SOCIETY OF ACTUARIES

Mortality and Longevity

Interstate Variations in Mortality in the United States, 1959-2018

July 2021

Interstate Variations in Mortality in the United States, 1959-2018

AUTHOR Magali Barbieri, Ph.D.
University of California, Berkeley

SPONSOR Mortality and Longevity Strategic
Research Program Steering Committee

CONTENTS

Executive Summary **4**

Section 1: Introduction **5**

Section 2: General mortality trends **5**

2.1. Overall similitudes in historical mortality trends by state 5

2.2. An increase in disparities, especially for women 7

2.3. A Western drift of high-mortality states 8

Section 3: A narrowing sex gap in life expectancy **11**

Section 4: Geographic variations in the age structure of mortality **13**

Section 5: Geographic variations in causes of death **16**

5.1 The major role of cardiovascular diseases as a driver of mortality decline everywhere 16

5.2 Causes of death explaining variability in mortality across states 17

Section 6: The last decade **19**

Section 7: Conclusion **21**

Section 8: Acknowledgments **23**

Appendix A: Cause of Death Categories and Corresponding Codes **24**

Appendix B: Variability in Mortality Rates by Cause-of-Death Category and by Age Group **25**

Appendix C: Maps of the Age Standardized Death Rates by State **28**

About The Society of Actuaries **31**

Interstate Variations in Mortality in the United States, 1959-2018

Executive Summary

Using recently updated data from the United States Mortality Database (USMDB, usa.mortality.org), this report presents an overview of historical mortality trends in all 50 U.S. states and the District of Columbia for the period 1959-2018.

Overall, historical mortality trends in the states mirror those at the national level, with stable or increasing rates during the 1960s, a sharp decline in the 1970s and continuous improvements in survival up to the first decade of the 21st century. The positive trend came to a halt in most states around 2010 and mortality deteriorated pretty much all over the country between 2014 and 2017 with clear mortality reversal in some states and a lack of further improvement in others. In 1959, male life expectancy at birth ranged from 62.4 years in the District of Columbia to 69.5 years in Hawaii while female life expectancy ranged from 69.8 years also in the District of Columbia to 75.6 years in Nebraska. In 2018, it ranged from 72.0 years in Mississippi to 78.9 years in California for men and from 77.6 years in West Virginia to 84.9 years in Hawaii for women.

Gains in life expectancy between 1959 and 2018 were higher in some states than in others and the gains appear to have been independent from the initial level of mortality. This is to say that we did not find a relationship between how high mortality was in 1959 and how much it declined over the following six decades. The additional number of years lived between 1959 and 2018 ranged from 4.8 years in Oklahoma to 12.4 years in the District of Columbia. In addition, the deterioration in mortality trends across states after 2010 was not statistically related to the level of mortality reached by that point or the gains in life expectancy of the previous period. The decline in life expectancy was most severe in the central United States around Illinois, Iowa and Missouri, in the three states in the extreme Northeast, and in Idaho and New Mexico, with New Hampshire, West Virginia and Ohio experiencing extreme losses of more than half a year of life during this period.

The result of these differential trends is a changing geography of U.S. mortality: the area of high mortality has been slowly moving toward the Southwest while expanding in the same direction. In 1959, high-mortality states stretched along a narrow strip from Louisiana to South Carolina (up to North Carolina for men). During the following period, some of the states in the high-mortality cluster experienced relatively fast improvements in life expectancy (Georgia and the Carolinas in particular) while others, located nearby (Oklahoma, Arkansas, Tennessee, Kentucky and West Virginia), experienced slower improvements. The result of these diverse trends is that, in 2018, high-mortality states clustered around Tennessee, Arkansas, Mississippi and Alabama in a star-shaped pattern.

An analysis of age-standardized cause-specific death rates at the state level showed the major role of cardiovascular mortality in driving the rapid progress in life expectancy at birth experienced throughout the United States starting around 1970. Cancer mortality played a much smaller role in this overall trend. After 2010, geographic variations in mortality appear to have been mostly determined by the severity of the drug overdose epidemic, though other factors also played a role, including a slowing down of the decline in cardiovascular mortality. The most remarkable result of the cause-of-death analysis is that, though in 1959 the maps looked very different depending on the cause-of-death category, in 2018 states located in the South (from Oklahoma and Louisiana through Kentucky and West Virginia, including Arkansas, Mississippi, Alabama and Tennessee) exhibit the highest level of mortality for all cause-

of-death categories except for external causes. The latter are highest in Alaska and along a narrow strip of states running from New Mexico and Oklahoma to West Virginia.

Section 1: Introduction

This report seeks to provide a comprehensive description of state-level mortality trends in the United States for the sixty years stretching from 1959 to 2018. Monitoring the level, structure and trends of mortality at a fine geographic level is useful both for the scholarly purpose of better understanding the factors driving cross-country variations in inequalities and for improving public health by helping to better allocate resources and to assess the impact of local interventions or policies. The purpose of the research reported here was to construct U.S. state-level lifetable series since 1959 (the first year when data are available) up to 2018 (the most recent year when data are available) by sex to be published in the United States Mortality DataBase (USMDB, accessible at usa.mortality.org) of which the author is the Director. In addition, a set of cause-specific age-standardized death rates were calculated also at the state level, to help formulate hypotheses as to the factors behind the observed geographic variations. Specifically, the aim of the research presented here was to answer the following three questions:

- What is the current geography of mortality in the United States and how has it changed over the past sixty years?
- Do differences in life expectancy across the U.S. states correspond to particular age patterns of mortality?
- What causes of death most contribute to interstate variations in life expectancy at birth?

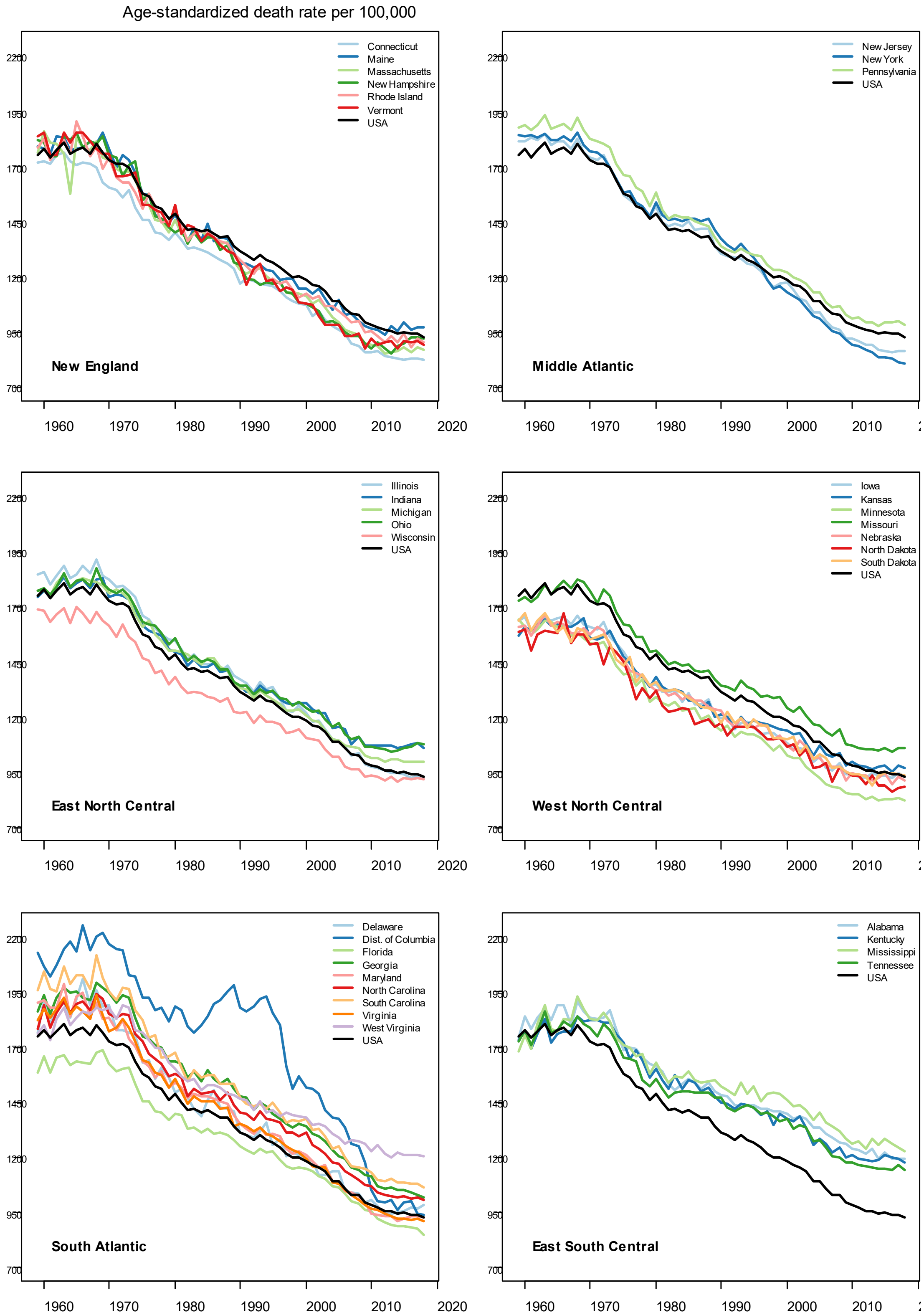
Section 2: General mortality trends

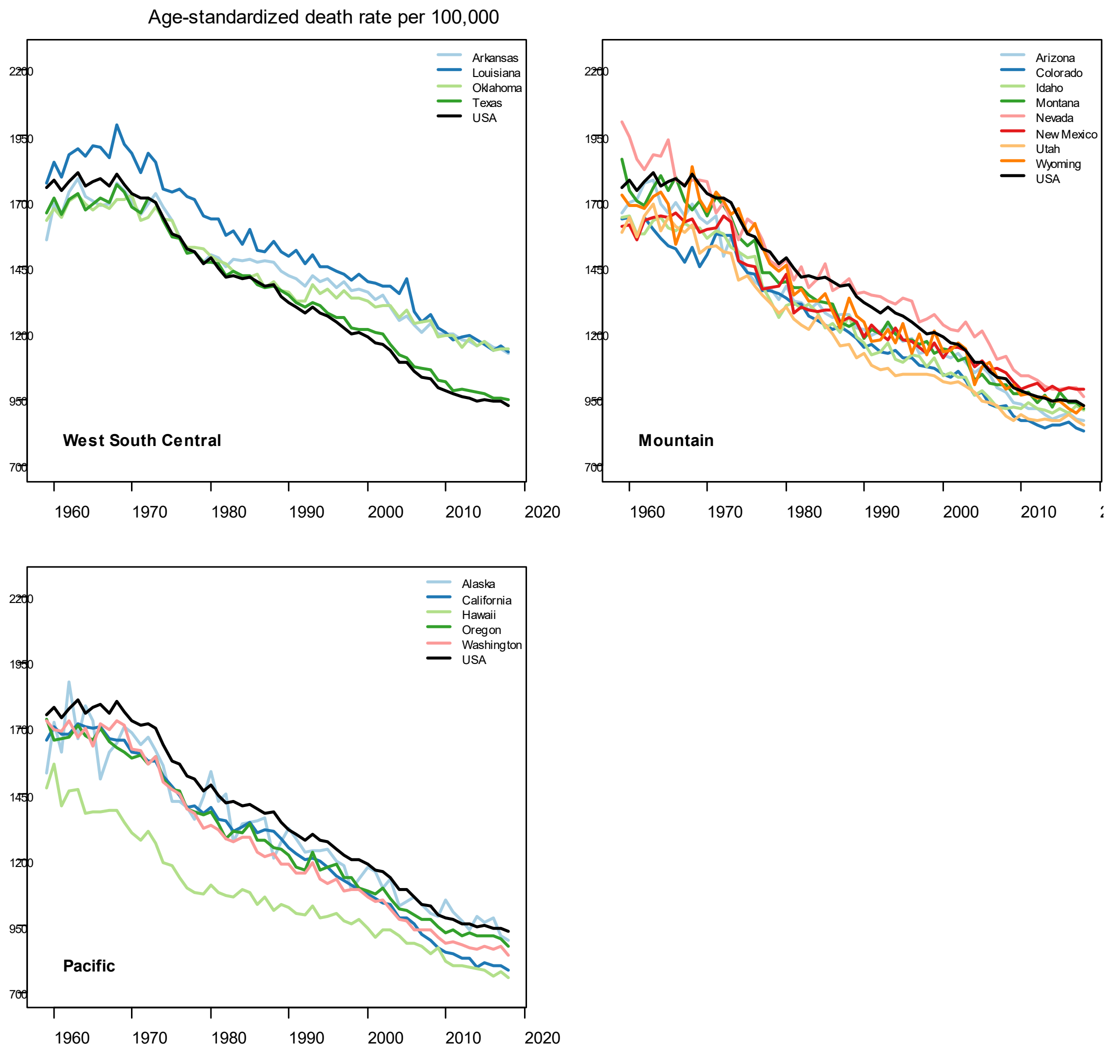
2.1. OVERALL SIMILITUDES IN HISTORICAL MORTALITY TRENDS BY STATE

Overall, with the notable exception of the District of Columbia, states have followed a similar trend as the country as a whole in the age-standardized mortality rates over 1959-2018. Three periods can be distinguished (Figure 1). At the beginning of the study period, rates were fairly stable in most regions and increasing in the South. Then, around 1970, mortality started declining everywhere and continued to decline until about 2010. In some areas, the decline was particularly fast at the beginning (between 1970 and 1980 roughly). After 2010, all states experienced a slowing down of their mortality decline or, more commonly, a plateau and, in many of them, mortality actually increased between 2014 and 2017.

Figure 1

AGE-STANDARDIZED DEATH RATES BY STATE WITHIN EACH CENSUS DIVISION, 1959-2018, BOTH SEXES COMBINED





2.2. AN INCREASE IN DISPARITIES, ESPECIALLY FOR WOMEN

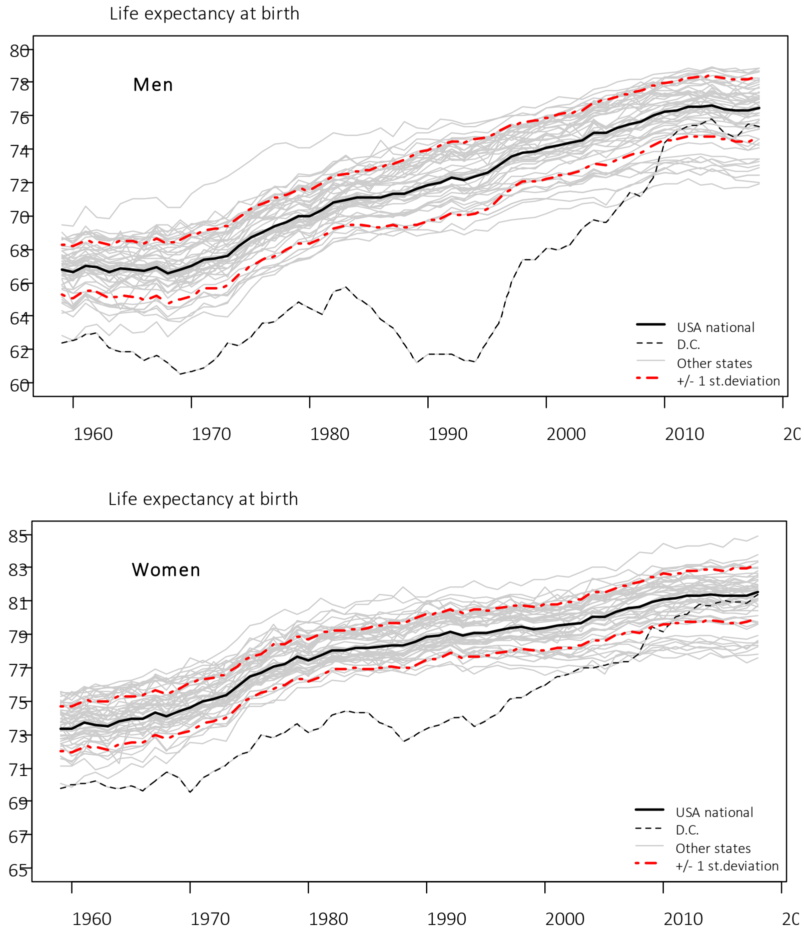
In 2018, life expectancy at birth in the United States was estimated at 76.5 years for men and 81.5 years for women. Compared to 1959, when the indicator stood at 66.8 and 73.3 years, respectively, men have gained 9.7 years of life and women have gained 8.2 years. These national averages conceal major geographic variations. In 2018, the difference between the life expectancy at birth in the two states at the top and bottom of the range was 6.9 years for men (Mississippi vs. California) and 7.3 for women (West Virginia vs. Hawaii). In 1959, the difference was 7.1 and 5.8 years respectively, and the states at the two extremes of the distribution were D.C. and Hawaii for men and D.C. and Nebraska for women (see Appendix Table 1 provided as a separate Excel file).

These statistics indicate that the magnitude of geographic disparities in mortality has increased slightly for men but much more significantly for women over the sixty-year period, as measured by the range of values in 1959 and 2018. However, within this range, there was an increase spread as the standard deviation across the state distribution by level of life expectancy at birth increased from 1.47 years to 1.87 years for men and from 1.33 to 1.63 years for women.

At its maximum, the range of life expectancy at birth across all U.S. states reached over 14.3 years in 1994 for men and 9.2 years for women in 1988 (Figures 2a and 2b). However, trends in the gap between the extreme values of the distribution are nearly entirely driven by D.C., which experienced very low relative levels of survival up until the mid-2000, when it caught up with other U.S. states. Once we remove the District of Columbia from the calculations, the maximum gap falls to 8.4 years and 7.3 years for men and women, respectively (in 1973 and 2018). When including D.C., the minimum gap was reached in 2006 for women (at 5.6 years) and in 2012 for men (at 6.6 years). When excluding D.C., it was reached in 1984 for women (at 4.3 years) and 1987 for men (at 5.9 years).

Figures 2a and 2b

TRENDS IN LIFE EXPECTANCY AT BIRTH BY STATE, EACH SEX, 1959-2018



2.3. A WESTERN DRIFT OF HIGH-MORTALITY STATES

When investigating more closely state-level life expectancy at birth across the United States, the most striking pattern is that of a drift in the cluster of high-mortality states. Figures 3a-3b show how states are grouped into five categories based on their level of life expectancy at birth for each sex in 1959 and in 2019. The middle group is around the mean (plus or minus half a standard deviation), the two surrounding groups are bounded by one standard deviation on either side and the remaining groups range from the minimum/maximum to one standard deviation below/above the average (Figures 3a-3d).

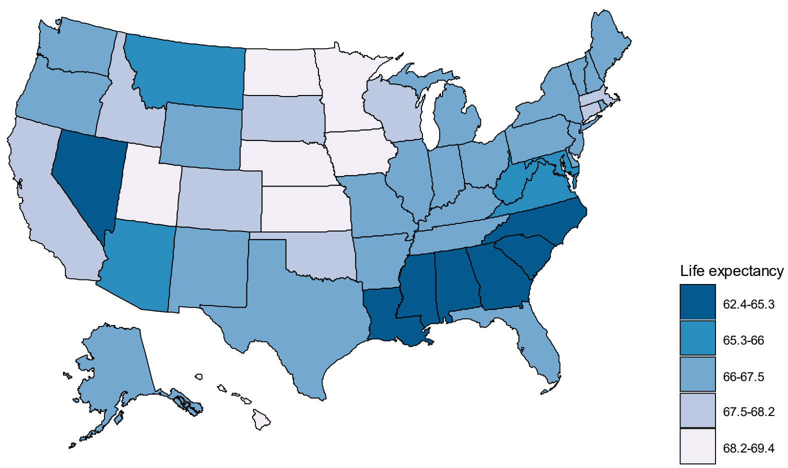
There was, and there still is, a very clear clustering of high mortality states in both 1959 and 2018 in a crescent resting in the Southeastern corner of the United States, to the Northeast of Florida, with a nearly identical pattern for men and for women. In 1959, states with the lowest levels of life expectancy at birth for both sexes were located in a narrow strip between Louisiana to the West and South Carolina to the East (up to North Carolina for men). Nevada was also part of this group for men but not for women. By 2018, a shift had occurred in the center of gravity of this high mortality cluster. In addition, the cluster of high mortality expanded to include more states. The changes were due to improvements in the relative level of mortality in the most Eastern states (Georgia, South Carolina – for women only – and North Carolina) as well as in Nevada, and a deterioration in the states located to the North and West of the initial cluster, namely Oklahoma, Arkansas, Tennessee, Kentucky and West Virginia.

By contrast, the clear clustering of low mortality states located in the Northern states of the Mid-West visible on the 1959 maps (especially for women) had been completely broken down by 2018, due to slower progress in survival in those states compared with others. At the beginning of the study period, North Dakota, Minnesota, Iowa, Nebraska and Kansas (plus South Dakota and Oklahoma for women) had the highest level of life expectancy at birth, in addition to a couple of scattered states (Hawaii and Utah for men, Oregon and Idaho for women). Of all these, only Minnesota and Hawaii remained in the lowest relative mortality group by 2018. All of the other states switched to less favorable groups. The deterioration was especially pronounced for South Dakota, Iowa and (for men) Nevada. Improvements favored Colorado and a few of the most Northeastern states (New York, Connecticut and Massachusetts) as well as Washington State for men, that had moved up to the most advantaged group by the end of the study period (2018).

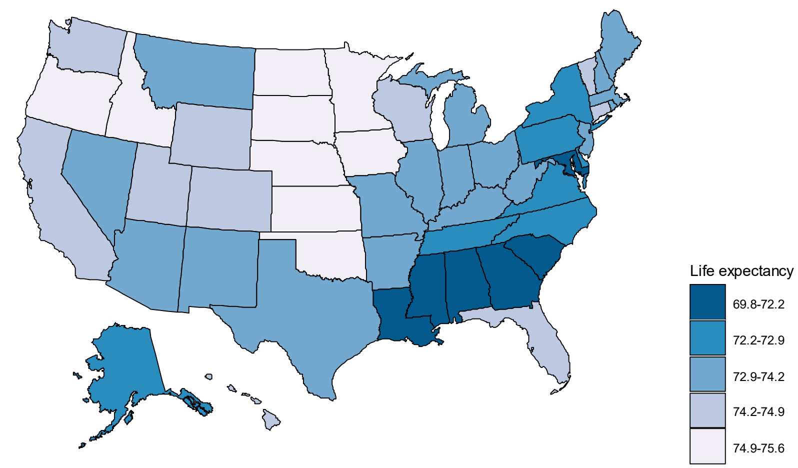
Figures 3a-3d

LIFE EXPECTANCY AT BIRTH BY STATE, EACH STATE, 1959 (TOP) AND 2018 (BOTTOM), MEN (LEFT) AND WOMEN (RIGHT)

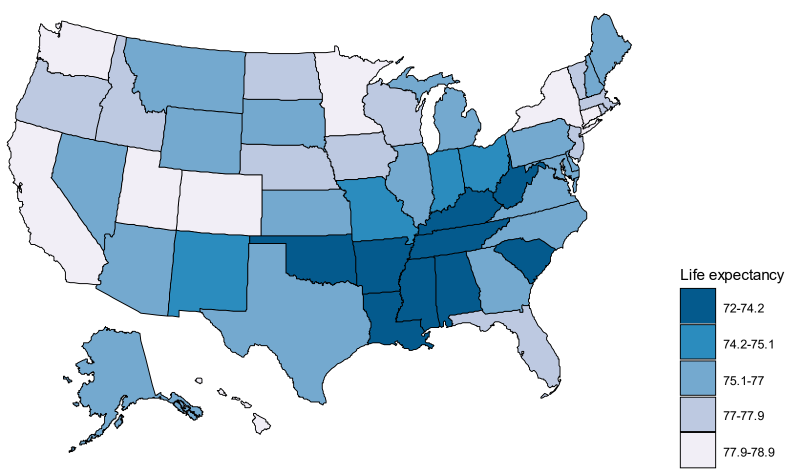
Male expectation of life at birth (e0) in 1959



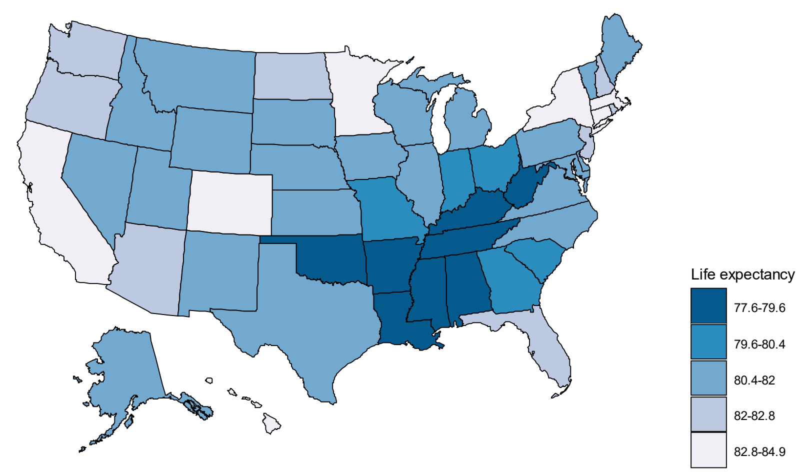
Female expectation of life at birth (e0) in 1959



Male expectation of life at birth (e0) in 2018



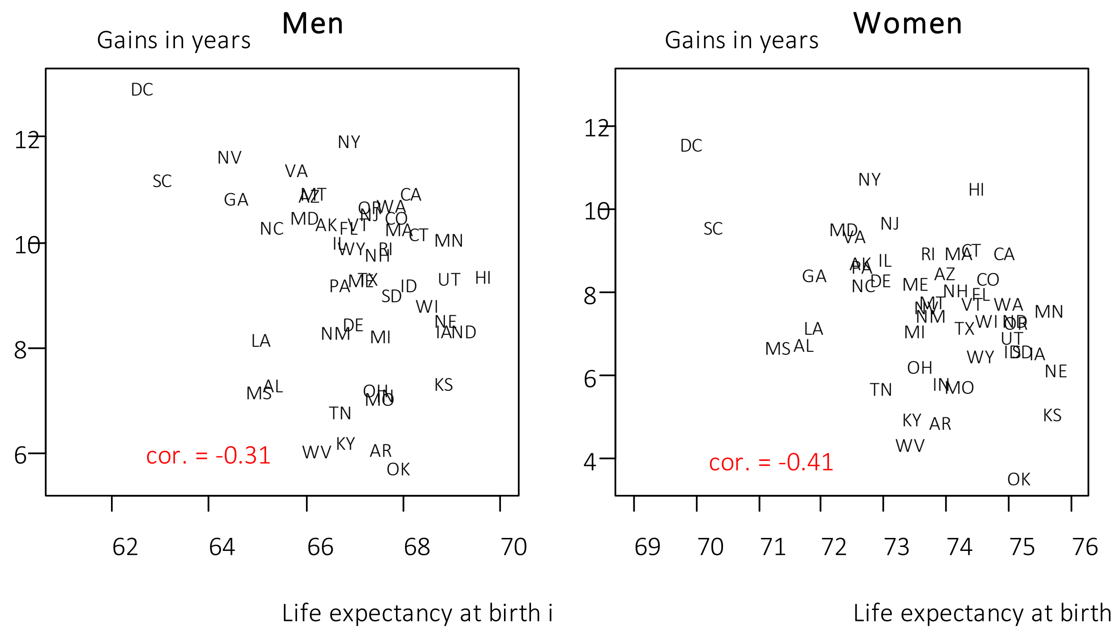
Female expectation of life at birth (e0) in 2018



Interestingly, there is no correlation between the level of life expectancy at birth experienced by the states in 1959 and the number of years of life gained over the following sixty years for neither men nor women (Figures 4a and 4b). Figures 4a and 4b also show that mortality declined more slowly for women than for men over the period.

Figures 4a and 4b

RELATIONSHIP BETWEEN THE LEVEL OF LIFE EXPECTANCY AT BIRTH IN 1959 AND THE NUMBER OF YEARS OF LIFE GAINED IN 1959-2018, EACH SEX

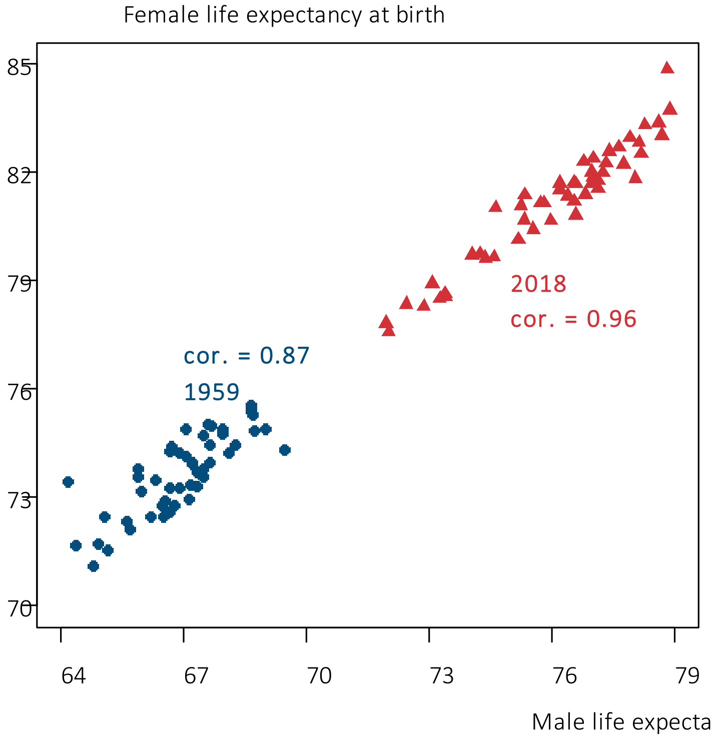


Section 3: A narrowing sex gap in life expectancy

There is a very close correlation between male and female life expectancy at birth: the states where life expectancy is low for men are generally those where it is also low for women in both 1959 and 2018. However, the relationship is stronger in 2018 than it was in 1959, with the red triangles being better aligned than the blue dots on Figure 5 and with a Pearson correlation coefficient of 0.96 for the 2018 values compared with 0.87 for the 1959 values.

Figure 5

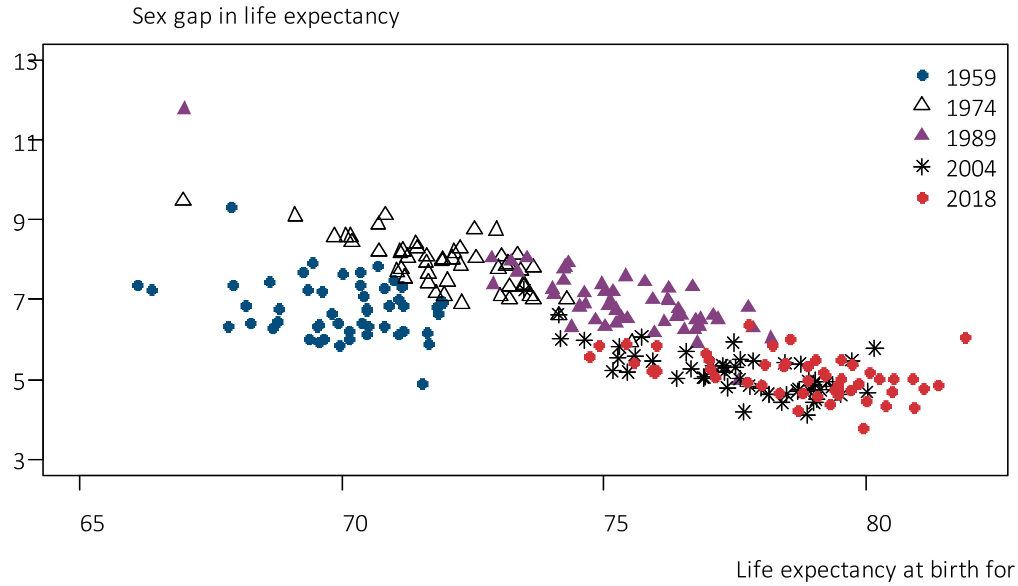
CORRELATION BETWEEN MEN AND WOMEN'S LIFE EXPECTANCY AT BIRTH, 1959 AND 2018



By contrast, there is little relationship between the sex difference and the initial level of life expectancy at birth in each state. That is the sex gap is not larger (or smaller) for states with higher (or lower) levels of life expectancy. Figure 6 represents the relationship between the sex gap in life expectancy at birth and the level of life expectancy for both sexes combined at 15-year intervals throughout the study period (14 years for the last one). It shows that the point clouds for each selected year are elongated around a virtual horizontal rather than diagonal line so that whatever the average length of life in any given state, the sex difference is fairly similar. It does, however, also shows that, overall, the gap increased pretty much everywhere during the first 15-year period (1959-1974) but declined during each subsequent period (i.e. the point cloud is lower and lower for each successive period after 1974).

Figure 6

RELATIONSHIP BETWEEN THE SEX GAP IN LIFE EXPECTANCY AT BIRTH AND THE LIFE EXPECTANCY AT BIRTH FOR BOTH SEXES COMBINED, SELECTED YEARS



Section 4: Geographic variations in the age structure of mortality

To classify US states based on the age structure of mortality, we first implemented a principal component analysis (PCA) on age-specific death rates using the R package *FactoMineR*[1] (Lê et al., 2008), which uses the Pearson coefficient to measure similarities between observations. The PCA was carried out to determine the typical age patterns of mortality across U.S. states. The analysis was applied to the age-standardized death rates calculated for each sex and age group using the U.S. population at the 2000 census as the reference structure. The standardized rates were calculated for 15-year age groups up to an open age interval at 90 years and above (i.e. 0-14, 15-29, 30-44, 45-59, 60-74, 75-89, and 90+ years) for each calendar year and each of the 50 states and the District of Columbia. We carried out the analysis for the beginning and ending years of the study period (i.e. 1959 and 2018) to examine how variations in age patterns of mortality have evolved over the past sixty years.

The first finding of the analysis is that mortality rates are highly correlated across the life span as demonstrated by the large amount of total inertia summarized by the first (or the first two) principal components as reflected by the eigenvalues. The first principal component (PC) expresses 52% of the overall variance in 1959 and 70% in 2018, and the first two PCs taken together express 81% of the overall variance in 1959 and 87% in 2018. The results also show that the correlation between all age-specific death rates has increased over time, suggesting that, overall, the age pattern of mortality does not vary much any longer across states and that the states which have high mortality at certain ages also have high mortality at other ages.

---

[1] Lê, S., Josse, J. & Husson, F. (2008). *FactoMineR: An R Package for Multivariate Analysis*. *Journal of Statistical Software*. 25(1). pp. 1-18. http://factominer.free.fr/

Table 1
EIGEN VALUES AND PERCENT VARIANCE CORRESPONDING TO EACH PRINCIPAL COMPONENT, 1959 AND 2018

Dimension/Principal Component	Eigenvalue	Variance (%)	Cumul. Variance (%)
1959			
1	3.64	52.05	52.05
2	2.05	29.23	81.28
3	0.78	11.12	92.40
4	0.30	4.27	96.67
5	0.16	2.28	98.95
6	0.05	0.71	99.66
7	0.02	0.34	100.00
2018			
1	4.88	69.77	69.77
2	1.21	17.25	87.01
3	0.51	7.26	94.27
4	0.23	3.34	97.62
5	0.10	1.45	99.07
6	0.05	0.72	99.78
7	0.02	0.22	100.00

The second interesting finding is that the relationship between mortality at various ages has changed over time, as indicated by the variable correlation plots for 1959 and 2018 (Figures 7a. and 7b.). On these plots, positively correlated death rates are grouped together while negatively correlated rates are positioned on opposite sides of the plot origin (i.e. in opposed quadrants). Furthermore, the distance between each death rate and the origin measures the quality of their representation on the factor map. Death rates located away from the origin are represented well on the map and contribute significantly to the corresponding principal component. Life expectancy at birth is represented as a supplementary variable, which means that it did not contribute to the construction of the principal components but additional calculations show how mortality in each broad age group contributes to variations in the length of life between U.S. states.

The factor map for 1959 shows that all variables are highly correlated to each of the first two principal components as they are located close to the perimeter of the correlation circle. The death rates for ages below 60 years, which are all grouped together on the right hand side of the plot, are positively correlated with each other. They are also negatively correlated to the death rate at 90 years and above, which is represented on the opposite side of the correlation circle (Figure 7a). This means that states can be opposed on whether they have high or low mortality below age 60 years but there is no correlation between mortality below age 60 and mortality above age 90. The position of the point representing life expectancy at birth suggests that it is most closely (negatively) correlated with the rate of mortality at ages 45-59 and 60-74 years. Mortality below age 60 and at 90 years and above is further independent from mortality at ages 60-89 years. States theoretically fall into one of the following five categories (Figure 8a):

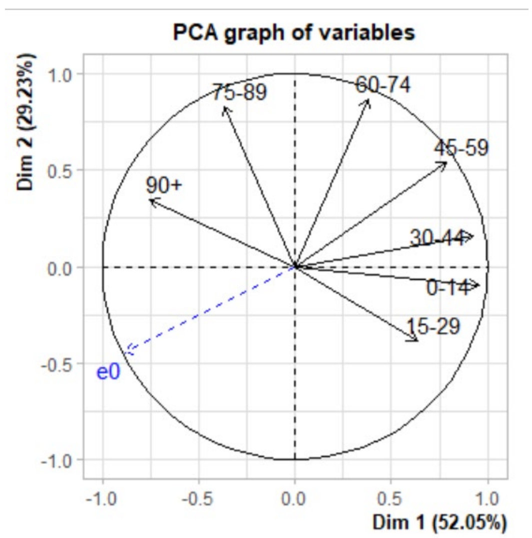
1. states close to the average for mortality at all ages (i.e. those states close to the center of the plot, where both axes intersect – e.g. Kentucky, Tennessee, West Virginia and Montana);

2. states with high mortality below age 60, high mortality at ages 60-89 years, and low mortality at ages 90 and above (those located in the upper right corner of the plot); those are the states with the lowest life expectancy at birth (e.g. D.C. and South Carolina)
3. states with low mortality below age 90 and high mortality at ages 90 and above (those in the lower left corner of the plot); those are also the states with the highest life expectancy at birth (e.g. Kansas, Utah and Nevada);
4. states with high mortality below age 60, low mortality at ages 60-89 and low mortality at ages 90 years and above (in the lower right corner) (e.g. Florida, New Mexico, and Arizona)
5. states with low mortality below age 60, high mortality at ages 60-89 and high mortality at ages 90 years and above (in the upper left corner) (e.g. Rhode Island, New Jersey, New York and Pennsylvania).

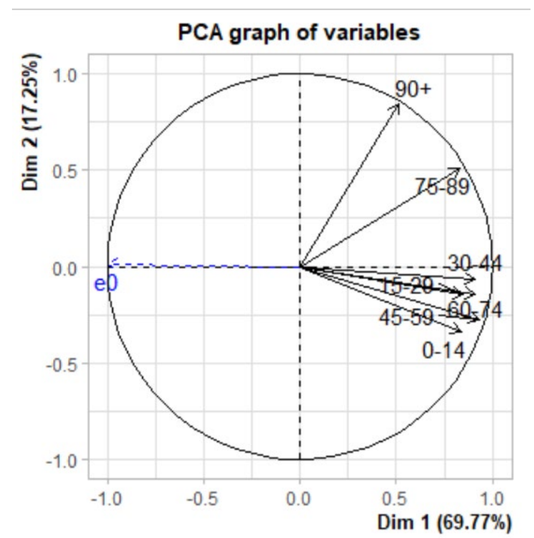
Figures 7a & 7b

VARIABLES FACTOR MAPS (PCA) OF THE AGE-SPECIFIC MORTALITY RATES ACROSS ALL US STATES FOR BOTH SEXES COMBINED, 1959 AND 2018

1959



2018

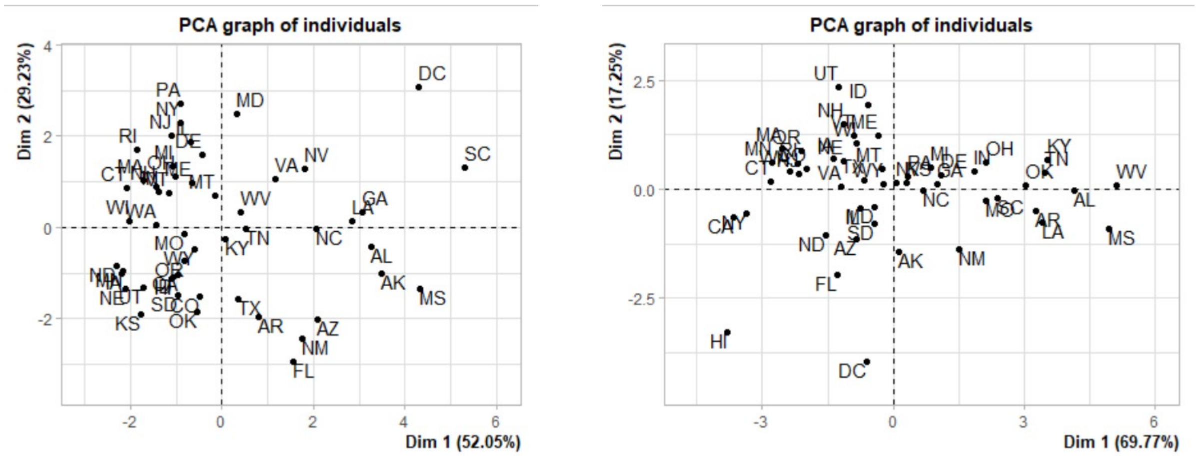


By contrast, the factor map for 2018 (and other output of the PCA) show that the situation has become much simpler (Figure 7b). On this map, all of the points are grouped towards the right hand side of the plot, meaning that, overall, states either have high or low mortality across all ages. However, some of the states have relatively low or high mortality at older ages (75-89 and, to a larger extent, at ages 90 years and above) compared to other states at similar levels of mortality below 75 years, but this pattern is not very pronounced. Again, states with average levels of mortality for all age groups are represented close to the center of the plot (e.g. Nevada, Wyoming, and Kansas in Figure 8b). States with high mortality at all ages are represented in the upper right corner of the plot (e.g. West Virginia, Kentucky, and Tennessee). States with low mortality at all ages are represented in the lower left corner of the plot (e.g. Hawaii). States with high mortality below 90 but low mortality above 90 are represented in the upper left corner (e.g. Utah, New Hampshire, and Idaho). Finally, states with low mortality below 90 but high mortality above that age would have been represented in the upper right corner of the plot but this part of the plot is empty, suggesting that no state falls into this category.

Figures 8a & 8b

INDIVIDUAL FACTOR MAPS (PCA) OF THE AGE-SPECIFIC MORTALITY RATES ACROSS ALL US STATES FOR BOTH SEXES COMBINED, 1959 AND 2018

1959 | 2018



Section 5: Geographic variations in causes of death

5.1 THE MAJOR ROLE OF CARDIOVASCULAR DISEASES AS A DRIVER OF MORTALITY DECLINE EVERYWHERE

Gains in the expected length of life over the period from 1959 to 2018 across all states ranged from 4.8 years in Oklahoma to 12.4 years in the District of Columbia, representing an average annual gain of nearly one month and 2.5 months respectively. On Figure 9, we show the contribution of each of five broad cause-of-death categories to the gains in life expectancy at birth in each state. The decomposition was carried out from state-level lifetable values as well as cause-specific mortality rates calculated for each state and each year of the study period for 5 broad cause-of-death categories, namely infectious and respiratory diseases, cancer, cardiovascular diseases, all other diseases, and external causes. The decomposition of the gains in life expectancy between the two years 1959 and 2018 was computed using a method developed by Andreev, Shkolnikov and Begun[2] (2002). Each segment to the left of the origin of the x-axis, i.e. with a negative value, indicate that mortality from the corresponding cause has increased over the period under consideration, while all segments to the right of the origin correspond to causes of death which have contributed to a decline in mortality (an increase in life expectancy). States are ordered by the gains in life expectancy at birth (indicated in parentheses next to the state name) from smallest to largest.

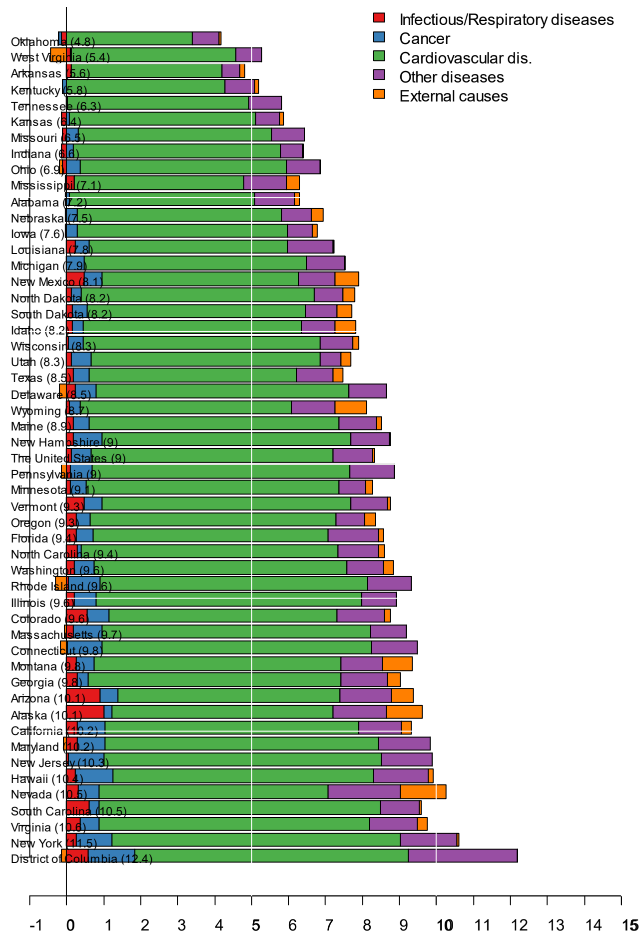
The graph demonstrates the overwhelming contribution of cardiovascular diseases to the decline in mortality between 1959 and 2018. Between 60 and 85% of the total gain in the length of life is attributable to these diseases during the study period. The other broad cause-of-death categories to have systematically contributed to the gains are those in the residual category. These "other diseases" is a disparate group affecting the very young, the very old and everyone in between as it includes diseases of the endocrine and metabolic system, mental and behavior disorders, diseases of the digestive system, diseases of the nervous system, complications of pregnancy and childbearing, perinatal conditions and

[2] Andreev, E. M., Shkolnikov, V. M., & Begun, A. Z. (2002). Algorithm for decomposition of differences between aggregate demographic measures and its application to life expectancies, healthy life expectancies, parity-progression ratios and total fertility rates. *Demographic Research*, *7*, 499-522.

congenital malformations. Cancer generally contributed positively to the increase in life expectancy at birth, though not in states with the smallest progress: Oklahoma, West Virginia, Arkansas, Kentucky, Tennessee, Kansas and Missouri. In these states, mortality from cancer hardly changed over the period. There was apparently not much noticeable progress in mortality from infectious and respiratory diseases. However, mortality from these diseases actually shifted over time from the young, for whom these used to be among the main causes of death, to the very old. As for mortality from external causes, its contribution varied from state to state. In several, mortality from external causes increased, albeit slightly. This was the case in West Virginia, Delaware, Pennsylvania, Rhode Island, Connecticut, Maryland and the District of Columbia. Elsewhere, mortality from external causes declined substantially, contributing to a gain of up to one year in the length of life in Nevada, Wyoming and Alaska.

Figure 9

DECOMPOSITION OF GAINS IN LIFE EXPECTANCY AT BIRTH BETWEEN 1959 AND 2018 BY CAUSE-OF-DEATH CATEGORY, EACH STATE AND D.C., BOTH SEXES COMBINED



5.2 CAUSES OF DEATH EXPLAINING VARIABILITY IN MORTALITY ACROSS STATES

In order to examine the medical causes of death by age group, we calculated death rates by calendar year, state, sex, age group and six broad cause-of-death categories. To simplify the analysis, we created even broader age groups than in the previous section. The age groups under consideration are: 0-14 (children), 15-29 (young adults), 30-44 (younger working age adults), 45-59 (older working-age adults), 60-74 (retirement age adults), 75-89 (older adults), 90 and above (elderly). The cause-of-death categories are 1) infectious and respiratory diseases; 2) cardiovascular diseases (which include heart diseases and cerebrovascular diseases); 3) cancer; 4) all other diseases; 5) external causes of death (violent deaths); and 6) ill-defined and unknown causes (see Appendix A for the corresponding codes of the successive

Revisions of the International Classification of Diseases). To increase comparability across states and over time, we redistributed all deaths of ill-defined or unknown causes proportionately over all of the other cause-of-death categories within each calendar year, state and age group.

We first looked at how the geography of mortality changed over time for each cause-of-death category (see maps for 1959 and 2018 in Appendix C). In every calendar year, states were distributed into five categories depending on their position compared to the average and standard deviation of the age-standardized death rate for each particular cause-of-death category: 1) from the minimum value to less than one standard deviation below the mean; 2) from one to less than half a standard deviation below the mean; 3) within half a standard deviation of the mean; 4) from half a standard deviation to one standard deviation above the mean; and 5) from more than one standard deviation above the mean to the maximum value. The most remarkable result is that, though in 1959 the maps looked very different depending on the cause-of-death category, in 2018 states located in the South (from Oklahoma and Louisiana through Kentucky and West Virginia, including Arkansas, Mississippi, Alabama and Tennessee) exhibit the highest level of mortality for all cause-of-death categories except for external causes. The latter are highest in Alaska and along a narrow strip of states running from New Mexico and Oklahoma to West Virginia.

We then investigated how each broad cause-of-death category contributed to variability in overall mortality across all states for selected years (every ten years from 1959 through 2009, and 2018). For calendar year, sex and each age group, the proportion of variability in the overall age-standardized mortality rates across all states due to each cause of death i was estimated by the ratio $C(x_i) / \mathrm{Var}(x)$ where:

$\mathrm{Var}(x)$ = variance in all-cause mortality; $C(x_i) = \mathrm{Var}(x_i) + \Sigma_{j \neq i} \mathrm{Covar}(x_i, x_j)$;
$\mathrm{Covar}(x_i, x_j)$ = Covariance between mortality rate x_i by cause i and rate x_j by cause j.

The results of this analysis are summarized in Appendix B for both sexes combined. Appendix B indicates how much of the overall variability in mortality is attributable to each cause-of-death category for each of the age groups under consideration. To provide some context, Appendix B also includes the age-standardized death rate (per 100,000 population) for the United States as a whole for each age group over all causes of death and for all causes over all ages. The reader should note that the contributions of the cause-of-death categories to *variability* of overall mortality across states do not necessarily correspond to their contribution to the overall *level* of mortality. Indeed, theoretically, it is possible for a given cause to represent a large share of overall mortality but if the mortality rate for this cause varies little across all states, it will contribute little to variability. In practice, however, we find that the contribution of each cause-of-death to variability generally mirrors its share of the overall mortality rate.

The analysis shows that, for children, interstate variations in mortality were mostly attributable to infectious and respiratory diseases, to other diseases and, to a smaller extent, to external causes (accidents) at the beginning of the study period (1959). Over time however, the contribution of infectious and respiratory diseases declined considerably (from 33 to 7%). The role of other diseases increased to dominate in the 1980s (when it rose from 45 to 78%) to fall thereafter (though still reaching 56% in 2018) and that of external causes followed the opposite trend (declining from 20% in 1959 to 12% in 1989 and rising again to 33% in 2018).

For older children and young adults (aged 15-29 years), over 80% of the variability in mortality across the states is attributable to external causes (with a peak at 94% in 1979). The role of external causes remains important for young working age adults (30-44 years old), especially at the end of the study period. In 2018, it contributes to more than half of the total amount of variability (52%). Cardiovascular diseases also contribute significantly (reaching a maximum of 43% in 1989) as well as other diseases, though to a smaller extent (between 15 and 25% depending on the year). Starting with this age group (30-44 years old), the share of cardiovascular diseases in the variability of overall mortality increases progressively over age. In 1959, for instance, this group of diseases contributes 39% to variability at ages 30-44, 63% at 45-59, 73% at 60-74 and around 85% at 75-89 and 90 years and above. However, in 2018, the respective proportions are 18%, 35%, 38%, 32% and 41%, thus, less than half of what they were in 1959 for most age groups. All other cause-of-death categories account for the difference though more or less depending on the age group.

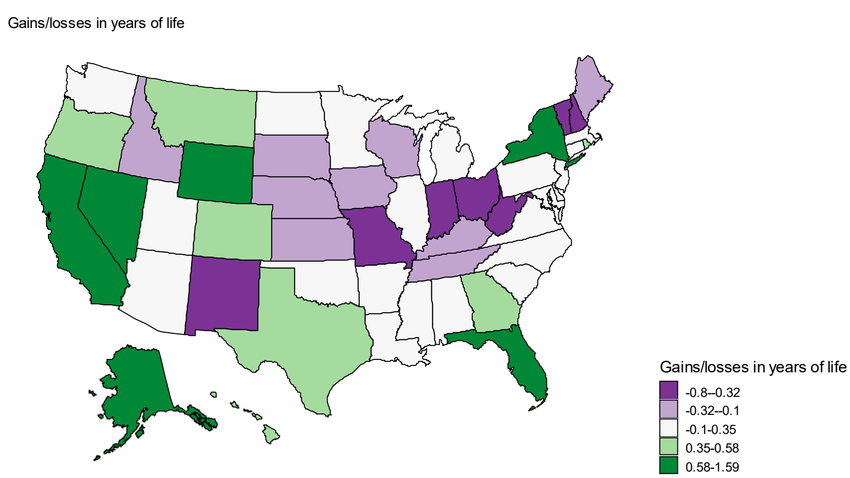
The share of variability attributable to cancer increased at all adult ages but it is highest at ages 45-59 and 60-74 years (increasing from 15-16% in 1959 to 26% in 1989 and declining to 18-22% in 2018). The proportion is much smaller at 75-89 years (12% in 2018) and even more so at ages 90 years and above (4%). The contribution of infectious/respiratory diseases is also significant to explain state variability in mortality at ages 45-59, 60-74 and 75-89 (from 15% at 45-59, to 20% at 75-89 in 2018). Their share is somewhat similar to that of other diseases at ages 45-59 and 60-74 though these other diseases contribute the same fraction of overall variability than cardiovascular diseases at ages 75-89 and 90 years and above (respectively 34 and 41% in 2018).

Section 6: The last decade

In this last section, we examine geographic variations in trends during the most recent period (i.e. since 2010), which was characterized at the national level by stalling and then reversal in the mortality decline of the modern period. In the United States as a whole, life expectancy at birth increased by 0.2 years between 2010 and 2018 (from 78.8 to 79.0 years), which is less than the average *annual* gain during the 20th century (and up to 2010). However, as indicated by Figure 10 below, there were large variations from state to state, with gains above half a year of life in the District of Columbia (with a record 1.6 years of extended life), New York, Alaska, California, Florida, Wyoming, Nevada, Rhode Island and Texas, in decreasing order of the years of life gained. By contrast, many states saw their life expectancy at birth shrink between 2010 and 2018. These states are mostly located in the central United States around Illinois, Iowa and Missouri, in addition to the three states in the extreme Northeast, and Idaho and New Mexico, with New Hampshire, West Virginia and Ohio experiencing extreme losses of more than half a year of life during this period.

Figure 10

YEARS OF LIFE GAINED OR LOST BETWEEN 2010 AND 2018 (BOTH SEXES COMBINED)

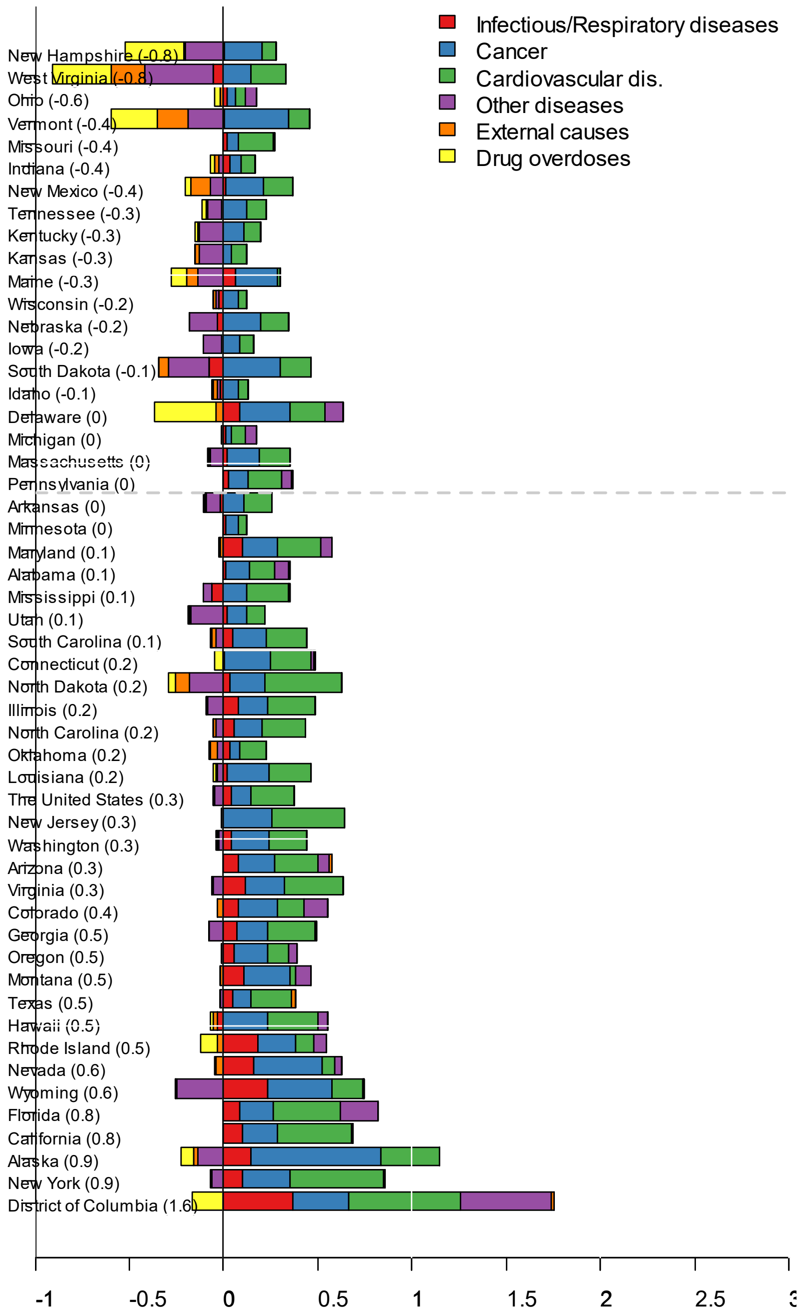


We resorted to the Andreev, Shkolnikov and Begun's technique previously mentioned to identify the causes of death responsible for the losses in life expectancy, decomposing the gains in years of life into six broad cause-of-death categories. The six categories include all of the previous ones (infectious and respiratory diseases, cancer, cardiovascular diseases, all other diseases, and external causes) except that we disaggregated external causes into drug overdoses on the one hand, and all other external causes on the other. The results are illustrated in Figure 11. The Figure shows how each category contributed to the change (gains or losses) in life expectancy at birth between 2010 and 2018 within each state. Again, the segment on the left of the origin correspond to cause of death for which mortality increased during this period while those to the right of the origin line correspond to causes for which mortality declined. States are ordered based on their total gain in years of life from smallest to largest.

Figure 11 clearly shows how mortality from the leading causes of death (cancer and cardiovascular diseases) continued to decline during the last decade while mortality from other diseases and external causes, including drug overdoses, deteriorated markedly in most states. The largest losses attributable to these cause-of-death categories occurred in New Hampshire, West Virginia, Vermont, South Dakota and Delaware but few states actually experienced progress in survival from these causes. The losses in life expectancy attributable to drug overdoses reached close to 0.5 years in West Virginia, New Hampshire and Delaware and was significant in Vermont, Maine, Rhode Island, Alaska and the District of Columbia. As for infectious and respiratory diseases, depending on the state, their contribution was either null (in most areas) or favorable (especially in those with the largest overall gains in life expectancy, e.g. the District of Columbia, Wyoming, Nevada, Alaska).

Figure 11

DECOMPOSITION OF GAINS IN LIFE EXPECTANCY AT BIRTH BETWEEN 2010 AND 2018 BY CAUSE-OF-DEATH CATEGORY, EACH STATE AND D.C., BOTH SEXES COMBINED



Section 7: Conclusion

After reaching a plateau in the 1960s, the length of life increased everywhere throughout the United States starting around 1970 and up to about 2010. Increase in survival was driven largely by the cardiovascular revolution brought about by decline in smoking among men and medical progress to both prevent and treat the diseases of the circulatory system. Though such diseases remain the leading cause of death in the United States, they now mostly kill at higher ages than they used to, driving a decline in mortality that has continued through the 21st century. Unfortunately, other forces have countered this positive impact, and the increase in the length of life has been interrupted in many states between 2010 and 2018. Drug overdoses have been responsible for the deterioration in several of them, though other diseases and external causes have also contributed. The current Covid-19 pandemic can have only worsened the situation. Preliminary death counts released by the Centers for Disease Control for 2020 indicate that overall mortality has increased in every single state compared to 2018 and 2019 and it is difficult to predict whether the rate of vaccination, improvement in treatment for Covid-19 and the ability to control the harmful impact of the economic crisis will foster a renewed increase in life expectancy in the short term, especially given the possible long-term detrimental impact of the disease on all of those who have been sick. However, by contrast with the deterioration of the mortality situation experienced by the United States between 2010 and 2018, which was very specific to this country, the negative impact of Covid-19 on further progress in survival has affected every other country.

Section 8: Acknowledgments

The researcher would not have been able to complete this work without the continuous support of the Human Mortality Database team at the University of California, Berkeley, and more specifically without the help of Celeste Winant, Lisa Yang, Denis Dukhovnov and Carl Boe. Their contributions have been essential to the success of this project. The researcher's deepest gratitude further goes to the Project Oversight Group and others who generously shared their wisdom, insights, advice, guidance, and arm's-length review of this study prior to publication. Any opinions expressed may not reflect their opinions nor those of their employers. Any errors belong to the authors alone.

Project Oversight Group members:

Mark Alberts, FSA, MAAA

Jean-Marc Fix, FSA, MAAA

Sam Gutterman, FSA, MAAA, CERA, FCA, FCAS, HONFIA

Kai Kaufhold, Aktuar DAV

Al Klein, FSA, MAAA

Larry Pinzur, Ph.D.

At the Society of Actuaries:

R. Dale Hall, FSA, MAAA, CERA, Managing Director of Research

Cynthia MacDonald, FSA, MAAA, Senior Director, Experience Studies

Patrick Nolan, FSA, MAAA, Senior Experience Studies Actuary

Jan Schuh, Senior Research Administrator

Ronora Stryker, ASA, MAAA, Senior Practice Research Actuary

Appendix A: Cause of Death Categories and Corresponding Codes

CAUSE OF DEATH CATEGORIES AND CORRESPONDING CODES IN REVISIONS 7 THROUGH 10 OF THE INTERNATIONAL CLASSIFICATION OF DISEASES

Category	ICD-7	ICD-8	ICD-9	ICD-10
1. Infectious and respiratory diseases	001-138, 240-241, 245, 470-527, 571, 764	000-136, 460-474, 480-486, 490-493, 500-519	001-139, 460-519	A00-B99, J00-J98, U04
2. Cardiovascular diseases	330-334, 440-468	390-458	390-459	I00-I99, G45
3. Cancer	140-205	140-209	140-208	C00-D48
4. All other diseases	Residual	Residual	Residual	Residual
5. External causes	E800-E999	E800-E999	E800-E999	V01-Y89
6. Ill-defined and unknown causes	242, 780-791, 793-795	780-791, 793-796	780-799	R00- R99

Appendix B: Variability in Mortality Rates by Cause-of-Death Category and by Age Group

VARIABILITY IN MORTALITY RATES BY CAUSE-OF-DEATH CATEGORY AND BY AGE GROUP ACROSS ALL US STATES AND THE DISTRICT OF COLUMBIA, AND STANDARDIZED DEATH RATE BY AGE GROUP AND BY CAUSE FOR THE US AS A WHOLE, SELECTED YEARS, BOTH SEXES COMBINED

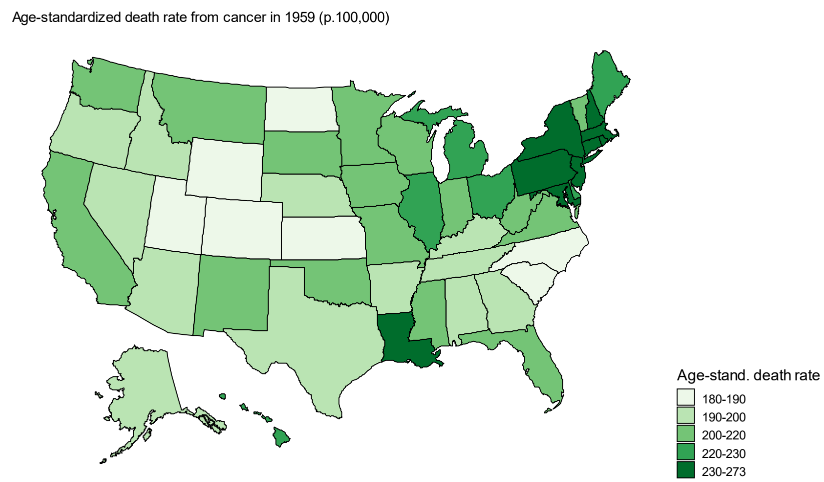
Cause-of-death category/Year	Age group							Stand.rate p. 100,000
	0-14	15-29	30-44	45-59	60-74	75-89	90+	
1959								
Cancer	0.4	0.3	8.7	15.3	16.2	8.4	0.4	271
Cardiovascular diseases	1.9	5.7	38.9	62.6	72.5	86.6	84.8	1081
Infectious/Respiratory diseases	33.3	1.0	8.0	5.3	3.2	3.1	7.6	98
Other diseases	44.6	10.3	16.1	12.7	8.1	0.2	1.9	191
External causes	19.8	82.8	28.3	4.2	0.1	1.7	5.4	110
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1751
Standardized death rate p. 100,000	266	162	317	1244	3896	12490	29693	
1969								
Cancer	0.9	1.4	7.6	16.4	14.3	5.5	0.4	292
Cardiovascular diseases	2.3	3.1	29.3	47.7	73.9	89.3	91.3	1041
Infectious/Respiratory diseases	16.3	1.3	7.5	8.1	2.9	4.6	3.3	110
Other diseases	58.4	7.8	26.5	19.4	8.7	0.5	4.9	196
External causes	22.2	86.4	29.1	8.4	0.3	0.1	0.1	124
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1763
Standardized death rate p. 100,000	218	198	350	1245	4004	12413	29379	
1979								
Cancer	0.7	1.2	9.7	25.5	23.1	11.5	6.3	310
Cardiovascular diseases	2.5	0.9	21.8	39.5	61.9	83.0	84.4	793
Infectious/Respiratory diseases	5.4	0.1	5.0	6.6	1.8	2.4	2.1	90
Other diseases	74.5	3.9	27.8	19.2	11.8	2.8	6.6	166
External causes	17.0	93.9	35.7	9.2	1.5	0.3	0.7	103
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1462

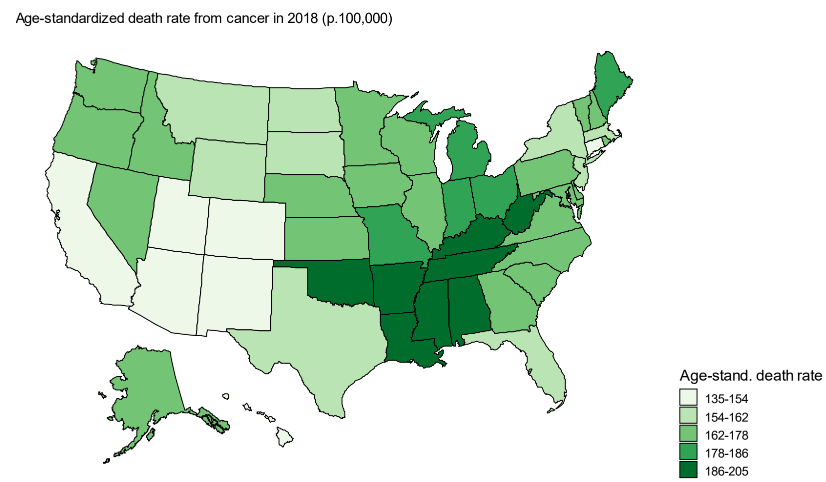
Standardized death rate p. 100,000	141	179	270	978	3267	10632	25735	
1989								
Cancer	1.0	0.4	9.0	25.8	25.6	14.8	5.3	315
Cardiovascular diseases	4.7	12.3	43.0	43.8	50.6	61.5	78.1	622
Infectious/Respiratory diseases	4.0	1.1	7.0	6.0	5.6	1.5	11.6	124
Other diseases	78.4	4.4	21.9	18.4	16.1	20.3	4.5	195
External causes	11.9	81.9	19.2	6.1	2.1	1.9	0.6	86
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1341
Standardized death rate p. 100,000	109	155	283	821	2846	10087	26144	
1999								
Cancer	0.6	0.9	9.0	23.6	25.1	12.4	2.0	287
Cardiovascular diseases	1.5	3.3	18.2	38.3	46.5	58.4	68.3	491
Infectious/Respiratory diseases	4.2	6.1	34.5	17.6	12.7	15.2	7.0	146
Other diseases	73.3	6.6	14.1	14.6	12.4	12.9	20.2	205
External causes	20.5	83.1	24.2	6.0	3.3	1.2	2.5	73
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1202
Standardized death rate p. 100,000	76	118	223	688	2372	9432	27729	
2009								
Cancer	2.9	0.1	7.2	22.7	25.8	11.9	2.4	241
Cardiovascular diseases	2.6	4.0	20.5	35.0	40.9	43.1	48.8	325
Infectious/Respiratory diseases	9.4	4.7	12.8	17.5	17.0	21.3	16.9	127
Other diseases	58.9	7.7	18.2	16.5	13.4	22.4	30.6	224
External causes	26.3	83.6	41.3	8.4	2.8	1.2	1.3	76
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	993
Standardized death rate p. 100,000	65	112	200	642	1863	7392	24866	

2018								
Cancer	0.7	0.1	4.9	19.0	22.1	11.5	4.4	203
Cardiovascular diseases	3.4	5.5	17.8	34.5	38.2	32.2	40.6	280
Infectious/Respiratory diseases	6.9	2.2	6.4	14.9	19.7	20.3	8.9	114
Other diseases	55.9	9.2	18.3	18.6	16.9	33.4	41.2	237
External causes	33.2	83.0	52.6	13.0	3.1	2.7	4.9	94
All causes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	928
Standardized death rate p. 100,000	57	120	232	619	1820	6583	22037	

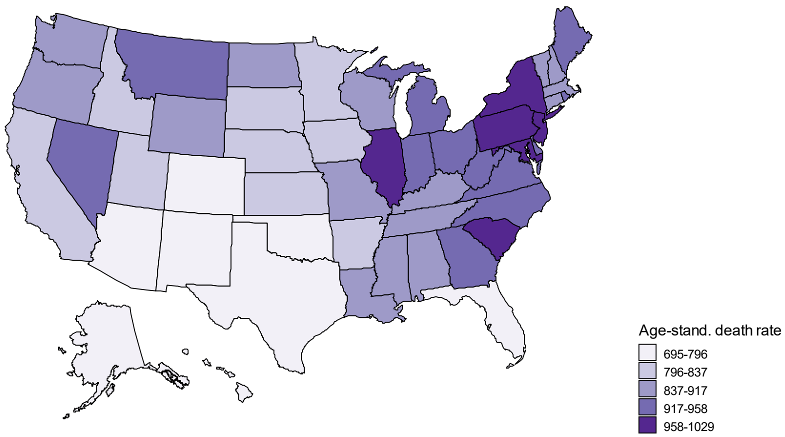
Appendix C: Maps of the Age Standardized Death Rates by State

MAPS OF THE AGE-STANDARDIZED DEATH RATES BY STATE FOR FIVE BROAD CAUSE-OF-DEATH CATEGORIES, BOTH SEXES COMBINED
Note: each pair of plots corresponds to a different disease category, with year 1959 on the left and 2018 on the right.

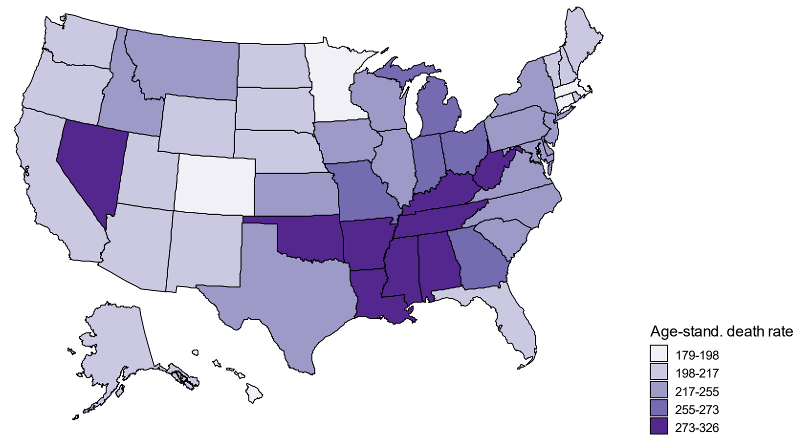




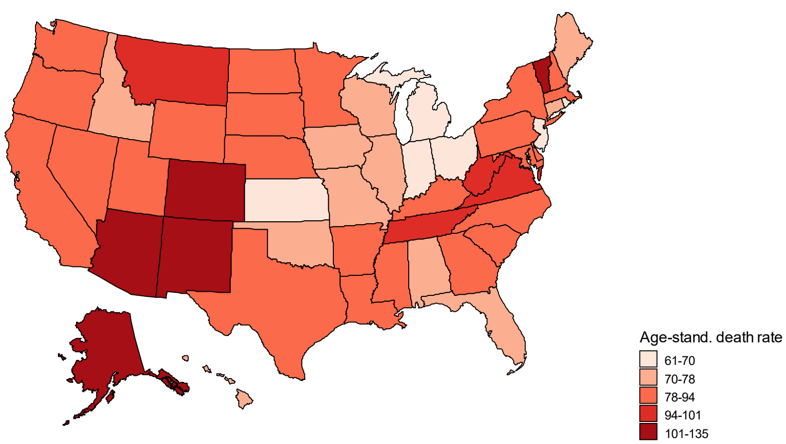
Age-standardized death rate from cardiovasc. diseases in 1959 (p.100,000)



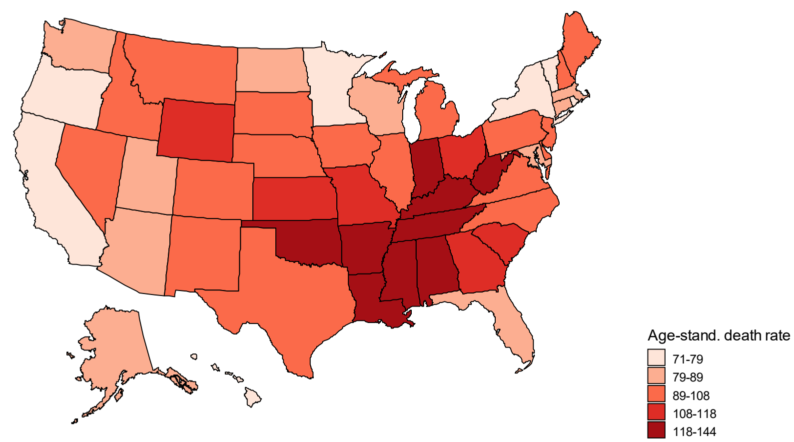
Age-standardized death rate from cardiovasc. diseases in 2018 (p.100,000)



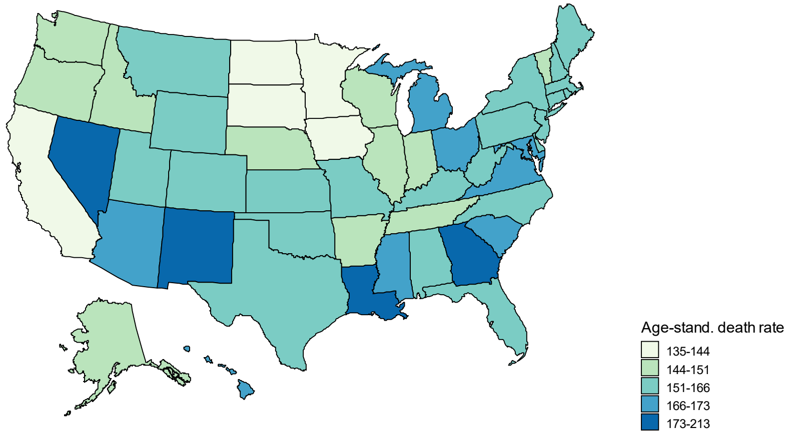
Age-standardized death rate from infectious diseases in 1959 (p.100,000)



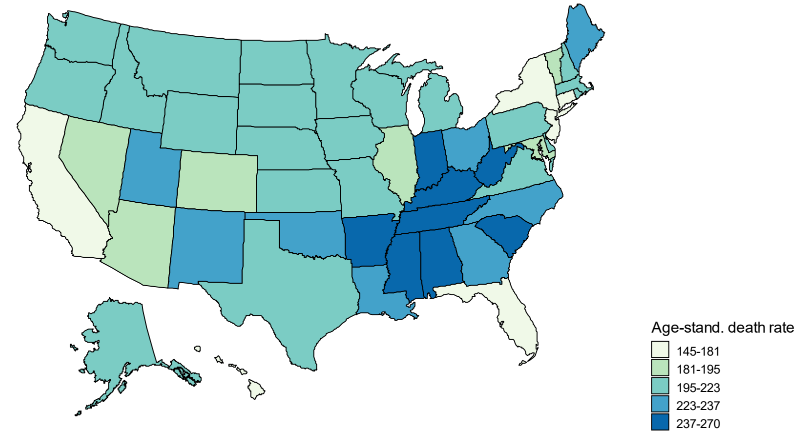
Age-standardized death rate from infectious diseases in 2018 (p.100,000)



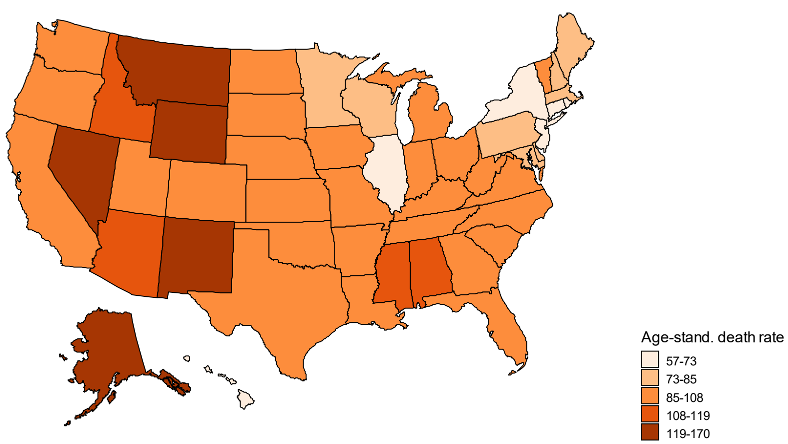
Age-standardized death rate from other diseases in 1959 (p.100,000)



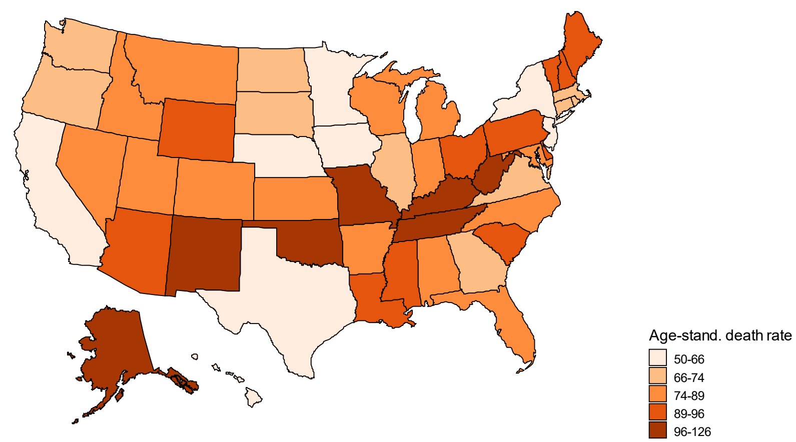
Age-standardized death rate from other diseases in 2018 (p.100,000)



Age-standardized death rate from external causes in 1959 (p.100,000)



Age-standardized death rate from external causes in 2018 (p.100,000)



About The Society of Actuaries

With roots dating back to 1889, the Society of Actuaries (SOA) is the world's largest actuarial professional organizations with more than 31,000 members. Through research and education, the SOA's mission is to advance actuarial knowledge and to enhance the ability of actuaries to provide expert advice and relevant solutions for financial, business and societal challenges. The SOA's vision is for actuaries to be the leading professionals in the measurement and management of risk.

The SOA supports actuaries and advances knowledge through research and education. As part of its work, the SOA seeks to inform public policy development and public understanding through research. The SOA aspires to be a trusted source of objective, data-driven research and analysis with an actuarial perspective for its members, industry, policymakers and the public. This distinct perspective comes from the SOA as an association of actuaries, who have a rigorous formal education and direct experience as practitioners as they perform applied research. The SOA also welcomes the opportunity to partner with other organizations in our work where appropriate.

The SOA has a history of working with public policymakers and regulators in developing historical experience studies and projection techniques as well as individual reports on health care, retirement and other topics. The SOA's research is intended to aid the work of policymakers and regulators and follow certain core principles:

Objectivity: The SOA's research informs and provides analysis that can be relied upon by other individuals or organizations involved in public policy discussions. The SOA does not take advocacy positions or lobby specific policy proposals.

Quality: The SOA aspires to the highest ethical and quality standards in all of its research and analysis. Our research process is overseen by experienced actuaries and nonactuaries from a range of industry sectors and organizations. A rigorous peer-review process ensures the quality and integrity of our work.

Relevance: The SOA provides timely research on public policy issues. Our research advances actuarial knowledge while providing critical insights on key policy issues, and thereby provides value to stakeholders and decision makers.

Quantification: The SOA leverages the diverse skill sets of actuaries to provide research and findings that are driven by the best available data and methods. Actuaries use detailed modeling to analyze financial risk and provide distinct insight and quantification. Further, actuarial standards require transparency and the disclosure of the assumptions and analytic approach underlying the work.

Society of Actuaries
475 N. Martingale Road, Suite 600
Schaumburg, Illinois 60173
www.SOA.org