysio evolution proposed by Fogel (1994; Fogel and Costa 1997), and the theory is important in assessing the likely health and economic implications of the recent increase in BMI in the total US population. In this theory it is not the biology of the individual that has recently evolved but the socioeconomic environment within which human physiology must operate. Fogel argues that social and technological evolution operates much faster (on the order of decades) than biological evolution (on the order of tens of thousands of years). The environment is assumed to have evolved in a way (presumably under human direction and planning, with an increasing ability to change the environment) that is increasingly beneficial to the operation of the physiological endowment of humans. Thus, as food becomes more plentiful and water quality and hygiene improve, a population's improved nutrition makes them more resistant to many types of infection. Complementing this benefit is a reduction in exposure to pathogens because of improvements in food preparation and storage as well as the development of antibiotics and, more recently, antivirals. Changes in infection and nutrition have been shown to have consequences for many chronic diseases (e.g., cardiovascular disease) in middle and later life (Manton 2003, 2004, 2005a).

The second data source is the 1982–99 National Long Term Care Survey (NLTCS) estimates of disability declines. These estimates suggest that the rate of disability improvement accelerated during 1982–99, with an overall change of 1.7 percent per annum (Manton and Gu 2001). This acceleration might have been anticipated given the introduction of Medicare in 1965 providing universal health care coverage for the US elderly population and the period of time necessary for its full implementation in this population and necessary adaptations by the US health care system. The introduction of Medicaid in the same year also had a positive impact on elderly health care for indigent and socially vulnerable subpopulations, both through the coverage of acute health care services, including medications, and through coverage of long-term care and institutional costs.

The NLTCS is the best data set for documenting recent disability declines in the US elderly population because it is based on a large Medicare list sample, uses face-to-face interviewing with a stable interview instrument, and covers both community and institutional residents in its sample frame (Freedman et al. 2002b; Fries 2003).

The third data source is US life tables generated by the National Center for Health Statistics (NCHS) and by SSA. SSA life tables for recent years, however, have built-in assumptions (i.e., late-age mortality is described by a Gompertz hazard function) that biased life expectancy downward at late ages (e.g., 95+) (NCHS 1999). Thus, NCHS life table estimates are preferred when available.

We use these three sources of data to produce estimates of life expectancy and active life expectancy at various dates to identify the burden assumed by Social Security at its introduction in 1935 and to examine the relation of changes in LE and ALE before and after the introduction of Medicare in 1965. The relative rate of change in total LE and ALE will help us examine the implications of improvements in health for the burden exerted by the Social Security program on the US economy and the elderly population. Any finding that investments in Medicare services increase human capital in the elderly population would provide an attractive option for stimulating US economic growth (Tolley et al. 2005) and would improve the linked fiscal status of the SSA, Medicare, and, possibly, Medicaid programs (Singer and Manton 1998).

Methods

Calculations of active life expectancy are frequently used to determine the period of time expected to be lived free of disability (Robine et al. 2003a). This is different from methods in which analysts apply subjective weights to differentiate the period of time lived with an externally perceived degree of functional impairment. Classically, ALE is calculated from multiple data sources: vital statistical data on mortality and census data on age- and sex-specific population counts, to calculate population life tables; and health survey data on proportions of the population reporting living in specific health states at specific ages (Lamb and Siegel 2003). For this article we estimate LE and ALE for different years during the twentieth century and projected into the twenty-first century. We use the Sullivan method of ALE estimation based on period life tables and survey-based period-specific estimates of disability prevalence (Sullivan 1971).

The Sullivan method uses period distributions of a population at specific ages and the proportions of persons without disability at those same ages. It is the most appropriate and frequently used method for estimating ALE with cross-sectional data. The Sullivan method, however, does not directly examine disability change in individuals over time or identify cohort effects. Such analyses have been done using the NLTCS because persons are longitudinally followed to the time of death (e.g. Manton and Land 2000; Manton and Yashin 2000). Those analyses require different models in which population changes are estimated by averaging over individual health pa-

rameters whose change is driven by individual stochastic processes (Yashin and Manton 1997). For the current study we use period-specific disability prevalence data (e.g., from the NLTCS) to make cross-sectional ALE estimates. Given that SSA and Medicare analyses frequently compare sequential cross-sections, the Sullivan method is most appropriate for those accounting purposes.

A number of US estimates of ALE were prepared in the 1980s (Lamb 2003). Since 1989 research on ALE has been promoted by REVES (Réseau Espérance de Vie en Santé, the International Research Network on Health Expectancy), whose members have estimated ALE for a number of countries (Robine et al. 2003a). The Sullivan method of ALE estimation has been adopted by the World Health Organization as a measure of health improvement over time that can be readily calculated from existing data for cross-country comparisons (WHO 2000).

Disability prevalence ratios are used to calculate the person-years of life lived in healthy states (i.e., nondisabled conditions) for the age intervals using the L_x life table function (see Kinter 2003, for a more detailed explanation of life table functions):

$$L_{x(hs)} = (1 - DPR) * L_x \qquad (1)$$

where the healthy state is denoted by *hs* and *DPR* is the age-specific disability prevalence ratio. Person-years of health for each age interval ($L_{x(hs)}$) are summed from age *x* to the end of the life table to obtain the total person-years that are healthy, or active (i.e., nondisabled):

$$T_{x(hs)} = \Sigma_{x=a}^{\infty} L_{[x(hs) = a]}. \qquad (2)$$

Healthy, or active, life expectancy is obtained by dividing total healthy person-years at each age by the l_x value at that age from the basic life table:

$$e_{x(hs)} = T_{x(hs)} \div l_x. \qquad (3)$$

Use of national life tables in calculating active life expectancy has the advantage of providing survival estimates with little sampling variability. Calculation of disability prevalence among survivors to a given age is typically done using data from large national health surveys. A comparison of life tables based on census and vital statistics data with life tables calculated from longitudinal health surveys (e.g., the NLTCS) is useful to check the population representativeness of the survey samples. Ideally, the mortality experience in the survey sample will be consistent with that in the national life tables (except for sampling variability) so that the survey marker of age at onset for disability can validly be combined with the vital statistics markers of age at death because each can be assumed to be driven by the same underlying population health processes.

Data

For the current study disability is broadly defined to indicate the loss of ability to perform specific physical functions, particularly those related to mobility and life-maintaining activities.

The Civil War Union Army pension sample

Few reliable estimates of US population health and health changes date back to 1935. The US vital statistics and mortality reporting system was not complete until Social Security was instituted in that year. More importantly, nationally representative survey and epidemiological data on the US elderly population were not systematically collected until after 1982 (Feldman 1983; Freedman et al. 2002b, 2004). The most complete and medically reliable data with which to produce population disability and morbidity estimates for 1935 were the aforementioned data collected on Civil War Union Army veterans who applied for pension benefits in 1900–10. This assessment is of an elderly population, and the measures examined were of chronic disease and disability—although infectious disease processes are important early etiological factors for later chronic disease rates (Manton 2003, 2004, 2005a).

Veterans were examined by a board of three physicians to determine eligibility for the Union Army pension program. Disabilities were assessed and reported in the records of examining physicians. The measures assessed to diagnose disability included difficulty walking, difficulty bending, paralysis, blindness in at least one eye, and deafness in at least one ear. These and other questions on disability were also asked in the NHANES and NHIS, which allowed Costa to estimate long-term trends in disability decline from these three data sources.

The 1982–99 NLTCS

The National Long Term Care Survey, a longitudinal survey of the Medicare-enrolled US population aged 65+, has been conducted in 1982, 1984, 1989, 1994, and 1999. In each survey year approximately 20,000 persons are screened for chronic limitations in activities of daily living and instrumental activities of daily living. Those sampled in each survey comprise 15,000 persons who were surveyed in the previous NLTCS and 5,000 persons who passed age 65 between the close of the previous survey and the selection of the supplementary sample for the new survey. The 5,000 persons in the age 65–69 supplemental sample approximately compensate for mortality experienced over the five years between surveys. Among the 15,000 persons who survive to the next survey, those who had chronic disability in

the previous survey are automatically scheduled for an interview to assess the circumstances surrounding changes, both positive and negative, in functional and health status between surveys. In 1994 and 1999 the disabled sample receiving a detailed interview was enhanced with a supplementary sample of persons who "screened out" as not disabled (i.e., a "healthy" subgroup) to increase the precision of estimates for the nondisabled.

Additionally, persons aged 95+ were oversampled in 1994 (N ~ 540), and 1999 (N ~ 600) to improve the precision of estimates for the oldest-old population. The 95+ oversample was included because the prevalence of chronic disability had been declining at younger ages to relatively low levels (e.g., for persons 65 to 84; Manton and Gu 2005). Thus, oversampling the very old was necessary to more precisely characterize a subgroup that will generate a growing portion of the total disability burden.

The NLTCS provides a representative sample of persons aged 65+ drawn at each date from Medicare enrollment files and includes all data elements necessary to conduct longitudinal analyses and to make long-range forecasts of chronic disability changes in the US elderly population (Manton et al. 2005a). Because the NLTCS sample covers both males and females and includes institutionalized persons, it provides more reliable estimates of national disability decline than the Union Army data. Despite the limitations of the Union Civil War samples, however, we believe they provide reasonable estimates of the long-term rate of decline in disability for elderly males in the early twentieth century.

For this study we use the 1982 and 1999 waves of the NLTCS to make sequential cross-sectional estimates of active life expectancy. Disability prevalence is measured in the NLTCS using the very stringent standard of the proportion of persons aged 65 years and older who have any health-related difficulty performing at least one instrumental activity of daily living (IADL; Lawton and Brody 1969) or activity of daily living (ADL; Katz et al. 1963) for 90 or more consecutive days, or currently residing in an institution providing medical services (Manton and Gu 2001). IADLs include heavy and light housework, laundry, cooking, grocery shopping, getting about outside, traveling, managing money, taking medication, and using a telephone. ADLs include eating, transferring in and out of bed or chair, getting around inside, dressing, bathing, and toileting. The absence of any chronic ADL or IADL impairment places individuals in the "active" or nondisabled population. In the Union Civil War Army pensioners study, the determination of disability is made by physicians but is based in part on measures emphasizing mobility and sensory limitations.

Life tables

We estimate life expectancy and active life expectancy at certain critical dates (i.e., 1935, 1965, 1982, 1999) and make projections for 2015, 2022, and

2080. The year 1935 was the date of inception of Social Security. The year 1965 refers to the start of the Medicare and Medicaid programs. The years 1982 (the year in which changes to the SSA entitlement age were made) and 1999 refer to the period for which we currently have longitudinal national data on individual disability changes. 2015 is the year to which most analysts expect current disability declines to continue. 2022 is the year to which Costa (2002) projects rapid increases in life expectancy (and ALE; Manton and Corder 1998) due to continued improvements in social (e.g., education) and economic factors. 2080 is the year to which official Social Security, Medicare, and Medicaid cost projections have been prepared.

We used life tables calculated by the National Center for Health Statistics (NCHS) for the years 1965, 1982, and 1999. For 1935 we used modifications of SSA-calculated life tables. We used NCHS life tables for the latter half of the twentieth century because current SSA life tables are closed out by imposing a Gompertz hazard smoothing function at late ages (i.e., 95+). NCHS life tables use Medicare data to close out life tables (NCHS 1999), because those data fully exploit the evidence on changes in US mortality at extreme ages. The effects of the Gompertz smoothing at advanced ages are less important for the early SSA life tables (i.e., pre-1950) because few persons survived to ages 95+ at that time. We use SSA life tables in our projections because we are contrasting our results with SSA estimates of projected Medicare and Social Security costs, as well as future Medicaid costs. Therefore we use the same mortality and fertility assumptions that were used for the GDP cost projections in Figure 1.

Estimates of disability decline

From 1910 to the early 1990s, Fogel and Costa's estimates of the rate of decline in chronic disease and disability average about 0.6 percent per year, with different measures of disability and chronic disease declining 0.3 to 0.9 percent per year (Fogel 1994; Costa 2002). To estimate the 1935 and 1965 point prevalence of disability, we use the 1910 estimate of disability prevalence from Costa (2002) and assume a 0.6 percent per year disability decline.

For 1982 to 1999, we rely on age-specific rates of decline in chronic disability in the US elderly population from the NLTCS. From 1982 to 1994 this annual rate of decline averages about 1.5 percent. From 1994 to 1999 the rate of decline in chronic disability and institutional use increased to 2.6 percent per annum, raising the 17-year average decline per annum to 1.7 percent (Manton and Gu 2001).

We use two scenarios to project rates of disability declines in the twenty-first century. For the first we assume a continuation to 2022 of the 1982 to 1999 disability decline of 1.7 percent per annum. Because we lack evidence on long-term trends for the 2022 to 2080 projection, we assume a drop in

the rate of disability decline and use the average rate of decline for most of the twentieth century (1910 to 1999), namely 0.8 percent per annum. In most respects this is a conservative scenario but it is sufficient to illustrate our basic arguments. For the second scenario we assume an even more modest disability decline of 0.8 percent beginning in 1999 to be used in projections to 2015, 2022, and 2080. This helps us understand the sensitivity of long-term trends to reasonable, conservative variation in assumptions about disability change.

Results

Table 1 shows estimates of life expectancy and active life expectancy at ages 65 and 85 for the US population. LE grew at about the same rate as ALE from 1935 to 1982 for ages 65+ with little change in the number of disabled years (column 3) because disability prevalence (among males), according to Fogel and Costa's estimates, declined only 0.6 percent per year. In contrast, because of the acceleration of the rate of decline in disability from 1982 to 1999, ALE grew much faster than total LE, that is, the percent of ALE increased from 72.8 percent to 78.5 percent. This percentage is projected to

TABLE 1   Life expectancy (LE) and active life expectancy (ALE) at age 65 and 85, US population, 1935 to 2080, selected years

Year	Age 65				Age 85			
	LE	ALE	Difference (disabled years)	ALE/LE (%)	LE	ALE	Difference (disabled years)	ALE/LE (%)
A. 1935 to 1999[a]								
1935	11.9	8.8	3.1	73.9	3.0	0.7	2.3	23.3
1965	15.0	10.9	4.1	72.7	5.4	1.5	3.9	27.8
1982	16.9	12.3	4.6	72.8	6.2	2.1	4.1	33.9
1999	17.7	13.9	3.8	78.5	6.4	3.0	3.4	46.9
B. 2015 to 2080, first projection scenario[b]								
2015	18.9	15.6	3.3	82.5	7.0	4.1	2.9	58.6
2022	19.4	16.4	3.0	84.5	7.3	4.6	2.7	63.0
2080	23.6	20.8	2.8	88.1	9.6	7.2	2.4	75.0
C. 2015 to 2080, second projection scenario[c]								
2015	18.9	15.1	3.8	79.9	7.0	3.6	3.4	51.4
2022	19.4	15.7	3.7	80.9	7.3	3.9	3.4	53.4
2080	23.6	20.1	3.5	85.2	9.6	6.6	3.0	68.8

[a]Per annum rates of disability decline: 1935 to 1965, 0.6 percent; 1982 to 1999, 1.7 percent.
[b]Per annum rates of disability decline: 1999 to 2022, 1.7 percent; 2022 to 2080, 0.8 percent.
[c]Per annum rates of disability decline: 1999 to 2080, 0.8 percent.

increase further from 1999 to 2022 (i.e., to 84.5 percent) and to 2080 (to 88.1 percent). Increases in the proportion of ALE in the long-range projections continue despite the relatively low rate of improvement (0.8 percent) because Social Security projections assume that future improvements in LE will occur slowly given that they are taking place in elderly populations.

An even more dramatic increase in the ALE/LE ratio is observed at ages 85+, where the ratio increases from 23.3 percent in 1935 to 46.9 percent in 1999, 63.0 percent in 2022, and 75.0 percent in 2080. Other analyses suggest that relative rates of improvement might be even faster at ages 95+ (Manton 2005b; Manton et al. 2005b). If such trends emerge, this would suggest improved productivity in health expenditures inasmuch as the Medicare–Medicaid/LTC crossover point in Figure 2 would be elevated to even later ages.

Let us consider the social and medical changes that may have produced these trends in life expectancy and active life expectancy. Changes from 1935 to 1965 were generated without the health service benefits of the Medicare and Medicaid programs and with few of the benefits of modern biomedical research. The first major US biomedical research programs began in the post–World War II period at NIH. For example, the Framingham Heart Study was initiated in 1948. Little national population benefit apparently was realized from that early research in the 1954 to 1968 period when male mortality due to CVD actually increased, although female mortality rates declined during the same period. Starting in 1969, however, benefits became evident at the population level with the start of reductions in male CVD mortality. The Surgeon General's report on smoking health hazards was issued in 1964. The so-called war on cancer was started in 1972 but, again, benefits were not immediately apparent (Bailar and Gornik 1997; Bailar and Smith 1986). Significant reductions in overall cancer mortality began in 1990 and continue. A number of analyses (Fox et al. 2004; Gregg et al. 2005; Imperatore et al. 2004) suggest that NIH-sponsored biomedical research likely started to have major population health effects on CVD risk factors, even in the population with chronic diseases (e.g., diabetes mellitus), in the late 1980s or early 1990s.

In the 30 years from 1935 to 1965, progress in ALE was relatively good, despite the Depression and World War II. In 1965 ALE at age 65 was 10.9 years and LE was 15.0. Survival to ages 90+ increased significantly. Consequently, the ALE/LE ratio declined modestly. The 1965 ALE/LE ratio at ages 85+ is much smaller than for ages 65+. About a quarter of LE is in an active state, although, in contrast to age 65, there was an improvement between 1935 and 1965.

A 65-year-old in 1982 had an ALE of 12.3 years (an increase of 1.4 years since 1965) comprising 72.8 percent of the total LE of 16.9 years. Survival to later ages showed considerable improvement. An 85-year-old in 1982 had an ALE of 2.1 years (an increase of 0.6 years since 1965). The proportion of LE at age 85 expected to be active increased from 27.8 percent in 1965 to 33.9 percent in 1982.

Chronic disability declined at 1.7 percent per annum from 1982 to 1999 (Manton and Gu 2001). ALE increased 1.6 years over the same interval (from 12.3 to 13.9 years at age 65), while total LE increased 0.8 years. The ALE/LE ratio increased from 72.8 percent to 78.5 percent. The proportion of ALE at age 85 increased even more rapidly, from 33.9 percent to 46.9 percent, or 0.9 years.

For Medicare, Medicaid, and SSA program evaluation, it is important to determine whether these changes will continue. One set of projections, based largely on changes in levels of educational attainment at ages 85+, suggested that a 2.1 percent annual decline in chronic disability could be supported to 2022 (Manton and Corder 1998). Analyses by Costa (2004) of changes in body mass index and other biometric measures of physical fitness also suggest that mortality declines and health improvement could continue to 2022.

Another assessment, based on both recent obesity trends in younger populations, and expansion of morbidity as a result of improved survival produced by medical innovations in persons with advanced disease, suggests disability declines may continue to only 2015 or 2020 (Bhattacharya et al. 2004). Olshansky et al. (2005) even suggested that total US life expectancy might drop by 2 to 5 or more years. These latter views are partly based on early evaluations of the obesity "epidemic" by McGinnis and Foege (1993) at the Centers for Disease Control and Prevention (CDC) and by other analysts (e.g., Allison et al. 1999). Those original estimates of the mortality effects of obesity trends, however, have been questioned on methodological and substantive grounds by more recent CDC studies (Flegal et al. 2004; Flegal et al. 2005; Gregg et al. 2005).

Also in Table 1 are LE and ALE projections based on our second scenario with the more modest assumption of a disability decline of 0.8 percent per annum (the average decline from 1910 to 1999) for the period 1999 to 2080. Those projections indicate that at age 65 the ALE/LE ratio increases from 79.9 percent in 2015 to 85.2 percent in 2080. These projections indicate that, at age 85, considerably more than half of the remaining years (68.8 percent) in 2080 will be lived in a nondisabled state.

Extrapolating 1999 to 2015 using the first scenario, ALE at age 65 increased 1.7 years and LE increased 1.2 years. The proportion of LE expected to be spent in an active state at age 65 grew from 78.5 percent to 82.5 percent; at age 85 the projected increase was from 46.9 percent to 58.6 percent. Overall, ALE increased by 5.1 years from 1935 to 1999 and a total of 6.8 years to 2015. The results of the second scenario only reduced the ALE projections by 0.5 years at ages 65 and 85 in 2015. By 2022 the increases at age 65 from 1935 using the first set of assumptions were 7.6 years of ALE and 7.5 years of LE. However, LE increases occurred largely from 1935 to 1982 when survival was rapidly rising at younger ages. After 1982 the relative proportion of life expectancy at age 65 expected to be spent in an active state increased from 72.8 percent to 84.5 percent in 2022.

The parallel increases from 1935 to 2022 at age 85, in the first scenario, were 4.3 years in life expectancy and 3.9 years in active life expectancy, with the proportion expected to be spent nondisabled growing from 23.3 percent to 63.0 percent. In the second scenario the 2022 ALE proportion is 53.4 percent. We would expect improvements in function to more advanced ages (e.g., 95+) to also show rapid increases (Manton and Gu 2001). One reason to expect improvements to occur at later ages (e.g., 85+) is that clinical guidelines for treatment with curative intent (e.g., use of chemotherapy in elderly patients with specific tumors) are being extended for older patients in reasonably good health (e.g., use of bone and hip joint replacement surgery; treatment of cardiovascular anomalies).

To parallel the long-term federal projections of Social Security, Medicare, and Medicaid costs, we projected active life expectancy to 2080. Life expectancy at age 65 is projected to be 23.6 years, which is almost double the estimate for 1935 (11.9 years). At age 85 LE is projected to be 9.6 years in 2080, a more than threefold increase over the estimate for 1935 (3.0 years). Under the first scenario we projected an ALE/LE ratio of 88.1 percent at age 65 and 75.0 percent at age 85. The second scenario yielded an ALE/LE ratio for 2080 of 85.2 percent at age 65 and 68.8 percent at age 85.

To illustrate the health improvements over the twentieth century and as projected to 2080, Figure 3 shows survival curve pairs for total and active life expectancy for 1935, 1999, and 2080. In 1935 65-year-olds were expected to live 11.9 years, of which 8.8 years would have been spent in an active state.

FIGURE 3 Survival curves (LE and ALE) between ages 65 and 100 for 1935, 1999, and projected to 2080, US population (first scenario)
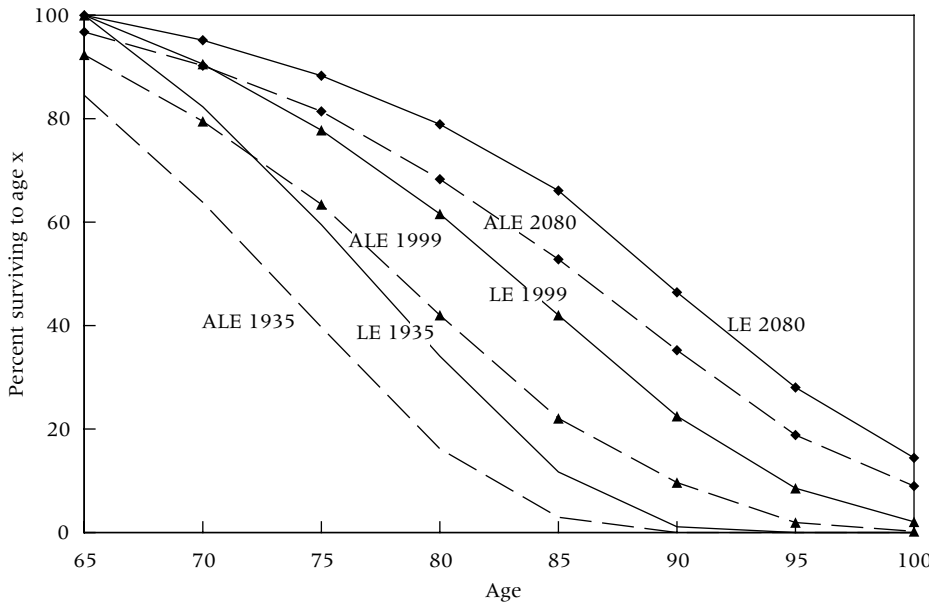
In 2080 life expectancy at 65 is projected to be 23.6 years, with a projected ALE of either 20.8 years with an ALE/LE ratio of 88.1 percent (first scenario) or 20.1 years with an ALE/LE ratio of 85.2 percent (second scenario).

Discussion

Our results suggest that at age 65 in 1999 one could expect to live an average of 13.9 years in the United States in a socially or economically productive state, compared to 8.8 years in 1935. Active life expectancy at age 65 is projected to be 16.4 years in 2022 and 20.8 years in 2080, assuming the 1982–99 rate of disability declines continues to 2022, with a 0.8 percent rate of decline assumed in the period 2022 to 2080. Thus, if one wished to take advantage of the increase in ALE to slow the growth in Social Security long-term liability, one could increase the SSA normal retirement age to 70 years in 2005–06 based upon existing ALE estimates and, if the extrapolations prove reasonable at later ages, to about 72.0 years in 2022 and to 77.0 years in 2080 (see Table 1). Increases in the retirement ages to these advanced ages would still provide the 8.8 years of Social Security benefits to persons in an active state that the original beneficiaries received when OASDI was introduced in 1935. Not to change the normal retirement age would imply an increase in total Social Security benefits received for persons in an active, but retired, state. Such changes would need to be carefully examined in terms of: (1) their social equity, (2) economic consequences, and (3) a reevaluation of the purposes of Social Security income support in conditions not remotely anticipated either in 1935 (SSA inception) or in 1965 (Medicare and Medicaid program inception). In addition, care must be taken to identify vulnerable groups who might not be part of such average improvements, with special provisions in Medicare/Medicaid and the disability insurance portion of Social Security considered for such groups.

These potential future increases in the normal retirement age may be contrasted to the small increase in the SSA eligibility age to 67 years scheduled to be implemented by 2022. The American Association of Retired Persons has estimated that each year of life expectancy above age 65 reflects about 7 percent of total SSA liability. This implies that the 7.6-year increase in active life expectancy expected to occur between 1935 and 2022 represents a real increase in benefits of more than 50 percent to persons in a potentially healthy and active state. This is independent of the expansion of the scope of health benefits, such as the expansion and improvement of Medicare (e.g., the prescription drug plan and "payment for performance") and Medicaid health care services.

Thus, one option to deal with fiscal concerns related to the Social Security Trust fund is to further raise, most likely in stages, the normal retirement age for Social Security to 72.0 years by 2022. This approach also sug-

gests that Medicare and Medicaid benefits, which may have been partly responsible for the large recent increases in active life expectancy, should be left in place—or even improved. Indeed, such improvement is already taking place through enhancing the quality of care in the Medicare program and might also be achieved by lowering the entitlement age for Medicare to 62 or even 60 years. Such a lowering is consistent with our overall argument because lowering the Medicare entitlement age would reduce the proportion of the US population without health insurance and could increase the rate of improvement in health at later ages and allow for further increases in the normal retirement age (Manton 2005b). Such an effect is amplified by the reduction in Medicare expenditures for nondisabled persons (Manton and Gu 2005)—a reduction that may be driven by a reduction in life-time long-term care benefits. This type of coordinated program change may be a more attractive option than either draconian cuts in OASI and Medicare benefits or increases in taxes, and may better reflect the reality of health and human capital changes in the US elderly population and their effects on the future US economy. It also makes clear the potential human capital benefits of current and future investments in biomedical research.

Conclusions

Research on disability trends of the US elderly initially was inconsistent in that some studies showed fluctuations with little to no improvement in health (Crimmins et al. 1989; Crimmins 1996), whereas other studies documented modest disability declines (Costa 2002). Data from the first three waves of the National Long Term Care Survey (1982, 1984, and 1989) showed declines in having difficulty in performing instrumental activities of daily living, with activities of daily living remaining stable (Manton et al. 1993a, 1993b). An analysis of trends in the first three waves of the NLTCS, the National Health Interview Survey (NHIS), and the Longitudinal Study of Aging (1984–90) confirmed the trends reported by Manton and colleagues (Freedman and Soldo 1994). Additional waves of the NLTCS documented an acceleration in the decline of chronic disability to 1994 (Manton et al. 1997, 1998) and to 1999 (Manton and Gu 2001).

The NLTCS is one of several surveys that have documented declines in chronic disability in the US elderly population at the end of the twentieth century. Declines in disability prevalence were found in the NHIS (Crimmins et al. 1997), the Medicare Current Beneficiary Survey (MCBS) (Waidmann and Liu 2000), the Survey of Income and Program Participation (Freedman and Martin 1998), the Health and Retirement Study (Freedman et al. 2004), and a comparison of the original and offspring cohorts of the Framingham Heart Study (Allaire et al. 1999). These trends were also manifest in multi-survey analyses restricted to a common set of measures and age groups (i.e.,

age 70+; Freedman et al. 2002a, 2002b; Schoeni et al. 2001). Disability trends of older adults in low-mortality countries (e.g., France, Japan, United Kingdom) also indicate declines in severe disabilities and in institutionalization rates (Robine et al. 2003b). Regarding gender differences, research indicates that females have longer years of life expectancy and males tend to have a higher proportion of active life expectancy. An examination of US gender trends between 1965 and 2022 for older adults indicates females and males will both have increased years of LE and ALE; however, the increase in the proportion of ALE is greater for males (Manton and Lamb 2005b).

One major question raised by this analysis is how certain one can be that disability declines will continue after 1999. In a recent criticism of analyses projecting continuation of the disability declines after 2020, Bhattacharya et al. (2004) examined a combination of data from the NHIS, which suggested obesity would increase disability prevalence at ages 30–49, and disability data above age 65 from the MCBS. Using the same two data sets, however, they found that the total elimination of obesity appeared to have only modest effects on Medicare costs to 2030 (Goldman et al. 2005). Flegal et al. (2004) examined recent CDC analyses on the effect of obesity and other mortality risk factors. They found that problems in the original forecasting methodology could induce overestimates ranging from 17 percent to 100 percent in the estimate of excess deaths due to obesity. Flegal et al. (2005), using recent data that more accurately reflected improvements in the management of major risk factors (i.e., hypertension, hypercholesterolemia, smoking, diabetes), found smaller risks of overweight and obesity (as defined by CDC) on mortality. Gregg et al. (2005) found the risk of death had decreased within specific BMI levels and concluded that the risk factor status of obese persons today is better than that for lean persons 30 years ago.

It is clear that obesity has fewer consequences for mortality and morbidity at later than at younger ages. For example, Luchsinger et al. (2003) found obesity was not a significant predictor of hospitalization costs past age 75 in the MCBS. The literature on the effect of obesity on disability is mixed. Using the first three waves (1993 to 1998) of the Assets and Health Dynamics Among the Oldest-old (AHEAD) study, Reynolds et al. (2005) found no significant differences in life expectancy by obesity status. The obese were found to have higher rates of disability and fewer years of ALE. However, the obese and the nonobese had similar rates of recovery from disability. A study that compared the original and offspring cohorts from the Framingham Heart Study found the offspring cohort to have significantly lower rates of disability while having higher BMI on average (Allaire et al. 1999).

A continuation of known improvements in therapy, in educational attainment, and in general public health and nutrition should support continuation of disability declines up to 2025. Further significant declines after that time will require biomedical and other technological innovations and

will have to occur at increasingly advanced ages (e.g., over age 85) and thus will involve effective interventions in basic parameters of aging and longevity. Medical advances and therapy innovations should be increasingly directed to reduce disability in elderly persons since such disability is likely to require labor-intensive long-term care and residential services not easily amenable to technological innovation. For example, technological innovation in sensory functions such as hearing (e.g., cochlear implants) and vision, and reduction in the risk of cognitive impairment (e.g., Manton and Gu 2005; Manton et al. 2005b), may, in the future, further greatly reduce ADL and IADL impairments. In addition, the projections to 2080 suggest that significant long-term potential benefits for Social Security and Medicare expenditures have already been produced by the rapid shifts in ALE and LE curves that occurred from 1982 to 1999.

Future surveys should be designed to more effectively monitor disability trends among older adults. First, the usual battery of disability questions (related to ADLs and IADLs) should be extended to include measures of higher levels of physical, sensory, and cognitive functioning, especially at ages 65 to 84, where most of the disability declines have occurred, and to establish measures of human capital. Health examinations, including brief tests of physical performance and sensory skills, would be useful to indicate early trends in changing health functioning. Second, links should be established with administrative data sets (e.g., Medicare, Medicaid, Veterans Benefits Administration, nursing home Minimum Data Sets) to determine demands for care and health care costs. Third, biomarker data should be collected for genomic, protenomic, and service-use studies of the aging process. Finally, it would be highly desirable to lower the age limit for sample surveys of older persons to 45+ or 50+ to better determine when aging processes begin.

Note

References

Allaire, S. H. et al. 1999. "Evidence for decline in disability and improved health among persons aged 55 to 70 years: The Framingham Heart Study," *American Journal of Public Health* 89(11): 1678–1683.

Allison, D. B., K. R. Fontanine, J. E. Manson, J. Stevens, and T. B. VanItallie. 1999. "Annual deaths attributable to obesity in the United States," *Journal of the American Medical Association* 282(16): 1530–1538.

Bailar, J. and H. Gornik. 1997. "Cancer undefeated," *New England Journal of Medicine* 336: 1569–1574.

Bailar, J. and E. Smith. 1986. "Progress against cancer?," *New England Journal of Medicine* 314: 1226–1232.

Bhattacharya, J. et al. 2004. "Disability forecasts and future Medicare costs," in D. Cutler and A. Garber (eds.), *Frontiers in Health Policy Research*. Volume 7. Cambridge, MA: MIT Press, pp. 75–94.

Costa, D. L. 2000. "Understanding the twentieth-century decline in chronic conditions among older men," *Demography* 37(1): 53–72.

———. 2002. "Changing chronic disease rates and long-term declines in functional limitation among older men," *Demography* 39(1): 119–137.

———. 2004. "The measure of man and older age mortality: Evidence from the Gould sample," *Journal of Economic History* 64(1): 1–23.

Crimmins, E. M. 1996. "Mixed trends in population health among older adults," *Journal of Gerontology: Social Sciences* 51B(5): S223–S225.

Crimmins, E. M., Y. Saito, and D. Ingegneri. 1989. "Changes in life expectancy and disability-free life expectancy in the United States," *Population and Development Review* 15(2): 235–267.

Crimmins, E. M., Y. Saito, and S. Reynolds. 1997. "Further evidence on recent trends in the prevalence and incidence of disability among older Americans from two sources: The LSOA and the NHIS," *Journal of Gerontology: Social Sciences* 52(2): S59–S71.

Feldman, J. J. 1983. "Work ability of the aged under conditions of improving mortality," *Milbank Memorial Fund Quarterly* 61(3): 430–444.

Flegal, K. M., B. I. Graubard, and D. F. Williamson. 2004. "Methods of calculating deaths attributable to obesity," *American Journal of Epidemiology* 160(4): 331–338.

Flegal, K. M., B. I. Graubard, D. F. Williamson, and M. H. Gail. 2005. "Excess deaths associated with underweight, overweight, and obesity," *Journal of the American Medical Association* 293(15): 1861–1867.

Fogel, R. W. 1994. "Economic growth, population theory, and physiology: The bearing of long-term processes on the making of economic policy," *American Economic Review* 84(3): 369–395.

———. 2004. *The Escape from Hunger and Premature Death, 1700–2100: Europe, America, and the Third World.* New York: Cambridge University Press.

Fogel, R. W. and D. L. Costa. 1997. "A theory of technophysio evolution, with some implications for forecasting population, health care costs, and pension costs," *Demography* 34(1): 49–66.

Fox, C. S. et al. 2004. "Trends in cardiovascular complications of diabetes," *Journal of the American Medical Association* 292(20): 2495–2499.

Freedman, V. A. and L. G. Martin. 1998. "Understanding trends in functional limitations among older Americans," *American Journal of Public Health* 88(10): 1457–1462.

Freedman, V. A. and B. Soldo. 1994. *Trends in Disability at Older Ages.* Washington, DC: National Academy Press.

Freedman, V. A., H. Aykan, and L. Martin. 2002a. "Another look at aggregate changes in severe cognitive impairment: Further investigation into the cumulative effects of three survey design issues," *Journal of Gerontology: Social Sciences* 57(2): S126–S131.

Freedman, V. A., L. G. Martin, and R. Schoeni. 2002b. "Recent trends in disability and functioning among older adults in the United States: A systematic review," *Journal of the American Medical Association* 288(24): 3137–3146.

Freedman, V. A. et al. 2004. "Resolving inconsistencies in old-age disability trends: Report from a technical working group," *Demography*, 41(3): 417–441.

Fries, J. 1980. "Aging, natural death, and the compression of morbidity," *New England Journal of Medicine* 303: 130–135.

———. 2003. "Measuring and monitoring success in compressing morbidity," *Annals of Internal Medicine* 139: 455–459.

Goldman, D. et al. 2005. "Consequences of health trends and medical innovation for the elderly of the future," *Health Affairs—Web Exclusive* (26 September): W5-R3–W5-R15.

Gould, B. A. 1869. *Investigations in the Military and Anthropological Statistics of American Soldiers.* New York: Published for the United States Sanitary Commission, by Hurd and Houghton. Cambridge, MA: Riverside Press.

Government Accountability Office. 2005. *Long-Term Care Financing. Growing Demand and Cost of Services Are Straining Federal and State Budgets.* Testimony of Kathryn G. Allen before the House Subcommittee on Health, Committee on Energy and Commerce, 27 April (GAO-05-564T).

Gregg, E. W. et al. 2005. "Secular trends in cardiovascular disease risk factors according to body mass index in US adults," *Journal of the American Medical Association* 293(15): 1868–1874.

Gruenberg, E. M. 1977. "The failure of success," *Milbank Memorial Fund Quarterly,* 55(1): 3–24.

Imperatore, G. et al. 2004. "Thirty-year trends in cardiovascular risk factor levels among US adults with diabetes: National Health and Nutrition Examination Surveys, 1971–2000," *American Journal of Epidemiology* 160(6): 531–539.

Katz, S., A. Ford, R. Moskowitz, B. Jackson, and M. Jaffe. 1963. "Studies of illness of the aged: The index of ADL, a standardized measure of biological and physical function," *Journal of the American Medical Association* 185: 914–919.

Kinter, H. J. 2003. "The life table," in J. S. Siegel and D. A. Swanson (eds.), *The Methods and Materials of Demography.* Second edition. San Diego: Elsevier Academic Press, pp. 301–340.

Kramer, M. 1980. "The rising pandemic of mental disorders and associated chronic diseases and disabilities," *Acta Psychiatrica Scandinavica* 285: 382–397.

Lakdawalla, D. N., J. Bhattacharya, and D. P. Goldman. 2004. "Are the young becoming more disabled? Rates of disability appear to be on the rise among people ages eighteen to fifty-nine, fueled by a growing obesity epidemic," *Health Affairs* 23: 168–176.

Lamb, V. L. 2003. "Health expectancy research in North American countries," in J-M Robine, C. Jagger, C. D. Mathers, E. M. Crimmins, and R. M. Suzman (eds.), *Determining Health Expectancies.* West Sussex, UK: John Wiley and Sons, pp. 377–390.

Lamb, V. L. and J. S. Siegel. 2003. "Health demography," in J. S. Siegel and D. A. Swanson (eds.), *The Methods and Materials of Demography.* Second edition. San Diego: Elsevier Academic Press, pp. 341–370.

Lawton, M. and E. Brody. 1969. "Assessment of older people: Self-maintaining and instrumental activities of daily living," *Gerontology* 9: 179–186.

Lubitz, J., L. Cai, E. Kramarow, and H. Lentzner. 2003. "Health, life expectancy, and health care spending among the elderly," *New England Journal of Medicine* 349(11): 1048–1055.

Luchsinger, J. A., W. Lee, O. Carrasquillo, D. Rabinowitz, and S. Shea. 2003. "Body mass index and hospitalization in the elderly," *Journal of the American Geriatrics Society* 51: 1615–1620.

Manton, K. G. 1989a. "Epidemiological, demographic, and social correlates of disability among the elderly," *Milbank Quarterly* 67(Part 1 Suppl. 2): 13–58.

———. 1989b. "Life-style risk-factors," *Annals of the American Academy of Political and Social Science* 503: 72–88.

———. 1991. "The dynamics of population aging: Demography and policy analysis," *Milbank Quarterly* 69(2): 309–338.

———. 2003. "The future of old age," in J. C. Brocklehurst , R. C. Tallis, and H. M. Fillit (eds.), *Brocklehurst's Textbook of Geriatric Medicine and Gerontology.* Sixth edition. London: Churchill Livingston.

———. 2004. "Aging and longevity of human populations," in L. Martini (ed.), *Encyclopedia of Endocrine Diseases.* San Diego: Elsevier, pp. 116–121

———. 2005a. "The demography of aging," in M. S. J. Pathy, J. E. Morley, and A. Sinclair (eds.), *Principles and Practice of Geriatric Medicine,* Fourth Edition. West Sussex, England: John Wiley & Sons.

———. 2005b. "The stochastic linkage of mortality declines and declines in functional disability," invited paper for *Projecting Mortality*, sponsored by the Office of Policy, Social Security Administration, and the Center for Retirement Research at Boston College, Brookings Institution, Washington, DC.

Manton, K. G. and L. C. Corder. 1998. "Forecasts of future disabled and institutionalized US populations 1995–2040," in T. R. Marmor and P. R. DeJong (eds.), *Ageing, Social Security and Affordability*. Aldershot, Hants, England: Ashegate, pp. 327–348.

Manton, K. G., and X. Gu. 2001. "Changes in the prevalence of chronic disability in the United States black and nonblack population above age 65 from 1982 to 1999," *Proceedings of the National Academy of Sciences, USA* 98(11): 6354–6359.

———. 2005. "Disability declines and trends in Medicare expenditures," *Ageing Horizons* 2(1): 25–34.

Manton, K. G. and V. L. Lamb. 2005a. "Medicare cost effects of recent US disability trends in the elderly: Future implications," invited presentation for *Understanding Trends in Disability Among Elderly Populations and the Implications of Demographic and Non-Demographic Factors for Future Health and Long-Term Care Costs*, organized by the European Commission and the OECD Working Group on Ageing, Brussels, Belgium.

———. 2005b. "US mortality, life expectancy, and active life expectancy at advanced ages: Trends and forecasts," presented at the International Congress of the International Union for the Scientific Study of Population, Tours, France.

Manton K. G. and K. C. Land. 2000. "Active life expectancy estimates for the US elderly population: A multidimensional continuous-mixture model of functional change applied to completed cohorts, 1982 to 1996," *Demography* 37(3): 253–265.

Manton K. G. and A. I. Yashin. 2000. *Mechanisms of Aging and Mortality: Searches for New Paradigms*. Monographs on Population Aging, 7, Odense University Press, Odense, Denmark.

Manton, K. G., L. S. Corder, and E. Stallard. 1993a. "Estimates of change in chronic disability and institutional incidence and prevalence rates in the U. S. elderly population from the 1982, 1984, and 1989 National Long Term Care Survey," *Journal of Geronotology: Social Sciences* 48(4): S153–S166.

———. 1993b. "Changes in the use of personal assistance and special equipment from 1982 to 1989: Results from the 1982 and 1989 NLTCS," *The Gerontologist* 33(2): 168–176.

———. 1997. "Chronic disability trends in elderly United States populations: 1982–1994," *Proceedings of the National Academy of Sciences, USA* 94: 2593–2598.

Manton, K. G., E. Stallard, and L. S. Corder. 1998. "Dynamics of dimensions of age-related disability 1982 to 1994 in the US elderly population," *Journal of Gerontology: Biological Sciences* 53A(1): B59–B70.

Manton, K. G., X. Gu, and G. L. Lowrimore. 2005a. "The use of meta data in assessing results from a longitudinal survey: The 1982–1999 National Long Term Care Survey," Working paper, Center for Demographic Studies, Duke University.

Manton, K. G., I. Akushevich, and A. Kulminski. 2005b. "Human mortality at extreme ages: New data and analysis," paper presented at the Annual Meeting of the Population Association of America, Philadelphia.

McGinnis, J. M. and W. H. Foege. 1993. "Actual causes of death in the United States," *Journal of the American Medical Association* 270: 2207–2212.

Miller, M. E. 2005. "Pay for performance," testimony presented before the Committee on Finance, US Senate, 27 July «http://www.medpac.gov/publications/congressional_testimony/Testimony_P4P.pdf».

Myers, G. C. 1981. "Future age projections and society," in A. Gilmore (ed.), *Aging: A Challenge to Science and Social Policy*. Oxford: Oxford University Press, pp. 248–260.

National Center for Health Statistics. 1999. *US Decennial Life Tables for 1989–1991,* Vol. 1, No. 3, *Some Trends and Comparisons of United States Life Table Data: 1900–1991*. Hyattsville, MD: NCHS.

Oeppen, J. and J. W. Vaupel. 2002. "Broken limits to life expectancy," *Science* 296: 1029, 1031.

Olshansky, S. J. et al. 2005. "A potential decline in life expectancy in the United States in the 21st century," *New England Journal of Medicine* 352(11): 1138–1145.

Omran, A. R. 1971. "The epidemiologic transition: A theory of the epidemiology of population change," *Milbank Memorial Fund Quarterly* 49(4): 509–538.

Pardes, H. et al. 1999. "Effects of medical research on health care and economy," *Science* 283: 36–37.

Reynolds, S. L., Y. Saito, and E. M. Crimmins. 2005. "The impact of obesity on active life expectancy in older American men and women," *The Geronologist* 45(4): 438–444.

Robine, J-M., C. Jagger. C. D. Mathers, E. M. Crimmins, and R. M. Suzman (eds.). 2003a. *Determining Health Expectancies*. West Sussex, UK: John Wiley and Sons.

Robine, J-M., I. Romieu, and J-P. Michel. 2003b. "Trends in health expectancies," in J-M Robine, C. Jagger, C. D. Mathers, E. M. Crimmins, and R. M. Suzman (eds.), *Determining Health Expectancies*. West Sussex, UK: John Wiley and Sons, pp. 75–101.

Schoeni, R., V. Freedman, and R. Wallace. 2001. "Persistent, consistent, widespread, and robust? Another look at recent trends in old-age disability," *Journal of Gerontology: Social Sciences* 56(4): S206–S218.

Singer, B. and K. G. Manton. 1998. "The effects of health changes on projections of health service needs for the elderly population of the United States," *Proceedings of the National Academy of Sciences, USA* 95(26): 15618–15622.

Social Security Administration. 2005. *A Summary of the 2005 Annual Social Security and Medicare Trust Fund Reports.* «http://www.ssa.gov/OACT/TRSUM/tr05summary.pdf». Retrieved 6/04/05.

Spillman B. and J. Lubitz. 2000. "The effect of longevity on spending for acute and long-term care," *The New England Journal of Medicine* 342(19): 1409–1415.

Sullivan, D. F. 1971. "A single index of mortality and morbidity," *HSMHA Health Reports* 86: 347–354.

Tolley, H. D., H. Palmer, and K. G. Manton. 2005. "On government funding of health care research," Working Paper, Center for Demographic Studies, Duke University.

Waidmann, T. and K. Liu. 2000. "Disability trends among the elderly and implications for future medicare spending," *Journal of Gerontology: Social Sciences* 55(5): S298–S307.

World Health Organization. 2000. *World Health Report 2000.* Geneva: World Health Organization.

Yashin, A. I. and K. G. Manton. 1997. "Effects of unobserved and partially observed covariate processes on system failure: A review of models and estimation strategies," *Statistical Science* 12(1): 20–34.