Falling Short of Highest Life Expectancy: How Many Americans Might Have Been Alive in the Twentieth Century

Magdalena M. Muszyńska

Roland Rau

The extraordinary improvements in human longevity over the twentieth century resulted in a steady increase in highest life expectancy of 3.0 months per year for females and 2.4 months for males.[1] At the same time, in the United States the average increase in life duration was 3.7 months annually for females and 3.3 months for males.[2] As a result, in 2000 the gap between life expectancy in the United States and the record value of life expectancy was considerably smaller than at the beginning of the twentieth century. Since the early 1980s, however, we observe faster increases in the mean duration of life for both sexes in the record-holding country than in the United States.

While the reasons for the comparatively poor performance of the United States are not fully understood, various explanations have been advanced. One is that—as a result of an undercount of deaths at older ages—life expectancy before the 1980s was overestimated, and improvements in data quality over time produced more accurate values of life expectancy (Coale and Kisker 1986; Manton and Vaupel 1995; Shrestha and Preston 1995). According to Meslé and Vallin (2006: 134), however, "problems with data quality are far from sufficient to explain recent unfavorable trends in US life expectancy at age 65." They conjecture that the United States—in contrast to countries like Japan or France—has not yet entered a new stage in the health transition in which mortality at advanced ages is substantially reduced. Other theories addressing these non-optimal improvements in life expectancy in the United

States discuss the lack of universal health care coverage (Torrey and Haub 2004), the obesity epidemic (Torrey and Haub 2004; Preston 2005), the emergence of new disease categories related to mental health (Meslé and Vallin 2006), and the consequences of smoking (Pampel 2002; Preston and Wang 2006).

Our aim here is to evaluate the effect of the mortality disadvantage in the twentieth century on the size and structure of the US population at the end of the century. Results obtained in this study are complementary to those presented by White and Preston (1996), where the authors—asking "How many Americans are alive because of twentieth-century improvements in mortality?"—compared the actual population size and structure in the year 2000 with one they projected assuming no mortality improvements since 1900. According to their study, the population in 2000 would have been half as large as the observed 276 million had death rates remained constant from 1900 until 1999 with fertility and migration at the actual levels. The largest share of this difference was attributed to improvements in infant, child, and young-adult mortality during the first decades of the twentieth century. Nevertheless, advances in survival during recent decades also resulted in considerable numbers of lives saved. White and Preston estimated that the population of the United States would have been smaller by 12 million persons in 2000—approximately the population of Illinois, Ohio, or Pennsylvania—if no further improvements in mortality had been achieved since 1960. The advancement in mortality reduction seen in the United States, however, could have been even greater if they had conducted the same exercise for countries with the lowest mortality.

We ask how many Americans could be alive in 2000 had mortality in the United States over the last century been the lowest possible at the time, and how the age and sex structure of this hypothetical population would differ from the observed structure. The lowest possible age-specific death rates in each year were taken from the country with the highest life expectancy in the respective year.

Methods and data

Method

We estimated the number of Americans who might have been alive, assuming the record mortality regime, in a female-based projection using the cohort component method (Preston et al. 2001; Shryock and Siegel 1976; Smith et al. 2002). As the first step in this method, we projected forward for each time interval the population that would still be alive at the beginning of the next interval, applying the probabilities of survival from the countries with record life expectancy. Second, we computed the number of newborns in that time interval who survived to the beginning of the next interval. Finally, we adjusted the size of the population at the beginning of an interval by the number of net migrants in each subgroup in the previous time interval. Because we assume that migration occurs at the end of a period, we do not need to adjust the total number of newborns for births that occurred to immigrants in the time interval during which they entered the United States. In addition, we assumed fertility rates and the volume of migration would have been unaffected by the change in mortality.

In the years 1935–2000, for single year and age, separately for both sexes, we projected the hypothetical population at the beginning of the year by applying the record probabilities of surviving, fertility rates, and estimated net migration to the population on 1 January of the previous year. For reasons of data availability, the estimates for the years 1900–1935 were made in five-year intervals of time and age. The record probabilities of survival were derived for countries with the highest value of life expectancy at birth in five-year intervals.

While numbers of males and females above age zero were estimated in separate projections, we assume that births are attributed to women only. In this "female-dominant" model the number of newborns was estimated by applying the single-age-specific fertility rates to the number of women in a given age group in the middle of a calendar year. The number of children under age one year who survived to 1 January 2000 was adjusted using the probability of dying for babies born in year 1999 (the lower right triangle in a conventionally drawn Lexis diagram).

Before comparing the total size of the actual population with the total number of people alive in the hypothetical scenario, we added to the latter the number of men and women aged 101 and older in the actual US population (alive on 1 January 2000). We argue that any error resulting from applying observed US death rates instead of record values to our hypothetical population at ages above 100 is negligible. Remaining life expectancy for men at age 101 in 1999 in the United States was the highest in the world, which means that for these ages mortality can be considered the record value. For women the potential error resulting from this approximation is small: in Japan, which in 1999 was the leading country in mortality at the highest ages, remaining life expectancy at age 101 was 2.2 years, compared to 2.1 years in the United States.

The number of people who might have been alive in 2000, assuming the record mortality regime, consists of those whose lives could have been saved in the last century and of those who would have been born otherwise: those whose parents' lives could have been saved and who, being alive, would give birth, and those whose grandparents would not have died before giving birth to their parents, and so on. To derive this cumulative effect of lost reproductive resources, we distinguish between (1) direct deaths (first generation) and

(2) indirect deaths (second and higher generations). To distinguish indirect deaths, we apply age-specific fertility rates to the number of women who might otherwise have been alive in each year over the period between 1900 and 1999 and age these newborns by applying probabilities of surviving until 1 January 2000 as in the countries with record life expectancy.

All estimations were carried out in the language R (R Development Core Team 2008).

Data

Population. US population counts in five-year age groups for ages 0 to 100, and the aggregate number of persons aged 101+, were taken from Haines (2006b) for every ten years between 1900 and 1930. For the years 1905, 1915, and 1925 we use the total size of the population derived from the US Bureau of the Census (1975), redistributed to five-year age groups, separately for males and females, according to the structure derived by assuming a linear change in the population distribution between ten adjusting years. The US population counts as of 1 January for the years 1935–2000 were obtained from the Human Mortality Database (2008) in single-year age groups for ages 0 to 100 and as an aggregate number of those aged 101 and older.

Fertility. No single source of data is available on fertility for the whole US population before the year 1920. Total fertility rates (TFRs) between 1900 and 1915 were derived separately for white women from Coale and Zelnik (1956) and for black women from Coale and Rives (1973). These rates were combined to obtain the TFR by weighting according to the number of women of reproductive age in each racial group.

The TFRs in 1900–04 and 1905–09 were redistributed into age-specific fertility rates using the age pattern estimated by Haines (1989) for the years 1900–10. Rates in the 1910s were redistributed to five-year age groups assuming linear change in the distribution between 1910 and 1920. Age-specific fertility rates in 1920–30 were obtained from the period estimates of Heuser (1976) and aggregated into five-year age groups. The data on age-specific fertility rates for five-year groups in 1935–99 were taken from *Vital Statistics* (National Center for Health Statistics). The sex ratio (M/F) at birth according to the age of a mother in five-year age groups for 1940–99 was derived from the same data source. The mean value of the sex ratio at birth was 1.05 over this period, with a typical standard deviation of 0.02 by age of the mother.[3]

Mortality. Highest survival probabilities were derived for each calendar year and both sexes from age-specific death rates observed in the country with the record life expectancy in a given year. To obtain highest survival, we retrieved data for the following low-mortality countries from the Human

Mortality Database (2008): Australia, Canada, Denmark, England and Wales, Finland, France, Iceland, Italy, Japan, Netherlands, New Zealand (non-Maori population), Norway, Sweden, Switzerland, and the United States. For each single year between 1900 and 1999, we used age-specific death rates from the country with the highest life expectancy in each year. Because the US mortality data in the Human Mortality Database (2008) starts only in 1933, for the years 1900–30 we applied death rates from Haines (2006a). Life expectancy in the United States for the record-value comparisons and migration estimations in the years 1900–30 are from Bell and Miller (2005).

Migration. Similar to White and Preston (1996), we estimated net migration to the United States in the twentieth century by comparing the actual population as of 1 January each year (1901–2000) to the population projected by applying age-specific fertility rates and probabilities of survival to the population of the previous year. Net migration was estimated by age and sex under the assumption that it occurs at the end of the year. In our projections with the highest life expectancy, migrants and their children were exposed to the same survival probabilities as the native-born population.

Results

Our main interest is the effect of a hypothetical mortality regime on population size and structure of the United States, assuming that the level of fertility and the volume of migration remained at actual levels. Because of the major role mortality plays in our analysis, we first present an overview of the development of the US mortality disadvantage by age during the twentieth century.

Although it has never been the record holder in life expectancy (see Table 1), US mortality in some years at certain ages was the lowest observed among low-mortality countries, as shown in Table 2. This table gives decadal averages of the ratio of US death rates to the corresponding rates from countries with record life expectancy for ten-year age groups separately for females and males.[4] Values below 1.0 indicate that US mortality was lower than the death rate observed in the country with highest life expectancy in that decade. The large gap in life expectancy between the United States and the respective record-holding country results primarily from high infant mortality. At the beginning of the twentieth century and again from the 1980s onward, US infant mortality was twice as high as in the record-holding country. In recent years, for males, survival disadvantages are largest at young-adult ages (20–40 years). But also for females at reproductive ages, mortality was typically at least 50 percent higher than in the countries with highest life expectancy. We conjecture that the elevated female mortality at young-adult ages implies a large cumulative effect on lives lost in a long-

TABLE 1 Population and life expectancy at birth for the United States and for countries with highest life expectancy (HLE) and difference in e_0 between HLE country and the US (in years and as a ratio), 1900–99, separately for females and males

	Females							Males						
Years	US population (millions)	US e_0	HLE	Country with HLE	HLE pop. (millions)	HLE – US e_0	HLE / US e_0	US population (millions)	US e_0	HLE	Country with HLE	HLE pop. (millions)	HLE – US e_0	HLE / US e_0
1900–04	39	47.2	60.4	New Zealand	0.4	13.2	1.28	41	49.3	57.9	New Zealand	0.4	8.6	1.17
1905–09	43	49.4	62.0	New Zealand	0.4	12.6	1.25	45	52.5	59.3	New Zealand	0.5	6.9	1.13
1910–14	47	52.0	63.6	New Zealand	0.5	11.6	1.22	49	55.8	60.6	New Zealand	0.5	4.8	1.09
1915–19	50	53.1	62.9	New Zealand	0.5	9.8	1.18	52	55.7	58.7	New Zealand	0.6	3.0	1.05
1920–24	54	55.6	65.0	New Zealand	0.6	9.4	1.17	56	57.6	62.4	New Zealand	0.6	4.8	1.08
1925–29	59	57.9	66.7	New Zealand	0.7	8.8	1.15	60	61.1	63.9	New Zealand	0.7	2.8	1.05
1930–34	62	59.0	68.2	New Zealand	0.7	9.2	1.16	63	62.8	65.5	New Zealand	0.7	2.8	1.04
1935	63	63.1	69.2	New Zealand	0.7	6.1	1.10	64	59.0	66.4	New Zealand	0.7	7.5	1.13
1936	63	62.6	68.5	New Zealand	0.7	5.9	1.09	64	58.4	66.1	Netherlands	3.1	7.7	1.13
1937	64	63.4	68.6	New Zealand	0.7	5.2	1.08	65	59.0	66.2	Netherlands	3.1	7.2	1.12
1938	64	64.6	69.0	Norway	1.5	4.4	1.07	65	60.5	66.5	Netherlands	3.1	6.1	1.10
1939	65	65.3	69.3	New Zealand	0.8	4.0	1.06	65	61.1	66.9	Netherlands	3.1	5.8	1.10
1940	66	65.6	69.7	New Zealand	0.8	4.1	1.06	66	61.1	66.1	New Zealand	0.8	5.0	1.08
1941	66	66.3	69.2	New Zealand	0.8	2.9	1.04	66	61.6	65.8	New Zealand	0.8	4.2	1.07
1942	67	67.2	70.4	Sweden	3.2	3.2	1.05	67	62.3	67.6	Sweden	3.2	5.3	1.08
1943	68	66.9	70.1	Sweden	3.3	3.2	1.05	66	61.9	67.3	Sweden	3.2	5.4	1.09
1944	69	67.8	70.0	New Zealand	0.8	2.2	1.03	65	62.5	66.3	Australia	3.7	3.8	1.06
1945	69	68.3	70.5	Norway	1.6	2.1	1.03	63	63.0	67.2	Sweden	3.3	4.2	1.07
1946	70	69.0	71.7	Iceland	0.1	2.7	1.04	66	63.8	68.3	Sweden	3.3	4.6	1.07
1947	72	69.5	71.7	Norway	1.6	2.2	1.03	70	64.2	68.3	Norway	1.6	4.2	1.06
1948	73	70.1	72.9	Norway	1.6	2.8	1.04	72	64.7	69.7	Netherlands	3.4	5.0	1.08
1949	74	70.5	73.2	Iceland	0.1	2.7	1.04	73	65.0	70.0	Norway	1.6	5.0	1.08
1950	76	71.0	73.5	Iceland	0.1	2.5	1.04	74	65.4	70.3	Netherlands	3.5	4.9	1.08

1951	77	71.2	74.3	Norway	1.7	3.1	1.04	75	65.4	70.8	Norway	1.6	5.4	1.08
1952	78	71.5	74.9	Iceland	0.1	3.4	1.05	76	65.6	71.0	Norway	1.6	5.5	1.08
1953	80	71.9	75.1	Norway	1.7	3.1	1.04	77	65.8	71.2	Norway	1.7	5.4	1.08
1954	81	72.7	75.6	Iceland	0.1	2.9	1.04	79	66.6	71.3	Norway	1.7	4.8	1.07
1955	83	72.8	75.9	Iceland	0.1	3.1	1.04	80	66.6	71.5	Norway	1.7	5.0	1.07
1956	84	73.0	75.5	Norway	1.7	2.6	1.04	82	66.6	71.5	Iceland	0.1	4.9	1.07
1957	86	72.7	75.5	Norway	1.7	2.8	1.04	83	66.4	71.7	Iceland	0.1	5.4	1.08
1958	87	73.0	76.0	Iceland	0.1	3.0	1.04	85	66.6	71.5	Sweden	3.7	4.9	1.07
1959	89	73.3	75.8	Norway	1.8	2.5	1.03	87	66.8	71.6	Sweden	3.7	4.8	1.07
1960	91	73.3	75.9	Norway	1.8	2.5	1.03	88	66.6	72.5	Iceland	0.1	5.8	1.09
1961	92	73.7	76.2	Iceland	0.1	2.5	1.03	89	67.0	71.6	Sweden	3.7	4.6	1.07
1962	94	73.6	76.1	Iceland	0.1	2.5	1.03	91	66.9	71.4	Iceland	0.1	4.5	1.07
1963	95	73.5	76.0	Iceland	0.1	2.5	1.03	92	66.6	71.5	Sweden	3.8	4.9	1.07
1964	97	73.8	76.4	Iceland	0.1	2.5	1.03	93	66.8	71.6	Sweden	3.8	4.8	1.07
1965	98	73.9	76.5	Norway	1.9	2.6	1.04	94	66.8	71.7	Sweden	3.9	4.9	1.07
1966	99	74.0	76.7	Norway	1.9	2.7	1.04	95	66.7	71.9	Sweden	3.9	5.2	1.08
1967	101	74.3	76.9	Norway	1.9	2.6	1.04	96	66.9	71.9	Sweden	3.9	4.9	1.07
1968	102	74.1	76.8	Norway	1.9	2.7	1.04	97	66.6	71.7	Sweden	3.9	5.2	1.08
1969	103	74.4	76.7	Norway	1.9	2.3	1.03	98	66.8	71.7	Sweden	4.0	5.0	1.07
1970	104	74.7	77.3	Norway	1.9	2.7	1.04	99	67.0	72.2	Sweden	4.0	5.2	1.08
1971	105	75.0	77.4	Sweden	4.0	2.4	1.03	100	67.4	72.0	Sweden	4.0	4.6	1.07
1972	107	75.1	77.5	Sweden	4.1	2.4	1.03	101	67.4	72.1	Iceland	0.1	4.7	1.07
1973	108	75.3	77.7	Sweden	4.1	2.4	1.03	102	67.6	72.2	Sweden	4.1	4.5	1.07
1974	109	75.9	77.9	Norway	2.0	2.1	1.03	103	68.2	72.2	Sweden	4.1	4.0	1.06
1975	110	76.5	78.7	Iceland	0.1	2.2	1.03	104	68.7	72.2	Iceland	0.1	3.5	1.05
1976	111	76.7	79.9	Iceland	0.1	3.2	1.04	105	69.1	73.7	Iceland	0.1	4.6	1.07
1977	112	77.1	79.2	Iceland	0.1	2.2	1.03	106	69.4	73.2	Iceland	0.1	3.7	1.05
1978	113	77.2	79.3	Iceland	0.1	2.1	1.03	107	69.6	73.7	Iceland	0.1	4.0	1.06
1979	115	77.7	79.4	Iceland	0.1	1.7	1.02	108	70.0	74.0	Iceland	0.1	3.9	1.06

TABLE 1 (continued)

	Females							Males						
Years	US population (millions)	US e_0	HLE	Country with HLE	HLE pop. (millions)	HLE – US e_0	HLE / US e_0	US population (millions)	US e_0	HLE	Country with HLE	HLE pop. (millions)	HLE – US e_0	HLE / US e_0
1980	116	77.5	80.1	Iceland	0.1	2.6	1.03	110	70.0	73.4	Iceland	0.1	3.4	1.05
1981	117	77.8	79.6	Iceland	0.1	1.8	1.02	111	70.4	73.8	Japan	57.3	3.4	1.05
1982	119	78.1	79.7	Japan	59.7	1.6	1.02	112	70.8	74.5	Iceland	0.1	3.7	1.05
1983	120	78.1	80.4	Iceland	0.1	2.3	1.03	113	71.0	74.2	Japan	58.2	3.3	1.05
1984	121	78.2	80.3	Japan	60.5	2.1	1.03	114	71.1	74.7	Iceland	0.1	3.6	1.05
1985	122	78.2	80.5	Japan	60.9	2.3	1.03	115	71.1	74.9	Japan	58.9	3.8	1.05
1986	123	78.3	81.0	Japan	61.2	2.7	1.03	116	71.2	75.4	Iceland	0.1	4.3	1.06
1987	124	78.4	81.4	Japan	61.5	3.0	1.04	117	71.3	75.6	Japan	59.5	4.3	1.06
1988	125	78.3	81.3	Japan	61.8	3.0	1.04	118	71.3	75.6	Japan	59.7	4.2	1.06
1989	126	78.6	81.8	Japan	62.1	3.2	1.04	120	71.6	76.1	Iceland	0.1	4.5	1.06
1990	127	78.9	81.9	Japan	62.3	3.0	1.04	121	71.9	75.9	Japan	60.1	4.1	1.06
1991	129	79.0	82.2	Japan	62.5	3.2	1.04	122	72.1	76.2	Japan	60.3	4.1	1.06
1992	130	79.2	82.3	Japan	62.7	3.1	1.04	124	72.4	76.7	Iceland	0.1	4.3	1.06
1993	132	79.0	82.5	Japan	62.9	3.5	1.04	126	72.2	77.0	Iceland	0.1	4.8	1.07
1994	134	79.1	82.9	Japan	63.1	3.8	1.05	128	72.5	77.1	Iceland	0.1	4.6	1.06
1995	135	79.2	82.8	Japan	63.3	3.6	1.05	129	72.7	76.4	Japan	60.9	3.8	1.05
1996	137	79.4	83.5	Japan	63.4	4.2	1.05	131	73.2	77.0	Japan	61.0	3.9	1.05
1997	139	79.5	83.8	Japan	63.6	4.2	1.05	133	73.7	77.2	Japan	61.1	3.6	1.05
1998	140	79.6	84.0	Japan	63.8	4.4	1.06	134	74.0	77.7	Iceland	0.1	3.7	1.05
1999	142	79.5	84.0	Japan	64.0	4.5	1.06	136	74.1	77.4	Iceland	0.1	3.4	1.05

SOURCES: Highest life expectancy and populations (1900–99), US life expectancy and population (1935–99): Human Mortality Database (2008); US life expectancy and US population (1900–34): Haines (2006a), US Bureau of the Census (1975).

term perspective: if a woman dies before giving birth, not only are her future children not born, but those children will not give birth to grandchildren, and so on.

For long periods of time, however, the United States appears to have had the best survival chances at advanced ages (Manton and Vaupel 1995). Although the advantage is dwindling, the United States is still doing much better at late ages than at younger ages in comparison to other low-mortality countries.

Table 3 provides an overview in 20-year periods of gains in record life expectancy and US life expectancy, of how many lives were saved as a result of improvements in mortality, and of how many potential lives could have been saved as a result of the difference between record-holding life expectancy and US life expectancy, separately for females, males, and both sexes combined. Generally speaking, US life expectancy was catching up to the record-holding country for the first six decades for females and the first four decades for males. For instance, female life expectancy in the United States rose between 1900 and 1920 by 3.7 months per year, whereas in the record-holding country, New Zealand (non-Maori), life expectancy grew annually by one month. Since 1980, life expectancy grew more slowly in the United States than in the record-holding country, especially among women (1.3 months vs. 2.7 months per year).

In the next two columns in Table 3, we provide figures on the number of people whose lives were saved by improvements in mortality and whose lives could have been saved under highest-life-expectancy conditions in each 20-year period. In all periods other than 1940–60, the number of people who could have been alive under the highest-life-expectancy level exceeds the actual number of lives saved by mortality improvements in the United States.

The two last columns show how many people are alive because of mortality improvements in the twentieth century ("Lives saved") and how many lives could have been saved had those improvements been optimal ("Potential lives saved"). These numbers are different from a simple aggregation of the previous two columns because the two last columns include the accumulation up to the year 2000 of descendants of those whose lives were saved/potentially saved in those 20-year periods.

Figures 1 and 2 illustrate how the numbers of potential lives saved accumulated since 1900 separately for males and females and in three age groups. The US population would have been smaller by 145 million people—or approximately 50 percent—had mortality remained at the levels of 1900. This number is truly remarkable and is comparable to the 137 million estimated by White and Preston (1996). Had mortality in the United States been at highest-life-expectancy levels throughout the twentieth century, even more lives could have been saved: an additional 66 million, split evenly between females and males. The number of lives saved in the years 1920–2000 is more than three times as high as the number of lives that could have been saved

TABLE 2 Decadal average ratio of US mortality rates to rates from countries with highest life expectancy for ten-year age groups, 1900–99, separately for females and males

Sex and age group	1900–09	1910–19	1920–29	1930–39	1940–49	1950–59	1960–69	1970–79	1980–89	1990–99
Females										
0	1.83	2.04	1.85	1.91	1.43	1.42	1.56	1.62	2.04	1.95
1–9	2.57	2.18	1.67	1.63	0.98	0.96	1.02	1.47	1.17	1.10
10–19	1.64	1.68	1.69	1.62	1.20	1.58	1.55	1.86	2.18	1.97
20–29	1.56	1.58	1.61	1.46	0.98	1.48	1.87	2.07	1.93	1.78
30–39	1.51	1.45	1.51	1.50	1.28	1.42	1.86	1.65	1.61	1.86
40–49	1.44	1.48	1.47	1.49	1.36	1.53	1.62	1.58	1.51	1.63
50–59	1.38	1.37	1.39	1.42	1.41	1.60	1.48	1.41	1.69	1.80
60–69	1.31	1.28	1.32	1.28	1.29	1.32	1.32	1.21	1.49	1.84
70–79	1.16	1.12	1.13	1.14	1.16	1.14	1.02	1.11	1.12	1.42
80–89	—	—	—	—	1.03	0.99	0.93	0.94	0.92	1.06
90–99	—	—	—	—	0.89	0.96	0.91	0.96	0.89	0.96
Males										
0	2.27	2.45	2.37	2.02	1.42	1.49	1.72	1.81	2.08	2.33
1–9	2.78	2.36	1.89	1.62	1.00	0.91	1.21	1.15	1.68	1.40
10–19	1.72	1.77	1.86	1.77	1.21	1.42	1.61	1.57	1.59	1.90
20–29	1.67	1.77	1.58	1.75	1.31	1.46	1.61	1.75	1.88	2.45
30–39	1.73	1.75	1.62	1.88	1.53	1.55	1.52	1.47	1.80	2.29
40–49	1.76	1.91	1.73	2.03	1.69	1.87	1.82	1.55	1.45	1.89
50–59	1.63	1.72	1.63	1.78	1.66	1.82	1.71	1.49	1.46	1.49
60–69	1.51	1.51	1.54	1.46	1.38	1.56	1.50	1.41	1.40	1.40
70–79	1.28	1.26	1.26	1.21	1.17	1.22	1.17	1.26	1.17	1.13
80–89	—	—	—	—	1.04	1.02	0.99	1.06	1.03	1.01
90–99	—	—	—	—	0.91	0.91	0.88	0.92	0.95	0.99

SOURCE: Authors' estimates based on data from Haines (2006a) and Human Mortality Database (2008).

TABLE 3 Average 20-year improvement in US life expectancy and in highest life expectancy (HLE), number of lives saved because of improvements in mortality in the United States, and number of potential lives that could have been saved with record-level life expectancy in 1900–2000, 1920–2000, 1940–2000, 1960–2000, and 1980–2000

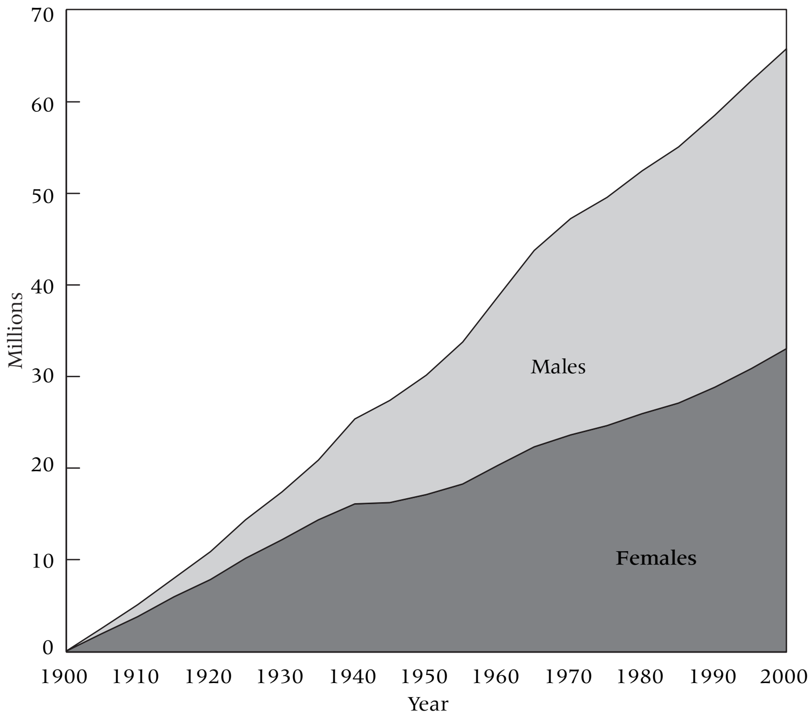
Sex and years	Average annual improvement (in months) US e_0	HLE	Lives saved (millions)	Potential lives saved (millions)	Years	Lives saved (millions)	Potential lives saved (millions)
Females							
1900–20	3.7	1.0	2	8	1900–2000	83	33
1920–40	6.6	4.4	2	7	1920–2000	62	15
1940–60	4.6	3.7	3	2	1940–2000	20	6
1960–80	2.5	2.5	2	2	1960–2000	6	5
1980–2000	1.3	2.7	1	4	1980–2000	1	4
Males							
1900–20	3.9	0.9	1	3	1900–2000	62	33
1920–40	4.5	3.6	1	3	1920–2000	40	16
1940–60	3.3	3.8	3	3	1940–2000	17	7
1960–80	2.0	0.6	1	4	1960–2000	6	6
1980–2000	2.6	2.7	2	4	1980–2000	2	4
Total							
1900–20	3.8	0.9	3	11	1900–2000	145	66
1920–40	5.5	4.0	2	10	1920–2000	101	31
1940–60	4.0	3.7	6	5	1940–2000	37	12
1960–80	2.4	1.5	3	6	1960–2000	12	10
1980–2000	1.9	2.8	4	7	1980–2000	4	7

SOURCES: Record life expectancy: Human Mortality Database (2008); US life expectancy (1940–2000): Human Mortality Database (2008); US life expectancy (1900–30): Haines (2006a).

under the record mortality regime. Similar observations can be made for the years between 1940 and 1960. Results of the estimates for 1960–2000 can be characterized as being roughly equally divided between number of lives saved and potential number of lives saved. As a result of the slowdown in the improvements in life expectancy in the United States since the early 1980s, in conjunction with remarkable improvements in the record-holding country, Japan, the number of potential lives saved in the last two decades exceeds the number of lives actually saved for the first time in our analysis. While fewer than 4 million lives have been saved because of mortality improvements, more than 7 million lives could have been saved had US mortality been at the level of the highest-life-expectancy countries.

Table 4 provides further insight into the age distribution of lives that could have been saved with optimal mortality improvements in the twentieth century. Below age 65, the population resulting from the highest-life-expectancy country over the last century would have been higher by about 20

FIGURE 1 Potential lives saved (millions) since 1900 if the United States had attained record-level life expectancy, females and males

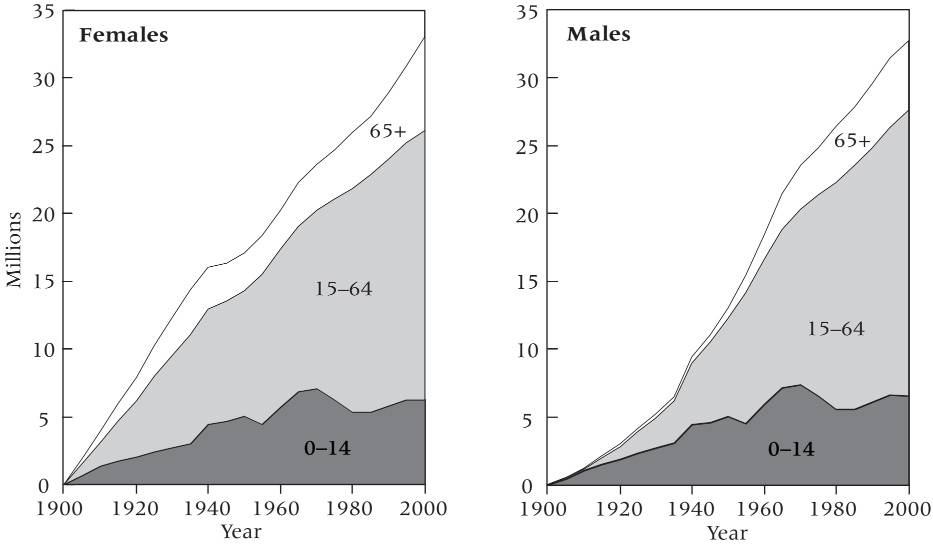


SOURCE: Authors' estimates.

percent than the one observed. This proportion grows with increasing age. According to our estimates, the population above working ages (ages 65+) would have been larger than the actual one by about one-third (33 percent for women, 37 percent for men, and 35 percent for both sexes combined).

As mentioned in the opening paragraphs, an important component of our analysis is the cumulative effect of potential lives saved on the final population size and structure in 2000. Table 5 decomposes the number of potential lives saved by age, sex, and generation. For simplicity, we differentiate only between the first generation (direct deaths) and all subsequent generations (indirect deaths). With the first generation, we refer to people who would not have died had mortality in the United States been the lowest observed. For example, mortality among adolescent men was rather high in the early 1990s in the United States. Many young males would still have been alive in 2000 had death rates among them been lower. These deaths are part of the "first generation." Imagine, however, a woman who died during the 1950s at age 20. It is quite probable that she would have given birth to at least one (more) child. This child would have been less than 50 years old in 2000 and

FIGURE 2 Potential lives saved (millions) since 1900 if the United States had attained record-level life expectancy, by age group, females and males



SOURCE: Authors' estimates.

therefore almost certainly still alive then. Such individuals were counted as belonging to the second generation of potential lives saved had mortality in the United States been the lowest possible in the last century.

Out of 66 million lives that might have been saved, 21 million (or about 32 percent) fall in the category of first-generation or direct deaths. The fact that 68 percent or 45 million come from the second or higher generations illustrates the importance of the cumulative effect of suboptimal mortality on population size. Again, the differences between females and males in the numbers of potential lives saved in the second and higher generations are rather negligible. With increasing age the proportion of lives saved in the second and higher generations in relation to all lives saved is gradually decreasing. There are two reasons behind this phenomenon. First, the number of direct deaths at older ages is higher as a result of higher absolute differences in mortality at those ages between the United States and the record-holding country. Second, lives lost at younger ages consist of more than one generation of indirect deaths, hence their number has accumulated over a longer period. As an extreme example, if one assumes a young age at childbearing of 15 years, then children aged 0–5 years in 2000 would consist of up to six generations of persons who were not born because their mothers, grandmothers, and so on died before childbirth. On the other hand, persons aged 50–55 who could be alive in 2000 represent fewer generations of lives lost, hence comprise indirect deaths that accumulated over a shorter period. In addition, their number has been depleted since ages 0–5 because those individuals had to survive from birth to age 50–55 in 2000.

TABLE 4 Hypothetical and actual US population as of 1 January 2000 (in thousands): Estimated with death rates from countries with highest life expectancy (HLE)

	Females				Males				Total			
Age group	With HLE mortality	With actual mortality	Potential lives saved	HLE / actual	With HLE mortality	With actual mortality	Potential lives saved	HLE / actual	With HLE mortality	With actual mortality	Potential lives saved	HLE / actual
0–4	11,277	9,356	1,921	1.21	11,841	9,802	2,040	1.21	23,119	19,158	3,961	1.21
5–9	12,200	10,041	2,159	1.22	12,806	10,538	2,268	1.22	25,006	20,579	4,427	1.22
10–14	12,099	9,958	2,141	1.21	12,737	10,468	2,268	1.22	24,836	20,427	4,409	1.22
15–19	11,801	9,821	1,980	1.20	12,471	10,384	2,088	1.20	24,272	20,205	4,068	1.20
20–24	10,879	9,198	1,681	1.18	11,389	9,604	1,785	1.19	22,268	18,802	3,466	1.18
25–29	11,348	9,640	1,709	1.18	11,663	9,844	1,819	1.18	23,011	19,484	3,527	1.18
30–34	12,209	10,183	2,025	1.20	12,508	10,313	2,196	1.21	24,717	20,496	4,221	1.21
35–39	14,101	11,447	2,654	1.23	14,278	11,378	2,900	1.25	28,378	22,825	5,554	1.24
40–44	13,804	11,255	2,549	1.23	13,939	11,068	2,871	1.26	27,743	22,324	5,420	1.24
45–49	12,046	10,159	1,887	1.19	11,978	9,844	2,134	1.22	24,025	20,004	4,021	1.20
50–54	10,408	8,859	1,549	1.17	10,269	8,490	1,780	1.21	20,678	17,349	3,329	1.19
55–59	8,261	6,906	1,355	1.20	7,917	6,454	1,463	1.23	16,177	13,359	2,818	1.21
60–64	8,181	5,646	2,534	1.45	7,612	5,114	2,498	1.49	15,792	10,760	5,033	1.47
65–69	6,457	5,138	1,319	1.26	5,673	4,403	1,271	1.29	12,131	9,541	2,590	1.27
70–74	6,451	4,963	1,488	1.30	5,225	3,900	1,325	1.34	11,676	8,864	2,813	1.32
75–79	5,958	4,365	1,593	1.36	4,311	3,039	1,272	1.42	10,269	7,404	2,865	1.39
80–84	4,390	3,133	1,257	1.40	2,636	1,848	787	1.43	7,026	4,981	2,045	1.41
85–89	2,777	1,969	808	1.41	1,335	903	432	1.48	4,112	2,871	1,240	1.43
90–94	1,164	833	330	1.40	438	273	164	1.60	1,601	1,107	495	1.45
95–99	326	260	66	1.25	95	59	36	1.60	420	319	101	1.32
0–14	35,576	29,355	6,221	1.21	37,384	30,808	6,576	1.21	72,961	60,164	12,797	1.21
15–39	60,338	50,289	10,049	1.20	62,309	51,523	10,788	1.21	122,646	101,812	20,836	1.20
40–64	52,700	42,825	9,874	1.23	51,715	40,970	10,746	1.26	104,415	83,796	20,621	1.25
65–89	26,033	19,568	6,465	1.33	19,180	14,093	5,087	1.36	45,214	33,661	11,553	1.34
90–99	1,490	1,093	396	1.36	533	332	200	1.61	2,021	1,426	596	1.42
All ages	176,136	143,130	33,007	1.23	171,122	137,726	33,396	1.24	347,259	280,856	66,403	1.24

SOURCE: Authors' estimates.

TABLE 5 US population in 2000 and the number of persons who could be alive had the optimal mortality conditions prevailed since 1900, apportioned into direct and 2nd+ generation potential lives saved, by five-year age groups

	Females					Males					Total				
		Potential lives saved (1000)					Potential lives saved (1000)					Potential lives saved (1000)			
Age group	Population (millions)	All	1st gen.	2nd+ gen.	2nd+ / All	Population (millions)	All	1st gen.	2nd+ gen.	2nd+ / All	Population (millions)	All	1st gen.	2nd+ gen.	2nd+ / All
0–4	9.4	1,921	24	1,897	0.99	9.8	2,040	42	1,997	0.98	19.2	3,961	67	3,894	0.98
5–9	10.0	2,159	34	2,125	0.98	10.5	2,268	46	2,222	0.98	20.6	4,427	80	4,347	0.98
10–14	10.0	2,141	68	2,073	0.97	10.5	2,268	96	2,172	0.96	20.4	4,409	164	4,245	0.96
15–19	9.8	1,980	109	1,871	0.94	10.4	2,088	135	1,952	0.94	20.2	4,068	244	3,823	0.94
20–24	9.2	1,681	121	1,560	0.93	9.6	1,785	162	1,623	0.91	18.8	3,466	283	3,183	0.92
25–29	9.6	1,709	143	1,566	0.92	9.8	1,819	201	1,618	0.89	19.5	3,527	344	3,184	0.90
30–34	10.2	2,025	143	1,882	0.93	10.3	2,196	257	1,939	0.88	20.5	4,221	400	3,821	0.91
35–39	11.4	2,654	174	2,480	0.93	11.4	2,900	365	2,535	0.87	22.8	5,554	539	5,015	0.90
40–44	11.3	2,549	362	2,187	0.86	11.1	2,871	634	2,237	0.78	22.3	5,420	996	4,424	0.82
45–49	10.2	1,887	362	1,525	0.81	9.8	2,134	599	1,535	0.72	20.0	4,021	961	3,060	0.76
50–54	8.9	1,549	297	1,252	0.81	8.5	1,780	520	1,260	0.71	17.3	3,329	817	2,512	0.75
55–59	6.9	1,355	483	873	0.64	6.5	1,463	601	862	0.59	13.4	2,818	1,083	1,735	0.62
60–64	5.6	2,534	1,667	868	0.34	5.1	2,498	1,667	831	0.33	10.8	5,033	3,334	1,699	0.34
65–69	5.1	1,319	1,100	219	0.17	4.4	1,271	1,077	194	0.15	9.5	2,590	2,178	413	0.16
70–74	5.0	1,488	1,455	33	0.02	3.9	1,325	1,298	27	0.02	8.9	2,813	2,753	60	0.02
75–79	4.4	1,593	1,593	0	0	3.0	1,272	1,272	0	0	7.4	2,865	2,865	0	0
80–84	3.1	1,257	1,257	0	0	1.8	787	787	0	0	5.0	2,045	2,045	0	0
85–89	2.0	808	808	0	0	0.9	432	432	0	0	2.9	1,240	1,240	0	0
90–94	0.8	330	330	0	0	0.3	164	164	0	0	1.1	495	495	0	0
95–99	0.3	66	66	0	0	0.1	36	36	0	0	0.3	101	101	0	0
All ages	143.1	33,007	10,596	22,411	0.68	137.7	33,396	10,392	23,004	0.69	280.9	66,403	20,988	45,415	0.68

SOURCE: Authors' estimates.

TABLE 6 Effect of highest-life-expectancy level on the hypothetical age structure of the US population in 2000

	Actual population	Population with highest life expectancy starting in				
		1900	1920	1940	1960	1980
Females						
Mean age (years)	37.1	37.9	37.9	37.9	37.9	37.7
Percent ages 0–14	20.5	20.2	20.1	20.1	20.1	20.1
Percent ages 15–64	65.1	64.2	64.0	63.9	63.9	64.1
Percent ages 65+	14.4	15.6	15.8	16.0	16.0	15.7
Males						
Mean age (years)	34.4	35.3	35.3	35.3	35.3	35.0
Percent ages 0–14	22.4	21.8	21.8	21.8	21.8	22.0
Percent ages 15–64	67.2	66.6	66.5	66.4	66.4	66.7
Percent ages 65+	10.5	11.5	11.6	11.8	11.8	11.4
Total						
Mean age (years)	35.8	36.6	36.6	36.6	36.6	36.4
Percent ages 0–14	21.4	21.0	21.0	20.9	20.9	21.0
Percent ages 15–64	66.1	65.4	65.3	65.1	65.1	65.4
Percent ages 65+	12.5	13.6	13.8	13.9	13.9	13.6
Dependency ratio[a]	51	53	53	53	53	53
Old-age dependency ratio[b]	19	21	21	21	21	21

[a] [(0–14) + (65+)] ÷ (15–64).
[b] (65+) ÷ (15–64).
SOURCE: Authors' estimates.

Because the number of lives potentially saved accumulates rapidly with every new generation, the question arises of the future consequences of the mortality disadvantage at young ages in the United States. For example, women whose lives could have been saved and who would be of reproductive age in 2000 (almost 17 million) would have given birth to 728,000 children under the prevailing fertility pattern in the year 2000. That figure represents 19 percent of all births that actually occurred in 2000 (National Center for Health Statistics).

Table 6 compares selected statistics for the actual population observed on 1 January 2000 and the hypothetical population that would have been observed had life expectancy in the United States been equivalent to that of countries with highest life expectancies since 1900, 1920, 1940, 1960, and 1980. We calculated only a few indicators such as the mean age of the population and the proportion of people at young ages (0–14), at working ages (15–64), and elderly (65+). Despite the huge impact on absolute numbers that we have shown in Tables 1–3, the effect on the age structure and the dependency ratio is surprisingly small—irrespective of when mortality hypothetically reached the highest life expectancy.

Conclusion

We have estimated the number of people in the United States who could have been alive on 1 January 2000 if the level of mortality had been the lowest possible throughout the twentieth century. The optimal mortality regime consisted of those death rates that have been observed in each year in the country with the highest life expectancy. We assumed that the hypothetical mortality regime did not influence fertility levels or the volume of net migration; hence we kept fertility and net migration at their actual levels over the projection period.

Around 1900 the mortality disadvantage of the United States, as compared to the countries with record life expectancy, was concentrated in early childhood. At the end of the twentieth century, this disadvantage, as far as the *absolute* difference in death rates is concerned, occurs mostly at older ages. Mortality in the United States, however, is much higher in *relative* terms at younger ages. The high death rates below age 50 over the study period, in particular for females, are of crucial significance for the results of this study: women who die before or during the reproductive ages do not give birth to as many children as they otherwise would. Moreover, children who have not been born would in turn not bear children. These individuals belong to second and subsequent generations of lives potentially saved. We demonstrated that this effect accumulates very quickly in successive generations.

As shown in the earlier study by White and Preston (1996), in the absence of the actual improvements in mortality throughout the twentieth century, the size of the US population would have been about 50 percent smaller. The life expectancy gains in the United States in the last century, however, were not as great as those in other high-income countries. In the year 2000, the number of additional people who could have been alive had the mortality levels in the United States during the twentieth century been as low as those in countries with the highest life expectancy was 66 million. This number accounts for almost a quarter of the actual population size in the year 2000 and is distributed equally between males and females. Suboptimal mortality at reproductive ages is crucial for the cumulative effect of potential lives saved, resulting from premature deaths of women who potentially could still become first-time mothers or still bear additional children. Out of the 66 million potential lives saved, 45 million belong to those indirect deaths. Although the differences in the composition of the population by sex and age under the two mortality regimes are minor, the majority of people who might have been born—54 million—were of working age or younger.

Notes

This work is supported by a NIH/NIA Grant ("Mortality Surface Analysis," R37-AG018444) and by the Max Planck Institute for Demographic Research, Rostock, Germany.

Earlier versions of this article were presented at a workshop of the European Association for Population Studies in Rome in 2007 and at the Annual Meeting of the Population Association of America in 2008 in New Orleans. The authors express their gratitude to James W. Vaupel for numerous suggestions.

1 See Oeppen and Vaupel (2002). The respective values were 59.95 for females and 57.37 for males in 1900, both recorded among the non-Maori population of New Zealand. The record holder in 2000 was Japan with 84.62 years for females and 77.64 years for males.

2 See Bell and Miller (2005). The values were 48.96 for females and 46.41 for males in 1900 and 79.39 (females) and 74.04 (males) in 2000.

3 Both fertility rates and the sex ratio at birth were redistributed to one-year age-group rates using the Karup-King third-difference osculatory interpolation formula. For each five-year age group the formula derives single-age rates by applying multiplicative coefficients to a value in that group and the neighboring ones (for a description of the method and values of the Karup-King coefficients, see Shryock and Siegel 1976: 699–702). We assume the sex ratio at birth in the years 1900–35 by age of the mother to be equal to the distribution in 1940, which is the earliest calendar year for which this information is available.

4 The corresponding colored surface maps with a finer grid in PDF format are available on request from mm135@duke.edu.

References

Bell, F. C. and M. L. Miller. 2005. *Life Tables for the United States Social Security Area 1900–2100*. SSA Pub. No. 11-11536. Social Security Administration, Office of the Chief Actuary.

Coale, A. J. and E. E. Kisker. 1986. "An investigation of the quality of old-age mortality data," Report to the National Center for Health Statistics, 8 August.

Coale, A. J. and N. W. Rives. 1973. "A statistical reconstruction of the black population of the United States 1880–1970: Estimates of true numbers by age and sex, birth rates, and total fertility," *Population Index* 39: 3–36.

Coale, A. J. and M. Zelnik. 1956. *New Estimates of Fertility and Population in the United States*. Princeton: Princeton University Press.

Haines, M. R. 1989. "American fertility in transition: New estimates of birth rates in the United States," *Demography* 26: 137–148.

———. 2006a. *Historical Statistics of the United States: Death Rates, by Sex and Age: 1900–1998*. New York: Cambridge University Press; Available at «http://hsus.cambridge.org/».

———. 2006b. *Historical Statistics of the United States: Population, by Sex and Age: 1850–1990*. New York: Cambridge University Press; Available at «http://hsus.cambridge.org/».

Heuser, R. L. 1976. *Fertility Tables for Birth Cohorts by Color*. US Department of Health, Education, and Welfare. DHEW Publication No. (HRA)76-1152.

Human Mortality Database. 2008. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at «www.mortality.org» (data downloaded on 10 June 2008).

Manton, K. G. and J. W. Vaupel. 1995. "Survival after age 80 in the United States, Sweden, France, England, and Japan," *New England Journal of Medicine* 333: 1232–1235.

Meslé, F. and J. Vallin. 2006. "Diverging trends in female old-age mortality: The United States and the Netherlands versus France and Japan," *Population and Development Review* 32: 123–145.

National Center for Health Statistics. 2007. *Vital Statistics of the United States*, Part I: *Natality*. Washington, DC: Government Printing Office, various years.

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

Pampel, F. C. 2002. "Cigarette use and the narrowing sex differential in mortality," *Population and Development Review* 28: 77–104.

Preston, S. H. 2005. "Deadweight? The influence of obesity on longevity," *New England Journal of Medicine* 352: 1135–1137.

Preston, S. H., P. Heuveline, and M. Guillot. 2001. *Demography: Measuring and Modeling Population Processes*. Blackwell Publishing.

Preston, S. H. and H. Wang. 2006. "Sex mortality differences in the United States: The role of cohort smoking patterns," *Demography* 32: 631–646.

R Development Core Team. 2008: *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Shresta, L. and S. H. Preston. 1995. "Consistency of census and vital registration data on older Americans: 1970–1990," *Survey Methodology* 21: 167–177.

Shryock, H. S. and J. S. Siegel. 1976. *The Methods and Materials of Demography*. San Diego: Academic Press.

Smith, S. K., J. Tayman, and D. A. Swanson. 2002. *State and Local Population Projections*. The Springer Series on Demographic Methods and Population Analysis, Springer, Netherlands.

Torrey, B. B. and C. Haub. 2004. "A comparison of US and Canadian mortality in 1998," *Population and Development Review* 30: 519–530.

US Bureau of the Census. 1975. *Historical Statistics of the United States, Colonial Times to 1970*. Washington, DC.: US Government Printing Office.

White, K. M. and S. H. Preston. 1996. "How many Americans are alive because of twentieth-century improvements in mortality?," *Population and Development Review* 22: 415–429.