The Impact of COVID-19 on the Socioeconomic Differential in Mortality in the United States

FEBRUARY | 2024

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The Impact of COVID-19 on the Socioeconomic Differential in Mortality in the United States

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Executive Summary

This report presents the findings of a research project to analyze the 2020 and 2021 direct and indirect impact of the COVID-19 pandemic on the previously documented socioeconomic gradient in mortality in the United States (Barbieri, 2020, 2022). The study is based on an analysis of mortality data by year, county, sex and age released by the National Center for Health Statistics at the Centers for Disease Control, combined with population data from the U.S. Census Bureau. These data were used to extend to years 2020 and 2021 the previously constructed sex-specific lifetable series and cause-specific mortality rates by socioeconomic (SIS) decile for 1982-2019. The overall goal of the project was to contribute to a better understanding of how the COVID-19 pandemic impacted different socioeconomic groups within the U.S. population and, ultimately, how the health crisis is likely to affect the work of actuaries in the insurance and reinsurance industry.

The main findings of the study are summarized in the following points:

- A deterioration of life expectancy at birth and the associated age-standardized mortality rates for all socioeconomic deciles and for both men and women in 2021 compared with 2019.
- A progressively smaller mortality impact with improved socioeconomic conditions, with a loss of life years ranging from 1.6 to 4.2 years from the top to the bottom decile for men and from 0.9 to 3.3 years for women.
- A resulting aggravation of the pre-existing socioeconomic gradient in life expectancy, with a gap between the top and bottom deciles of the distribution increasing from 5.8 to 8.1 years for women and from 7.3 to 9.9 years for men between 2019 and 2021.
- A very similar age pattern of excess mortality for both sexes and over all SIS deciles, albeit more muted for those at the top of the socioeconomic distribution, with a particularly large relative increase in mortality among working age adults.
- A large direct impact of the SARS-CoV2 virus leading to a jump in mortality from the associated acute respiratory disease and possibly on some chronic conditions such as cardiovascular and metabolic diseases, but also a significant indirect impact, through external causes in particular (drug overdoses, alcoholism, homicides and traffic accidents).

Section 1: Motivation and Background

Prior research has demonstrated the disproportionate mortality impact of recent natural disasters (e.g., heat waves, hurricanes, floods) on the most disadvantaged populations in the United States (Bolin and Kurtz, 2018; Dash, 2013; Fothergill and Peek, 2004; Laska and Morrow, 2006). Recent analyses based on data for 2020 and 2021 indicate that this is the case for COVID-19 as well. These studies have shown that COVID-19 cases and deaths are concentrated in areas characterized by low median household income, high levels of income inequality, and low levels of education attainment (Chen and Krieger, 2020, 2021; Mollalo, Vahedi and Rivera, 2020; Seligman, Ferrana and Bloom, 2021). More generally, a growing body of evidence, including our own work, has indicated an unequal mortality burden from COVID-19 across the U.S. (Andersen et al. 2021; Andrasfay and Goldman, 2021; Chen and Krieger, 2021; Cheng et al. 2020; Cordes and Castro, 2020; Desmet and Wacziarg, 2020; Dukhovnov and Barbieri, 2021; Fielding-Miller, Sundaram and Brouwer, 2020; Kim and Bostwick, 2020; Pro et al. 2020; Stokes et al. 2021a, 2021b).

A precise measure of the pandemic direct and indirect impacts on mortality and associated socioeconomic disparities within the U.S. is the first step towards understanding the proximate causes and underlying factors driving the uncovered patterns. A second step is to investigate the particular mechanisms at play and how the pathways of influence from upstream socioeconomic factors on mortality operate through an analysis of the causes of death that have contributed to the excess mortality of 2020 and 2021 beyond COVID-19 given the combination of direct and indirect impact of the pandemic on life expectancy as defined below.

Direct effects of COVID-19

COVID-19 has had both direct and indirect effects on mortality. Its direct effects are the acute biological attack of the virus on vital organs of infected individuals, where COVID-19 is listed as the underlying cause of death on the death certificate. However, some of the biological impacts of COVID-19 on mortality have operated indirectly, where infection from COVID-19 aggravated pre-existing health conditions (immediate impact) or inducing new vulnerabilities to unrelated disorders, thus increasing the risk of death from other medical causes (delayed impact).

Indirect effects of COVID-19

Among the indirect effects of COVID-19 are also those not mediated by biological mechanisms. Delayed care for non-COVID-19 acute conditions due either to individuals not seeking care in a timely manner when needed for fear of contracting the infection in a medical setting or to the scarcity of health care resources in hospitals overwhelmed by COVID-19 could have affected conditions like cancer and cardiovascular events. The CDC has reported from early data that an estimated 40% of the population has delayed seeking care between March and June 2020, including emergency care for 12% (Czeisler et al. 2020). In the CDC study, delays in seeking care were especially prevalent among economically disadvantaged populations. Delays in diagnosis due to care avoidance or scarcity have been identified for a number of acute conditions, including major causes of deaths such as stroke, ischemic heart disease and cancer, in the U.S. and other high-income countries (Bakouni et al. 2021; Maringe et al. 2020; Schirmer et al. 2020; Wu et al. 2020). The disarray of services provided to counteract potentially fatal behavior, like drug use and alcohol consumption, could have had a similar impact, as suggested by early research on these issues (Baumgartner and Radley, 2021; Da et al. 2020; Gloppen, Roesler and Farley, 2020; Pollard, Tucker and Green, 2020). These effects could operate both during and immediately after the pandemic.

A second type of indirect effect is even more distant as they result from the economic and social consequences of the epidemic and associated lockdowns: e.g., the increasing level of poverty and income inequality associated with job losses and other economic hardship, or the rise in mental health issues due to the isolation induced by physical distancing and shelter-in-place policies. We believe that a careful analysis of cause-of-death data could contribute to clarify and differentiate between all of these different types of effects of COVID-19 on mortality in different segments of the U.S. population (i.e., within each socioeconomic decile of counties, taking sex and age into account).

1.1 MAIN PROJECT CONTRIBUTIONS

The project is motivated by the increasing actuarial interest in better understanding socioeconomic differences in mortality patterns in the recent past and more specifically during the COVID-19 crisis, both to more accurately determine pricing and to refine mortality improvement models. Beyond the insurance industry, inequalities in mortality and the impact of the current health crisis are of much importance to the American public and policy makers in general due to issues that have to do with inequities and with economic inefficiencies. Disparities in survival have been growing in the United States since around 1980 and the pandemic appears to have further aggravated this trend. As we have demonstrated in previous work, inequalities have slowed down progress in life expectancy for the U.S. population as a whole and they have contributed to the increasing gap in survival with other high-income democracies (Wilmoth, Boe, and Barbieri, 2011; Barbieri, 2022). In this context, this study contributes to:

- Improvement in pricing by actuaries in the insurance and reinsurance industry
- Monitoring changes in socioeconomic variations in mortality due to the COVID-19 crisis
- Strengthening our understanding of the mechanisms driving the change
- Providing tools to policy makers to evaluate disparities during the crisis
- Assessing the impact of interventions to facilitate a rebound from the crisis

Section 2: Research Design

The study is based on the analysis of the previously constructed set of lifetables for groups of counties based on their relative socioeconomic position extended to years 2020 and 2021. This updated data series has allowed us to measure the impact of the pandemic on socioeconomic disparities in survival.

In our previous work, the position of each county on the affluence ladder was determined by a score (or index) combining indicators of several measures of access to material and social resources following common approaches. All US counties were ranked based on a single socioeconomic score calculated from county-level data in the 2000 Population Census and distributed among ten deciles of approximately equal demographic weight. Using mortality data from the National Center for Health Statistics (NCHS), one set of lifetables was constructed for each socioeconomic decile in each year from 1982 to 2019.

The lifetables were constructed following the methods implemented in the Human Mortality Database (HMD) project of which the Principal Investigator is the Co-Director (Wilmoth et al., 2021). One of the original aspects of the HMD methods is to include ways to improve estimation of mortality at high ages. A combination of the extinct cohort and the survival ratio methods reduces the impact of data limitations (i.e., when death counts are not provided by single year of age up to the maximum age possible but up to an open age interval, typically 85 years and above) and data quality issues (i.e., the well-documented problem of age overstatement). These methods require that each additional year of data is used to improve estimation of the mortality rates for previous years[1]. Mortality rates at ages 85 and above in the existing lifetable series were thus augmented with data for 2020 and 2021. Relying on the same restricted-use NCHS Multiple Cause Mortality Files, we also updated the cause-specific death rates by sex and age calculated for each socioeconomic decile during the same years.

The impact of COVID-19 on mortality is assessed by measuring excess mortality, by estimating the difference between the expected level of mortality in the absence of the pandemic and its actual level using an array of approaches as further discussed below. Compared to a direct estimation of COVID-19 that would involve relying exclusively on deaths directly attributed to the SARS-CoV-2 virus, excess mortality offers the advantage to reflect both the direct and secondary effects of the pandemic on the overall mortality rate and to bypass the issue of differential misreporting of COVID-19. Though the possibility of an *overcount* of COVID-19 deaths has been considered (due to a confusion between people dying of COVID-19 versus dying with COVID-19), it has been proved negligible (Slater et al. 2020).

[1] Estimation of mortality above age 85 years in the HMD is based on a combination of methods, each applied to a different set of cohorts, i.e. the extinct cohort method, for all cohorts for which we can presume no survivors remain; the survival ratio method, for all non-extinct cohorts which members have reached age 90 years or above in the last calendar year for the series; and the cohort component method for all non-extinct cohorts which members have reached between the ages of 85 and 90 in the last calendar year. With every new calendar year of data added to the series, there is a shift in the set of cohorts to which each method is applied, hence the slight change in mortality rates by age at 85 years and above with each new update. However, much of this effect is canceled by the modeling applied to the mortality rates at very high ages. For more details about the HMD methods, see the HMD Methods Protocol at https://mortality.org/File/GetDocument/Public/Docs/MethodsProtocolV6.pdf.

Because of the sudden reversal in mortality trends in calendar year 2020 and 2021 data due to COVID-19, there is a larger change in the mortality estimates for ages 80 and over in the new update in comparison to the existing life tables than seen in past mortality updates. See Appendix 3. We are in the initial stages of investigating how to better estimate mortality at these ages in light of abrupt mortality changes from year to year.

By contrast, the Centers for Disease Control (CDC) has acknowledged a likely *undercount* of COVID-19 deaths due to a range of factors (Rossen et al. 2020). These include the availability of diagnostic testing and the accuracy of cause-of-death reporting on the death certificate. There are early indications of differential rates of under-reported COVID-19 deaths by socioeconomic characteristics (Lieberman-Cribbin et al. 2020) due to lower rates of COVID-19 testing in more deprived areas during the early months of the pandemic (Lewis et al. 2020; Rentsch et al. 2020).

The undercount of COVID-19 deaths was also found to vary widely geographically, especially when diagnostic tests for the virus were still scarce. Prior research estimated that the number of excess deaths was 11 to 28% higher than the official number of COVID-19 deaths at the national level, depending on measurement methods and periods of reference, with substantial heterogeneity in COVID-19 associated mortality across geographic regions. For instance, less than half of all excess deaths had COVID-19 as the underlying cause in rural areas, where much of the disadvantaged populations are concentrated (Stokes et al. 2021). Of course, some of these deaths are not the result of misclassification but of the indirect impact of COVID-19, as previously discussed. In any event, evaluating excess mortality rather than mortality directly attributable to the infection enables us to capture the overall mortality burden of the pandemic (Dorn et al., 2022).

However, measuring excess mortality in 2020 and 2021 necessitates an accurate counterfactual: it requires knowledge about what the level of mortality in these two years would have been without the pandemic. Researchers have followed three different approaches to carry out this estimation.

1. They have compared the level of mortality in 2020 and 2021 to the level of mortality in prior years (typically 2019 but sometimes 2015-2019 or 2010-2019).
2. They have implemented a cause-deleted lifetable approach, which consists into removing all deaths from COVID-19 and considering that those who were thereby kept alive would have had the same risks of dying as the general population.
3. They have assumed that pre-pandemic mortality improvement rates would have continued to be applied in 2020 and 2021 in the absence of COVID-19. Though this approach makes particular sense in countries with regular and monotonic mortality change over the pre-pandemic years, it is complicated in the United States by the erratic trends of the previous decade. After decades of decline, mortality remained stable during 2010-2014, then increased from 2014 to 2017, and declined again in 2018 and 2019. Predicting whether mortality would have continued to decline, whether it would have stopped declining, or whether it would have increased again (which is not implausible considering that drug-related deaths, which largely caused the earlier increase in mortality, started picking up again after two years of falling) is thus a precarious exercise.

Out of cautiousness, we estimated excess mortality in 2020 and 2021 using all these different approaches and present the results in the next section. More specifically, we estimated lifetables for 2020 and 2021 from the actual mortality data obtained from the NCHS and compared them to:

1. 2019 lifetables (also constructed using the NCHS mortality data).
2. 2020 and 2021 cause-deleted lifetables calculated by implementing classic demographic methods (which consist into removing all deaths attributed to COVID-19 and assuming the same mortality risks for these survivors as for the rest of the population).
3. 2020 and 2021 lifetables calculated from projected age-specific death rates for the period 2010-2019.

Note that the second approach (the calculation of cause-deleted lifetables) was implemented in two different ways: by deleting all deaths with COVID-19 as the underlying cause and by deleting all deaths with any mention of COVID-19 on the death certificate.

To enhance our understanding of the mechanisms at play in the excess mortality recorded in 2020 and 2021, we also conducted an analysis of the causes of death involved beyond COVID-19. We calculated the contribution of 58 exhaustive cause-of-death categories (with COVID-19 as its own category) combined into six broad groups to the lower life expectancies, as well as to the higher age-standardized mortality rates in 2020 and 2021.

The six broad cause-of-death categories are 1) infectious and respiratory diseases, 2) cardiovascular diseases, 3) cancer, 4) all other diseases, 5) external causes, and 6) ill-defined and unknown causes. The 58 more detailed causes-of-death categories are presented in Appendix Table 1, together with their corresponding ICD-10 codes.

An understanding of whether non-COVID-19 excess mortality during this period was attributable to a small number of specific causes of death (and which ones) or to a broad range of causes can provide insight into the underlying drivers of the mortality increase not directly related to COVID-19. Information on non-COVID-19 causes of excess mortality could be used by policy makers, clinicians, and public health professionals to inform more targeted interventions and resource allocations to accelerate recovery from the crisis and reduce inequities. We also calculated age-standardized death rates for the 58 detailed causes of death grouped into the six broad categories over the whole period 1982-2021 for each sex and each SIS decile using the distribution of the population by age (both sexes combined) in the 2000 Census as the reference.

The Multiple Cause-of-Death Data Files provided by the NCHS include information for all deaths occurring in the country and, more specifically for our purpose, the sex, age, and county of residence of the deceased, and the multiple causes of death reported on the certificate, coded to the 4^{th} digit of the International Classification of Disease 10^{th} Revision (ICD-10). We recoded all causes to a shortlist of 58 exhaustive and mutually exclusive categories (see Appendix 1 for the list of cause-of-death categories and their corresponding ICD codes) for all calendar years from 1982 to 2021.

Section 3: Results

We first present the result of our various estimation approaches in measuring excess mortality in 2020 and 2021 in each of the ten SIS deciles by sex. We then describe the differential impact of COVID-19 on historical trends in life expectancy at birth and at other ages across all SIS deciles and its consequence for the pre-existing socioeconomic gradient in mortality. We last examine which causes of death were most sensitive to the increased risks associated with the pandemic and their contributions to changes in social disparities in mortality.

3.1 EXCESS MORTALITY IN 2020 AND 2021 BY SIS DECILE

Table 1 below presents the estimated level of life expectancy at birth measured under the various methods for each sex and SIS decile while Table 2 shows the difference between each of these estimates and the actual level of life expectancy at birth recorded in 2021[2]. To simplify the discussion, we concentrate on the loss of years of life in 2021 though note that life expectancy at birth declined in both 2020 and 2021 for all deciles except the top one. For the top decile (10), both men and women experienced a very small rebound in 2021 compared with 2020, though the expected length of life remains lower in 2021 than in 2019 (by 1.61 years for men and 0.92 years for women).

The results of our analysis indicate that the magnitude of the excess estimated for the pandemic years is very sensitive to the counterfactual used to measure it, especially at the lower end of the socioeconomic gradient. The cumulative loss of life expectancy between 2019 and 2021 varies from 1.07 to 1.66 years for men and from 0.78 and 1.04 years for women in the top (most advantaged) SIS decile and from 2.21 to 4.18 years for men and from 2.05 and 3.25 years for women in the bottom (least advantaged) SIS decile, depending on the method of estimation (Table 2). In nearly every decile and for both sexes, simply comparing the observed mortality of 2021 to 2019 (column 1 in Table 2) yields the largest excess. In the first (most disadvantaged) decile, the loss of life expectancy estimated with this simple comparison is nearly 2 years higher for men and 1 year for women than when a more sophisticated cause-deleted estimation approach is used. This is true whether COVID-19 deaths are excluded only when the condition appears on the death certificate as the underlying cause (column 4 in Table 2) or whether it appears anywhere (as the underlying or as an associated cause) (column 5).

This result stems from the fact that COVID-19 killed both directly (through its biological impact on the human body) and indirectly (for instance through the change in behavior it induced). Thus, taking only the first type of impact into account logically yields a lower amount of excess mortality than accounting for all of the pandemic effects. However, for the vast majority (90 percent) of the death certificates with a mention of COVID-19, the infection was listed as the underlying cause (rather than as an associated or contributing cause), which explains why the difference between the two is small.

[2] Similar tables are presented for the expectation of life at ages 25, 45, 65, and 85 in Appendix 2.

Table 1

2019, 2020 AND 2021 ACTUAL LIFE EXPECTANCIES AT BIRTH AND ESTIMATED LIFE EXPECTANCIES AT BIRTH FOR 2021 USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	72.74	69.81	68.56	70.77	70.96	72.57	78.51	76.22	75.26	77.31	77.53	78.37
2	74.57	72.24	71.06	73.08	73.27	74.50	80.07	78.26	77.31	79.14	79.33	79.97
3	74.93	72.92	71.42	73.44	73.62	74.70	80.15	78.62	77.56	79.29	79.48	79.96
4	76.18	73.65	72.68	74.72	74.89	76.05	81.44	79.77	79.12	80.75	80.92	81.34
5	75.53	73.23	72.38	73.98	74.14	75.29	81.01	79.49	78.84	80.21	80.38	80.85
6	76.43	74.20	73.49	75.19	75.36	76.23	81.62	79.97	79.51	80.91	81.08	81.46
7	76.92	75.13	74.06	75.71	75.88	76.79	81.93	80.67	79.95	81.27	81.44	81.83
8	77.58	75.88	75.33	76.68	76.82	77.47	82.35	81.19	80.91	81.95	82.09	82.33
9	79.00	77.27	76.72	78.00	78.15	78.89	83.40	82.18	82.07	82.98	83.11	83.38
10	80.06	78.15	78.45	79.52	79.65	80.11	84.31	83.02	83.39	84.17	84.29	84.43
All	76.39	74.23	73.37	75.10	75.27	76.27	81.49	79.95	79.39	80.81	80.98	81.41

(1) 2019 actual lifetable
(2) 2020 actual lifetable
(3) 2021 actual lifetable
(4) 2021 COVID-deleted lifetable (with COVID-19 as the underlying cause only)
(5) 2021 COVID-deleted lifetable (with any mention of COVID-19)
(6) 2021 predicted lifetable from 2010-2019 trends in the probabilities of dying (q_x)

Table 2

DIFFERENCE IN LIFE EXPECTANCY AT BIRTH BETWEEN THE ACTUAL LIFETABLE FOR 2021 ON THE ONE HAND AND THAT IN THE 2019 AND 2020 ACTUAL LIFETABLES AS WELL AS IN THE LIFETABLE FOR 2021 ESTIMATED USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	4.18	1.25	0.00	2.21	2.40	4.01	3.25	0.96	0.00	2.05	2.27	3.11
2	3.51	1.18	0.00	2.02	2.21	3.44	2.76	0.95	0.00	1.83	2.02	2.66
3	3.51	1.50	0.00	2.02	2.20	3.28	2.59	1.06	0.00	1.73	1.92	2.40
4	3.50	0.97	0.00	2.04	2.21	3.37	2.32	0.65	0.00	1.63	1.80	2.22
5	3.15	0.85	0.00	1.60	1.76	2.91	2.17	0.65	0.00	1.37	1.54	2.01
6	2.94	0.71	0.00	1.70	1.87	2.74	2.11	0.46	0.00	1.40	1.57	1.95
7	2.86	1.07	0.00	1.65	1.82	2.73	1.98	0.72	0.00	1.32	1.49	1.88
8	2.25	0.55	0.00	1.35	1.49	2.14	1.44	0.28	0.00	1.04	1.18	1.42
9	2.28	0.55	0.00	1.28	1.43	2.17	1.33	0.11	0.00	0.91	1.04	1.31
10	1.61	-0.30	0.00	1.07	1.20	1.66	0.92	-0.37	0.00	0.78	0.90	1.04
All	3.02	0.86	0.00	1.73	1.90	2.90	2.10	0.56	0.00	1.42	1.59	2.02

(1) 2019 actual lifetable
(2) 2020 actual lifetable
(3) 2021 actual lifetable
(4) 2021 COVID-deleted lifetable (with COVID-19 as the underlying cause only)
(5) 2021 COVID-deleted lifetable (with any mention of COVID-19)
(6) 2021 predicted lifetable from 2010-2019 trends in the probabilities of dying (q_x)

Overall, there were 384,536 deaths with COVID-19 mentioned on the death certificate in 2020 and 416,893 in 2021 (both sexes combined) but in 91 and 90 percent of those, respectively, COVID-19 was identified as the underlying cause. In only 9 and 10 percent of all cases, COVID-19 was reported as an associated or contributing cause. In such cases, the most common underlying cause was, in decreasing order of magnitude, heart diseases (in 31 and 26 percent of all such cases for men and women, respectively), diseases of the nervous system (9 and 14 percent), neoplasms (12 and 11 percent), acute respiratory diseases other than COVID-19 (8 and 9 percent), cerebrovascular diseases (6 and 7 percent), and diseases of the endocrine, nutritional and metabolic systems (7 and 5 percent). Other diseases accounted each for less than 5 percent of all cases. Combined together, diseases of the circulatory systems accounted for 38 and 33 percent of all cases with mention of COVID-19 as an associated or contributing cause.

It might be surprising that, for all but the top SIS decile and for both men and women, estimating the counterfactual life expectancy projecting mortality trends from 2010-2019 for each SIS decile yields a smaller difference in the length of life (column 6 in Table 2) than when simply comparing to 2019 (column 1). This is due to the previously mentioned erratic trends in mortality during this period. The difference would have been larger if survival had consistently improved over the previous decade.

3.2 IMPACT OF EXCESS COVID-19-ASSOCIATED MORTALITY ON HISTORICAL TRENDS IN LIFE EXPECTANCY

COVID-19 has accelerated the negative trend in life expectancy that started in the first half of the 2010s, after several decades of continuous gains in survival (Figure 1). For men, between 1982 and 2010, the average length of life increased from 68.6 to 73.0 years for the bottom (first) decile and 72.5 to 79.4 years for the top (tenth) decile. The corresponding gains were 4.35 years and 7.0 years, respectively, with all other deciles experiencing progressively higher gains. The maximum was reached in 2012 for men in the first decile (at 73.11 years) and in 2019 for those in the tenth (at 80.06 years). Life expectancy at birth had continued to improve up to this later year only for the top two deciles (the 9^{th} and 10^{th}). Men in all other deciles have experienced a decline in life expectancy at birth during the second half of the 2010s, mostly between 2014 and 2017, with losses ranging from a tenth to a third of a year, depending on the decile.

However, the losses associated with the pandemic were considerably larger over both years 2020 and 2021 and affected all SIS deciles. The maximum loss was experienced in 2020 but a further, albeit smaller, decline was experienced in 2021 for all deciles but the top one, in which the length of life declined by 1.91 years in 2020 compared to 2019 but recovered slightly with a gain of 0.3 year in 2021. In total, between 2019 and 2021, the losses in years of life ranged from 2.3 years (for deciles 7 and 8) to 4.2 years (for decile 1) (Tables 1 and 2).

The toll of the COVID-19 pandemic on the 10% of Americans in the most deprived counties is vividly reflected by the fact that the mortality conditions of 2021 were exactly the same as those of 1982 (with 68.6 years of e0 in both years), a thirty-year progress (between 1982 and 2011) eradicated in a single decade. Though the health crisis of 2020 and 2021 has clearly aggravated the trend, some rebound is expected in the forthcoming years.

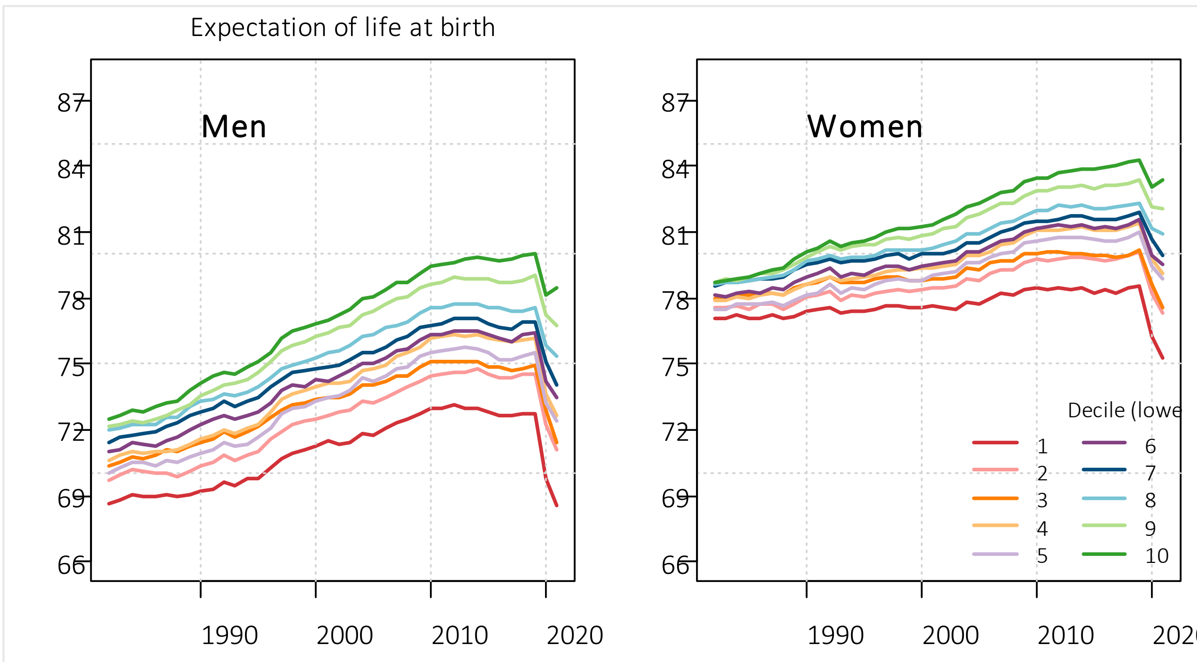
The absolute impact of COVID-19 on women's life expectancy has been less dramatic than for men. The loss of life experienced in the first year of the pandemic continued in 2021 (except for the top decile which recovered to the same extent as for men, i.e., with a gain of 0.3 years from 2020 to 2021) but to a smaller extent than in 2020, with a total loss over these two years ranging from 0.9 years in the top (most advantaged) decile to 3.25 years in the bottom decile. However, the relative impact has been even more dramatic than for men given the fact that the gains in years of life between 1982 and 2019 were much lower for women than the loss experienced in the following two years, except for the top two deciles.

Though women experienced nearly continuous progress in life expectancy at birth between 1982 and 2019 (except for a slight increase in mortality in the early 1990s due to the HIV-AIDS epidemic), the gains were much smaller than for men (from 1.4 years in the bottom decile to 5.6 years in the top one) and also smaller than the losses experienced between 2019 and 2021. The result is that in 2021, life expectancy at birth was lower than in 1982 for the first three deciles (from -0.4 years in the third to -1.8 years in the first). By contrast, all other deciles (4th to 10th) suffered a relatively smaller loss, with a setback ranging from 25 years for the 4th to 12 years for the 10th decile.

In the end, these differential trends by SIS decile resulted in a sudden increase in the gap in life expectancy at birth between the bottom and top deciles. Compared to 2019, the gap increased by 2.6 years for men and 2.3 years for women, thus reaching 9.9 and 8.1 years overall in 2021.

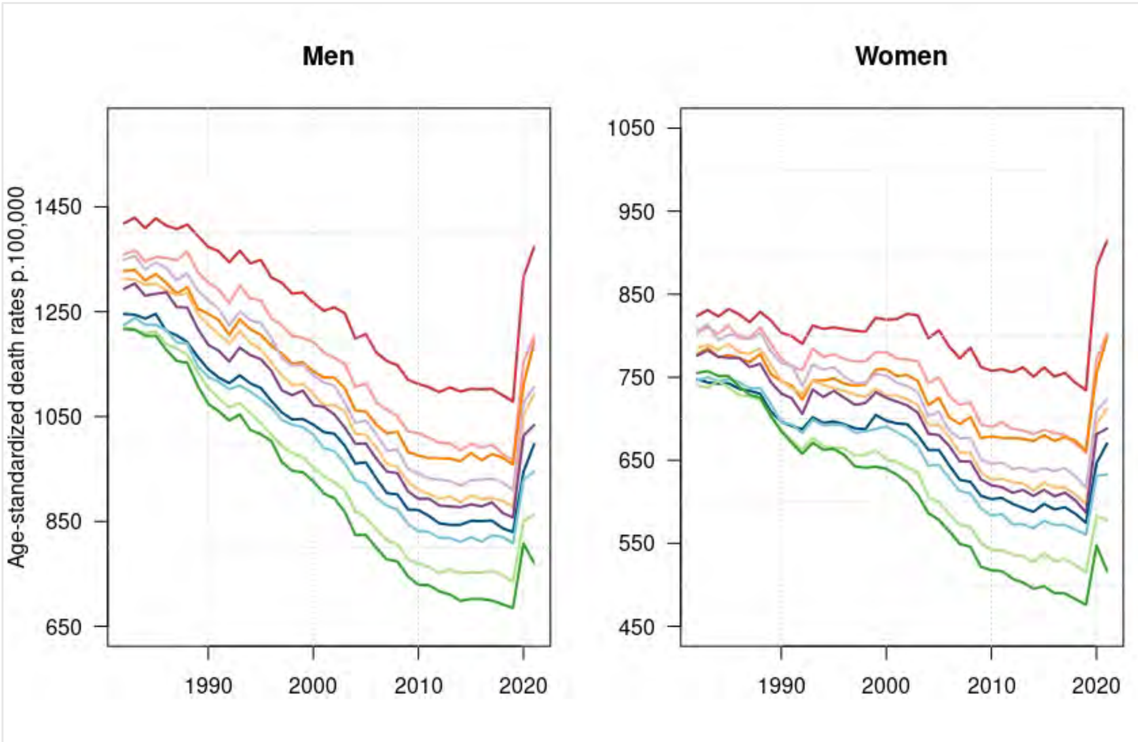
Figure 1

LIFE EXPECTANCY AT BIRTH BY SIS DECILE, 1982-2021, EACH SEX



The decline in life expectancy at birth in 2020 and 2021 is associated with a dramatic jump in the age-standardized death rate, another synthetic measure of mortality. Figure 2 represents the trend in the standardized rates per 100,000 for each SIS decile and for men and women separately between 1982 and 2021. It shows that the age-standardized death rate for all causes combined increased from 13 and 9 percent for men and women, respectively, in the top SIS decile, to 27 and 25 percent in the bottom decile between 2019 and 2021, with a very clear progression across all other deciles, thus increasing the gap between the two extreme deciles. In 2019, the difference in the age-standardized death rate between these two deciles was 394 per 100,000 for men and 248 per 100,000 for women. It increased to 602 and 397 per 100,000, respectively, in 2021, a jump of 53 and 60 percent in a mere two years. For the 10% of Americans in the bottom decile, the health crisis brought the level of mortality back to 1990 for males and to well above that of the earliest year in the series (1982) for women.

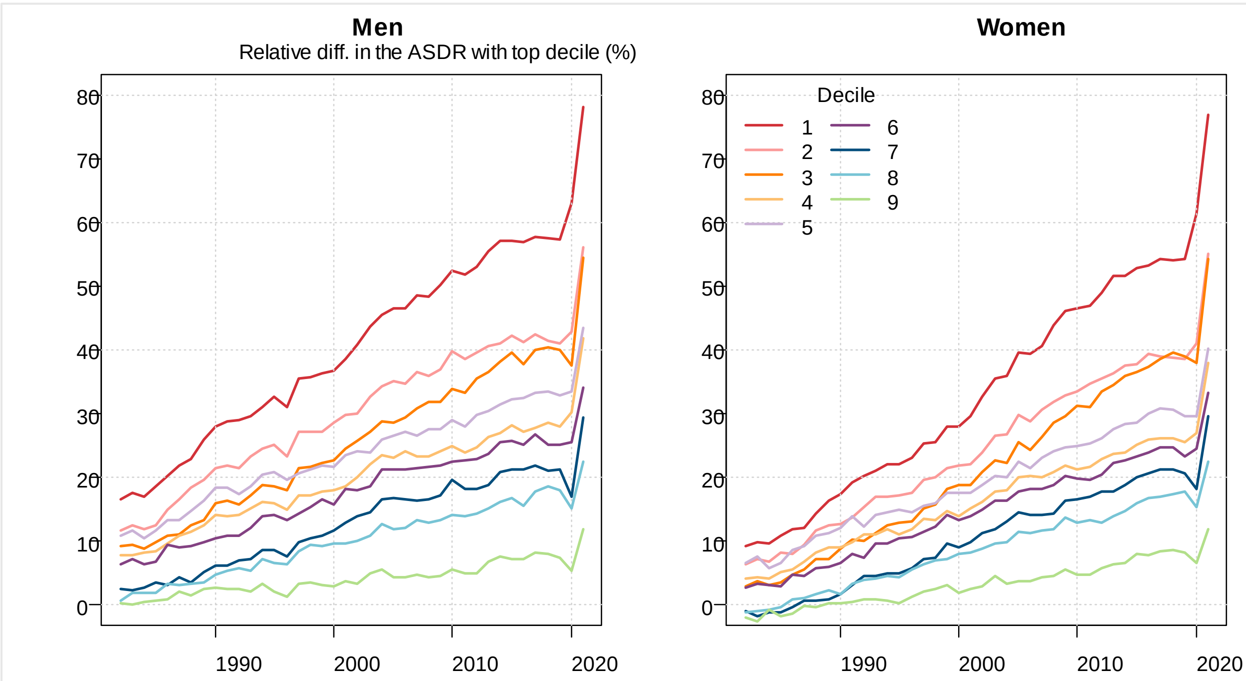
Figure 2
AGE-STANDARDIZED DEATH RATE (ALL CAUSES OF DEATH) BY SIS DECILE, 1982-2021, EACH SEX



The result of these differential trends and the clear socioeconomic gradient in the impact of the pandemic on historical mortality trends has been a further increase in inequalities. Figure 3 shows the difference in the age-standardized death rates between each SIS decile and the top (10th) decile from 1982 and 2021 relatively to the level of mortality in the top decile. The figure provides evidence of a clear and progressive jump in the gap between the top and each subsequent decile between 2019 and 2021. The absolute difference in the rates ranged from 50 to 393 per 100,000 in the 9th to 1st deciles compared with the 10th for men in 2019, and 39 to 258 per 100,000 for women. This jumped to 91 to 602 per 100,000, respectively, for men and 61 to 398 per 100,000 for women in 2021. The initial gap in mortality between the best-off Americans and all subsequent deciles increased from 7 to 10 percent between 2019 and 2021 for men in the second most advantaged decile (decile 9) to 57 to 78 percent for those in the most disadvantaged decile (decile 1). It was very similar for women: from 8 to 12 percent for those in the 9th decile and from 54 to 77 percent for those in the 1st.

Figure 3

DIFFERENCE IN THE AGE-STANDARDIZED DEATH RATES (ASDR) FROM ALL CAUSES BETWEEN SIS DECILE 1 TO 9 AND THE TOP (10TH) DECILE RELATIVE TO THE RATES IN THE TOP DECILE (%), EACH SEX

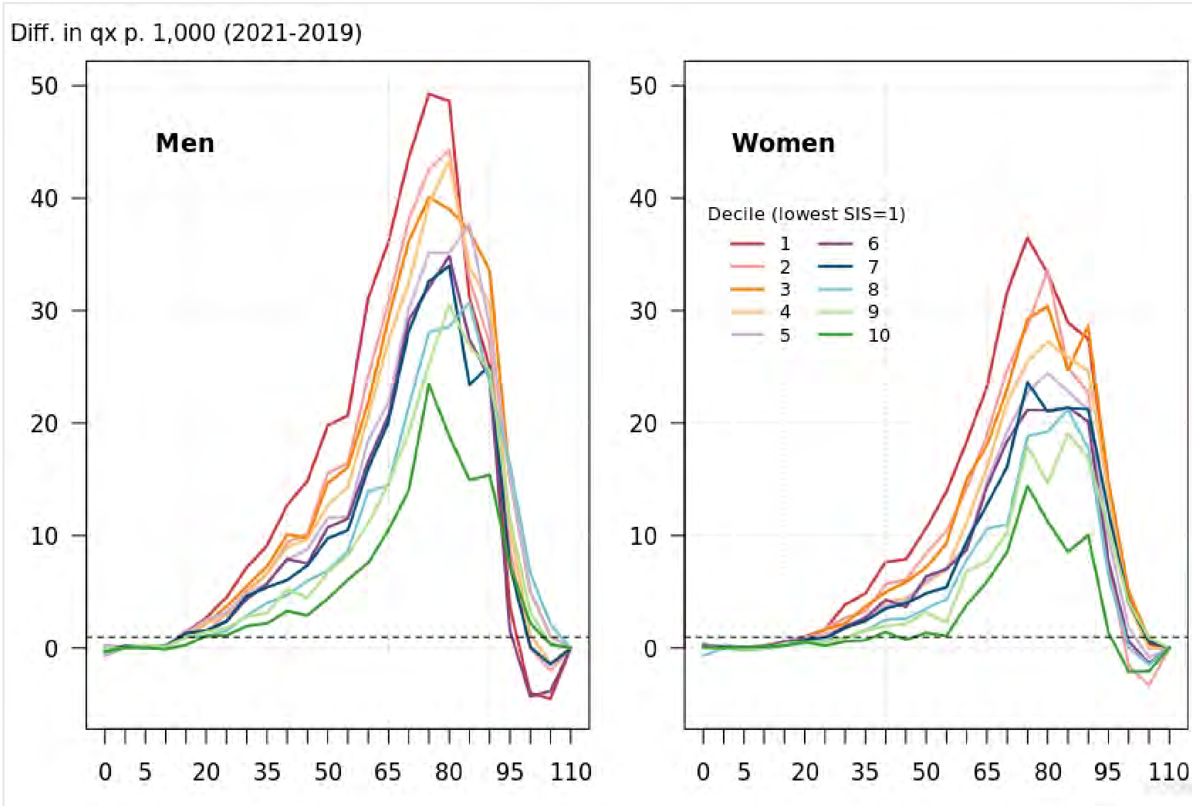


3.3 AGE CONTRIBUTIONS TO THE INCREASE IN MORTALITY IN 2020 AND 2021

The mortality toll of the pandemic varied widely by age. Figure 4 represents the difference in the probabilities of dying by age group between 2019 and 2021 by sex and by SIS decile. It clearly shows the large excess mortality at ages 65 years and above, with a peak around 75-80 years. The patterns are similar for all SIS deciles, albeit progressively more muted with each successive decile, reflecting the lower impact of the epidemic at all ages on individuals living in the most advantaged areas. The lower mortality at ages 95 years and over observed in 2021 compared to 2019 probably results from a combination of harvesting among the frailest individuals and additional protection among healthy older adults.

Figure 4

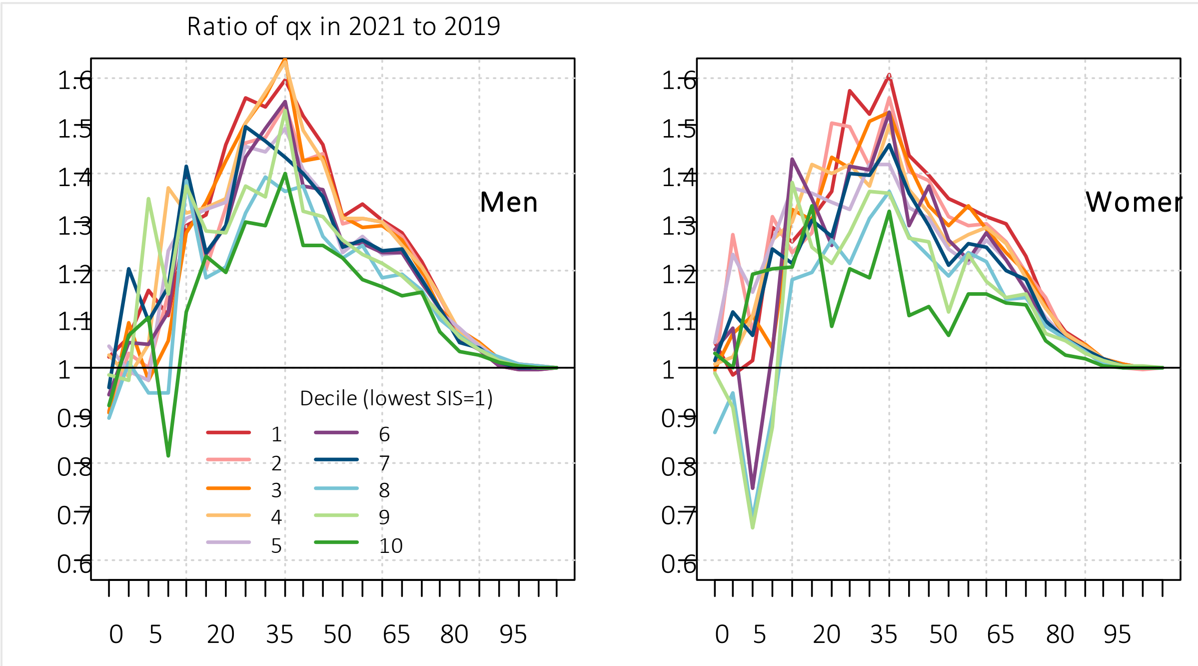
DIFFERENCE IN THE PROBABILITIES OF DYING (QX) BY FIVE-YEAR AGE GROUP BETWEEN 2019 AND 2021 (2021-2019) FOR EACH SIS DECILE, EACH SEX



However, compared to the underlying level of mortality, the relative impact of COVID-19 was much larger on younger than on older adults, albeit with very different medical causes contributing to the increased risk of death for the two groups as further discussed in a following section. Figure 5 shows the ratio of the probabilities of dying by age group in 2021 to those in 2019. Overall, for every SIS decile, excess mortality was disproportionately high for adults aged 30 to 50 years of age, reaching near or above 50 percent for men and women in the four deciles at the bottom. In those deciles, excess mortality was also high for adolescents, with probabilities of dying at ages 10-14 or 15-19 years 20 to 30 percent higher in 2021 than in 2019, especially for males. After reaching its peak at age 40 years, excess mortality declines progressively for both sexes and disappears after age 80 or 90 years, depending on the decile. The declining trend in excess mortality by age reflects the fact that, though the risk of dying from COVID-19-associated causes increases with age, mortality from other medical causes increases so quickly that the impact of the pandemic is proportionately smaller than at younger ages, when historical mortality risks are much smaller.

Figure 5

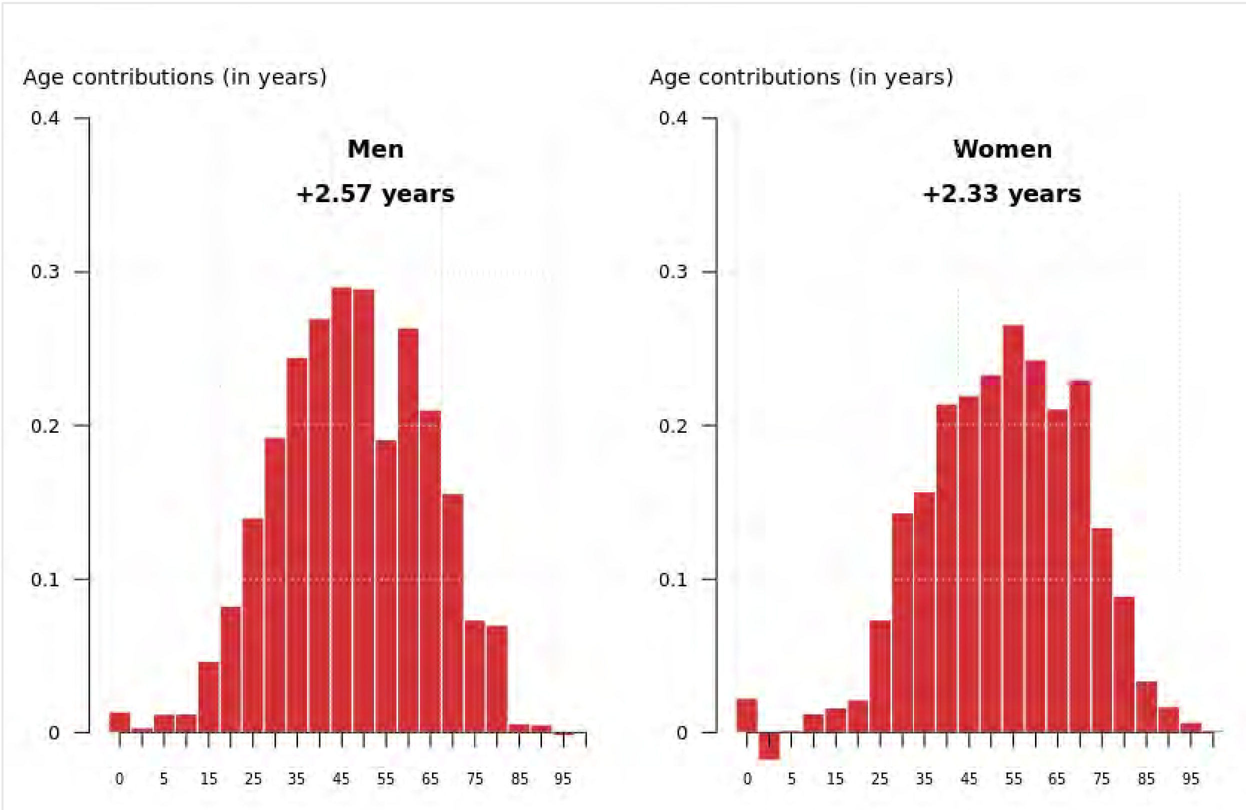
RATIO OF THE PROBABILITIES OF DYING (QX) BY FIVE-YEAR AGE GROUP IN 2021 TO THOSE IN 2019, EACH SEX



Because of the lower mortality excess in the top deciles compared with the bottom deciles at every age and the proportionately larger excess for the bottom deciles at relatively young ages, when deceased individuals have lost more potential years of life than their older peers, the increased gap in life expectancy at birth between the bottom and the top decile (2.57 years for men and 2.33 years for women) is mostly attributable to ages 35 to 70 years (for 68 and 66 percent of the increase in the gap for each sex respectively) (Figure 6).

Figure 6

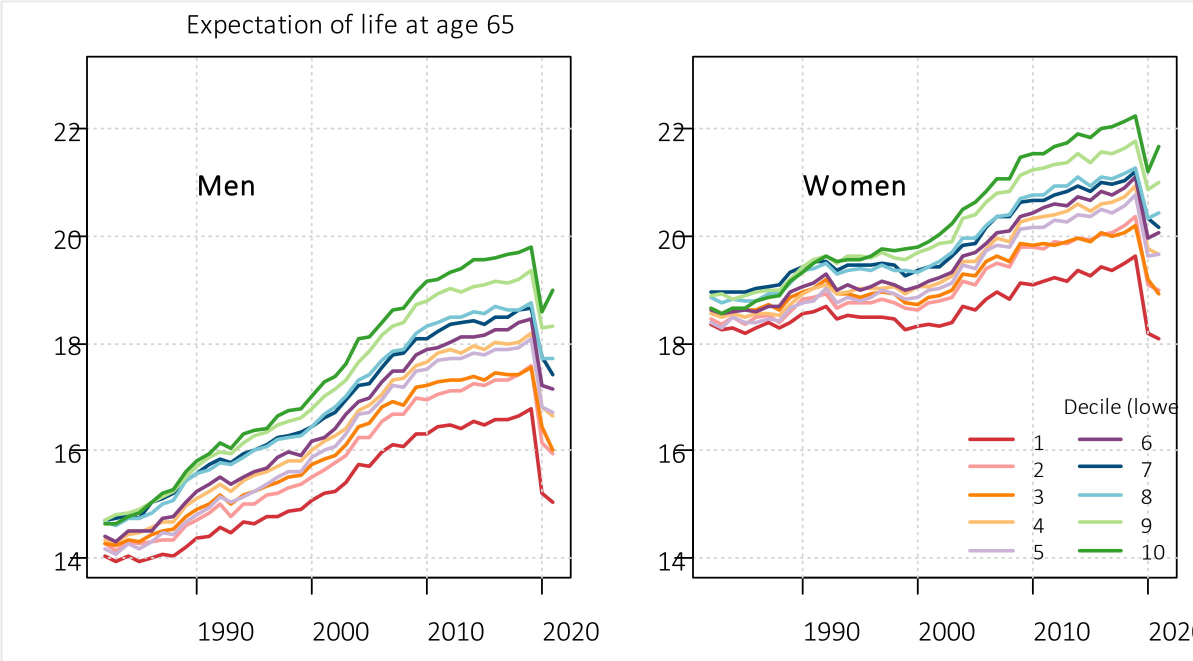
AGE GROUP CONTRIBUTIONS TO THE ADDITIONAL GAP IN LIFE EXPECTANCY AT BIRTH BETWEEN DECILE 1 AND DECILE 10 FROM 2019 TO 2021, EACH SEX



Even though excess mortality was proportionately lower at retirement ages than for working age adults, the overall impact on mortality was quite significant. For instance, losses in life expectancy at age 65 years between 2019 and 2021 ranged from 0.79 years to 1.73 years from the most to the bottom SIS decile for men, and from 0.58 to 1.55 years, respectively, for women (Appendix Table 8 – Note that Appendix 2 also shows the losses in life expectancy at ages 25, 45, and 85 years). However, most of these losses occurred in 2020 and for Americans in several SIS deciles, there was some recovery between 2020 and 2021. The recovery was nonetheless far insufficient in all deciles to catch up to the 2019 level (Figure 7).

Figure 7

LIFE EXPECTANCY AT AGE 65 BY SIS DECILE, 1982-2021, EACH SEX



3.4 EXCESS MORTALITY FROM CAUSES OTHER THAN COVID-19

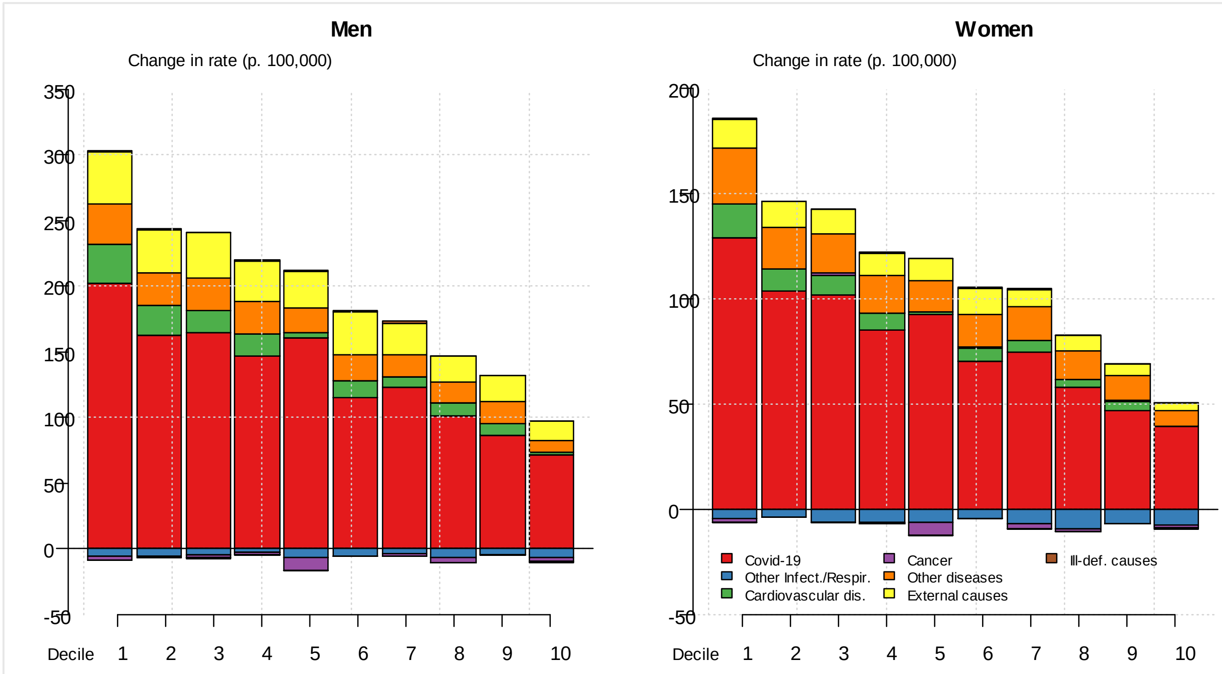
Since we know that not all excess mortality was due to the direct effects of COVID-19, it is interesting to examine trends in cause-specific mortality in 2020 and 2021 by socioeconomic decile. The results of this analysis highlight the possible pathways through which COVID-19 might have indirectly influenced mortality and help determine how these varied across SIS deciles since the mechanisms of operation might be different across sub-groups of the population.

Figure 8 shows how each broad cause-of-death category contributed to the increase in the age-standardized death rate between 2019 and 2021 for each sex. The calculations are based on deaths classified by the underlying medical cause of death. All detailed causes of death are grouped into six broad categories plus COVID-19.

The results show that, beyond the overwhelming impact of COVID-19 as the direct cause of death (accounting for 65 to more than 95 percent of the increase in the age-standardized death rate, depending on the sex and on the decile), several other causes contributed significantly. The largest contribution has been that of external causes, which accounted for 13 to 19 percent of the excess for men and 8 to 12 percent for women, followed by other diseases, with a share of 10 to 13 percent for men and 14 to 19 percent for women, and cardiovascular diseases, which contributed up to 10-12 percent of the increase for both men and women. Mortality from infectious and respiratory diseases other than COVID-19 actually declined between 2019 and 2021, probably due to the fact that people susceptible to these diseases might have died of COVID-19 first and that the protection awarded by social distancing behavior protected the others. Without this decline, the age-standardized mortality rate in 2021 would have been up to 8 percent higher for men and 10 percent for women. Cancer mortality also exhibited a decline in most SIS deciles and there was no material change in mortality from ill-defined or unknown causes over the two years under consideration.

Figure 8

CAUSE-OF-DEATH CONTRIBUTIONS TO THE INCREASE IN THE AGE-STANDARDIZED DEATH RATES BETWEEN 2019 AND 2021 IN EACH DECILE FOR EACH SEX

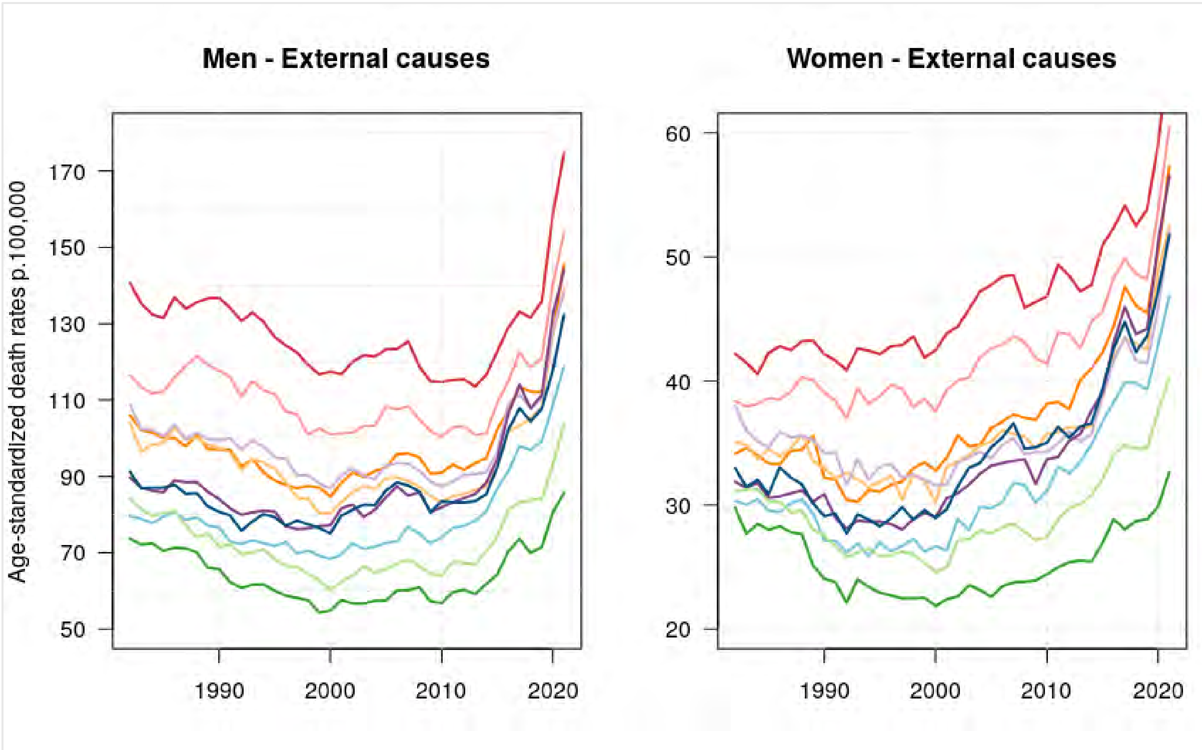


An analysis of the impact of the pandemic on historical trends in cause-specific mortality by SIS decile provides additional details on its effects on the socioeconomic gradient in mortality within the broader historical context.

3.4.1 MORTALITY FROM EXTERNAL CAUSES

External causes represent one of the main cause-of-death categories that contributed to the excess mortality recorded in 2021 compared with 2019, ranking first for men, after COVID-19. This occurred in spite of the fact that death rates from external causes are much lower than those for all of the other broad categories considered here. For both men and women, the age-standardized mortality rate from all external causes combined was higher in 2021 than it has ever been since 1982 in all SIS decile (except for women in the best-off decile). For men, the rate had actually either declined or remained fairly stable between 1982 and 2010/2012, depending on the decile, before increasing progressively up to 2020-2021, when it jumped to a much higher level (Figure 9). For women, the minimum was reached earlier than for men with a sustained increase thereafter and a similar jump as for men in 2020-2021. For instance, for the 10% of Americans living in the least advantaged counties, the rate was 141 and 42 per 100,000 for men and women, respectively, in 1982, declining to a minimum of 114 in 2013 for men and reaching again 42 in 1999 for women, then increasing to 136 and 54 in 2019, and to 175 and 67 in 2021.

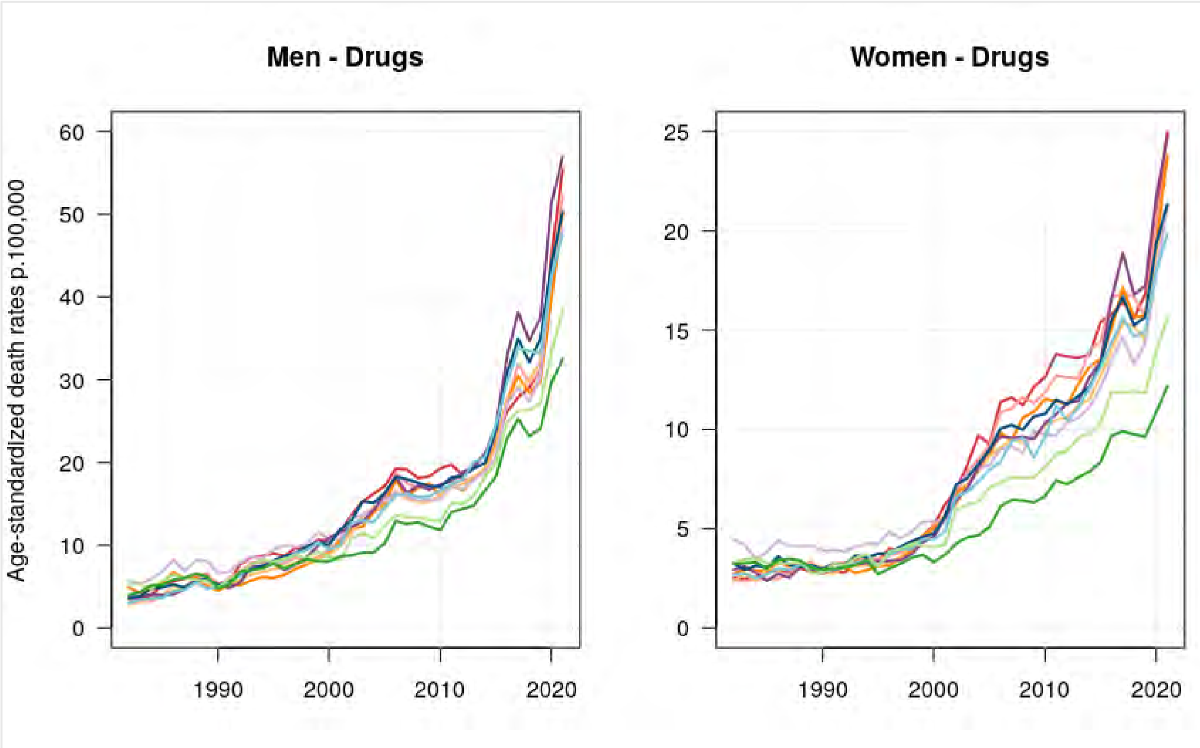
Figure 9
AGE-STANDARDIZED DEATH RATES FOR ALL EXTERNAL CAUSES BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)



Among all external causes, drug overdoses are the most concerning as the rate has been increasing continuously since 1982 from 5 or less per 100,000 for both men and women to 30 to 55 per 100,000 for men and 12 to 25 per 100,000 for women in 2021. In the top decile, drug overdoses represented the largest component of mortality of external causes. By contrast with other more detailed categories, mortality from drug overdoses exhibited the least variations across SIS deciles, except for women in the two best-off deciles, who have been slightly less affected than their peers in all other deciles (Figure 10). However, the mortality gap between the top and bottom SIS decile has increased progressively over time, with an acceleration in 2020 and 2021. While the age-standardized death rate from drug overdoses was 30 percent higher for men and 74 percent higher for women in the first compared with the tenth SIS decile in 2019, it was 70 percent and 205 percent higher, respectively, in 2021.

Figure 10

AGE-STANDARDIZED DEATH RATES FOR DRUG OVERDOSES BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)



After declining during the 1990s and the early 2000s, mortality from alcoholism also started to increase in all SIS deciles (from 2005 to 2010, depending on the decile) and for both sexes and the trend accelerated during the pandemic, so that in 2021, the corresponding age-standardized death rate was about twice or more the level recorded in 2010 for both sexes (Figure 11). The 10% of Americans in the most privileged decile show distinctly lower mortality from this cause than others. However, the overall level of mortality from alcoholism remains less than half that of drug overdoses and the relative gap in mortality between the two extreme deciles did not increase as much during the pandemic.

For the three other main external causes (traffic accidents, suicides, and homicides), the pandemic-related trends in mortality remained within the typical variations observed in the age-standardized mortality rate of the previous four decades. Mortality from traffic accidents had typically declined for all deciles until the early 2010 but the increase of 2020 and 2021 (higher for the bottom decile than for the top one) remained within the range of previous fluctuations and below the level recorded in the late 2000s (Figure 12). Homicides had increased sharply around 1990 and though they had declined since to reach a low in the mid-2010, they started increasing again thereafter. The first year of the pandemic is associated with a discernible jump (though not so much the second) but mortality from homicides is still lower than at its peak (Figure 13). Suicide is the only cause of death category which shows a clear decline in 2020 in all SIS deciles (except for the most disadvantaged men) before picking up again in 2021, thus continuing the previous increasing trend of the 2000s and 2010s (Figure 14).

Figure 11
AGE-STANDARDIZED DEATH RATES FOR ALCOHOLISM BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)

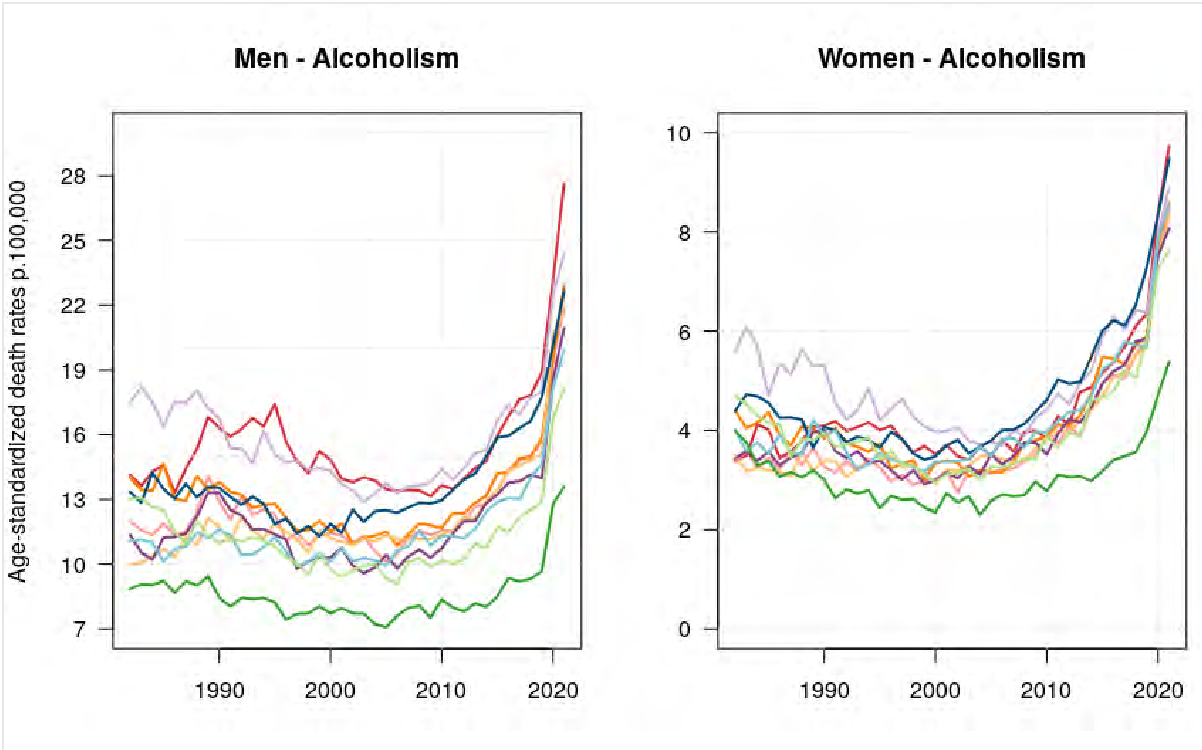


Figure 12

AGE-STANDARDIZED DEATH RATES FOR TRAFFIC ACCIDENTS BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)

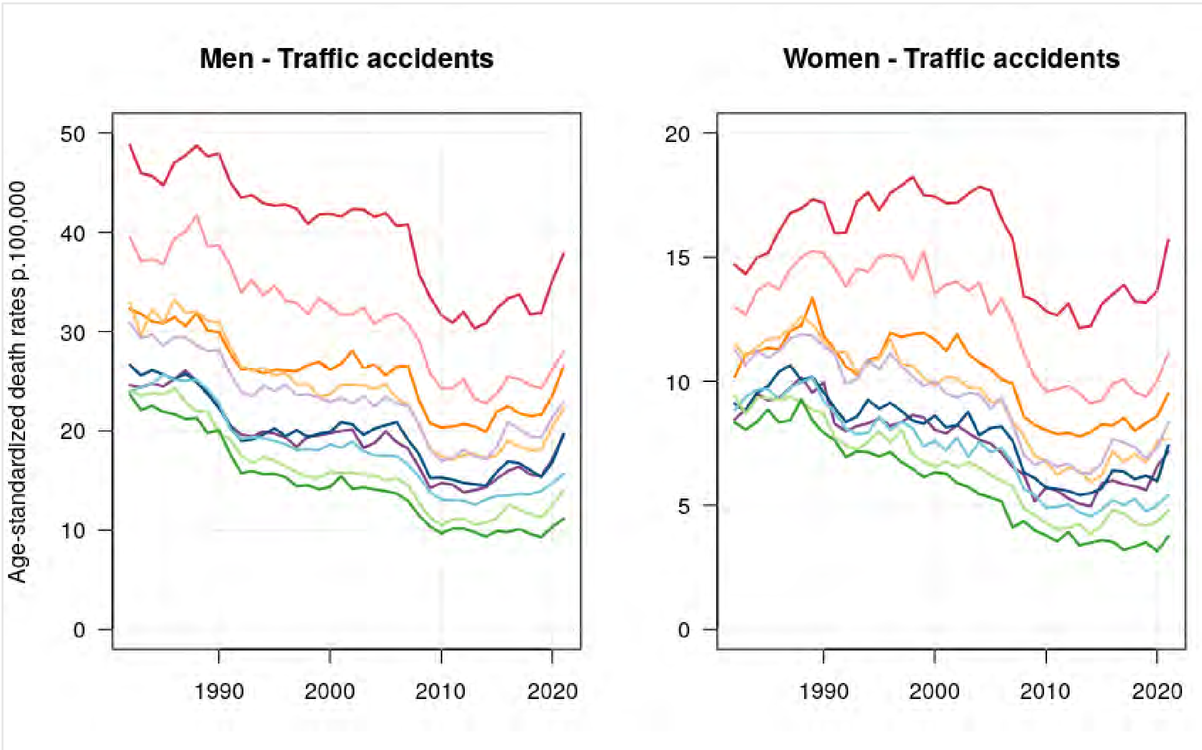


Figure 13

AGE-STANDARDIZED DEATH RATES FOR HOMICIDES BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)

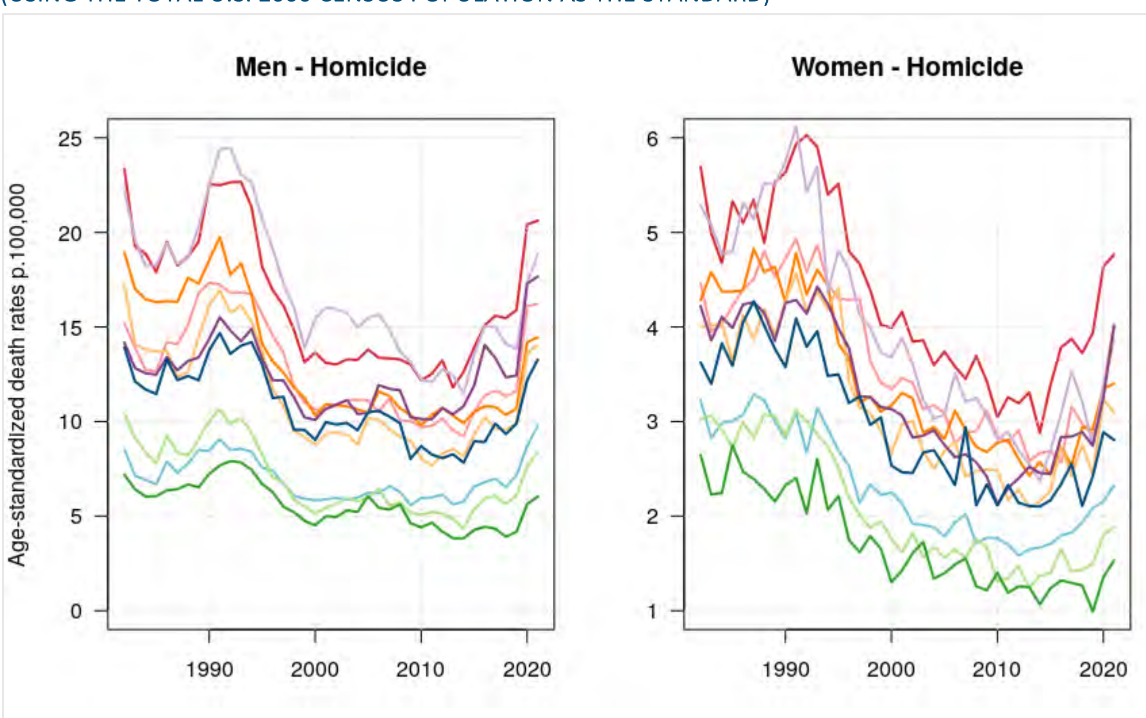
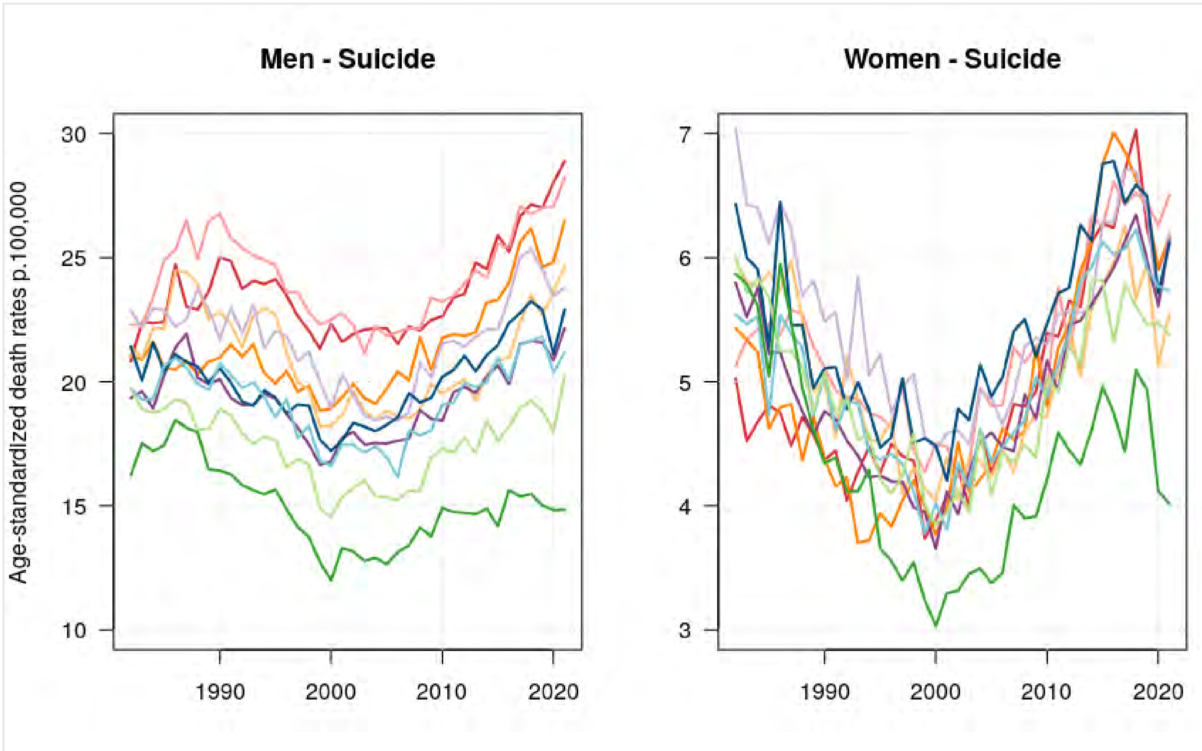


Figure 14

AGE-STANDARDIZED DEATH RATES FOR SUICIDE BY DECILE AND SEX
(USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)



3.4.2 CARDIOVASCULAR MORTALITY

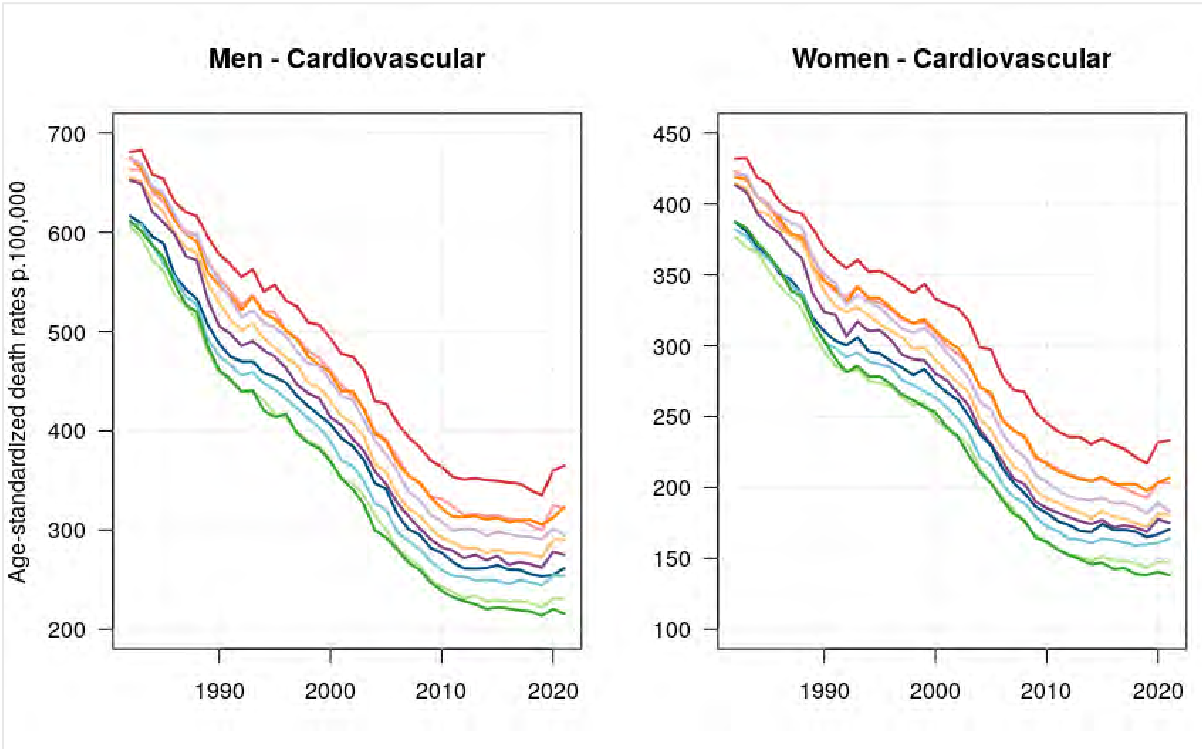
Declines in cardiovascular mortality had driven most of the improvement in life expectancy at birth for all Americans during the last decades of the 20th century and up until about 2010, though the slower progress in the bottom decile after 1990 had increased the gap with the top decile (Figure 15). Since about 2010, however, the decline had slowed down and little further progress had occurred. This relatively flat trend continued during the pandemic years in the top SIS deciles and mortality from cardiovascular diseases actually increased for the bottom decile.

Excess mortality from the diseases of the circulatory system has been high in absolute terms but low in relative terms given the very high level of mortality from these diseases, which represent the main cause of death in the United States. Furthermore, in most SIS deciles, the age-standardized death rate improved again in 2021 to reach close to its pre-pandemic level. This pattern is similar for all diseases in this category, including the most lethal (ischemic heart diseases and cerebrovascular diseases). In the top (most advantaged) SIS decile, the rate for all diseases of the circulatory system stood at more than 600 per 100,000 for men and 387 per 100,000 for women in 1982, declining to 213 and 138 per 100,000, respectively, in 2019, then increasing to 221 and 141 in 2020, and declining again to 216 and 138 per 100,000 in 2021.

In the bottom decile, the corresponding numbers stood at 681 and 432 per 100,000 in 1982, then 335 and 217 in 2019, 360 and 232 in 2020 and 365 and 233 in 2021. For both men and women, the age-standardized mortality rate from all diseases of the circulatory system was 60 percent higher in the 1st compared to the 10th decile in 2019, increasing to 70 percent in 2021, a relatively small increase compared with other cause-of-death categories (though representing a considerable increase in the absolute number of deaths given the very high level of cardiovascular mortality).

Figure 15

AGE-STANDARDIZED DEATH RATES FROM DISEASE OF THE CIRCULATORY SYSTEM BY SIS DECILE AND SEX (USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)



3.4.3 CANCER MORTALITY

An opposite pattern is found for cancer, where the continuous decline in mortality through 2020 was interrupted in 2021 due to the increase in mortality in most deciles (including for the most advantaged women). Like for the diseases of the circulatory system, the mortality increase from cancer in 2021 represents only a small uptick when considering the long term trends, with a very similar patterns for smoking-related cancers and for all other types of cancers (Figures 16 and 17). There was no discernible increase in the mortality rate for either of these two types of cancer in the socioeconomic gradient between 2019 and 2021.

The delayed impact of the pandemic on cancer mortality could be due to the lag between changes in the risk factors for the disease and their impact on mortality. For instance, some early evidence suggested that some cancer diagnoses were delayed because of reduced cancer screening, either due to people's reluctance to leave home or to a diversion of health care resources towards COVID-19, especially in the most socioeconomically disadvantaged groups of the population, though more recent studies tend to call into questions these earlier findings (Bakouny et al., 2021; Fedewa et al., 2022). Other factors might also have been operating, like delayed surgery or changes in behavior (e.g., more smoking and drinking during the pandemic). In addition, infection from COVID-19 has been shown to represent a risk factor for worse cancer outcomes. Studies have suggested that COVID-19 survivors with cancer exhibit increased organ frailty and others have shown reduced aggressive care for cancer patients with a COVID-19 infection

(Kuderer et al., 2020; Lee and Purshouse, 2021). Whatever the mechanism, it will be important to monitor future post-COVID-19 trends in cancer mortality as the effects of some of these might continue to operate beyond the acute phase of the pandemic.

Figure 16

AGE-STANDARDIZED DEATH RATES FROM SMOKING-RELATED CANCERS
BY SIS DECILE AND SEX (USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)

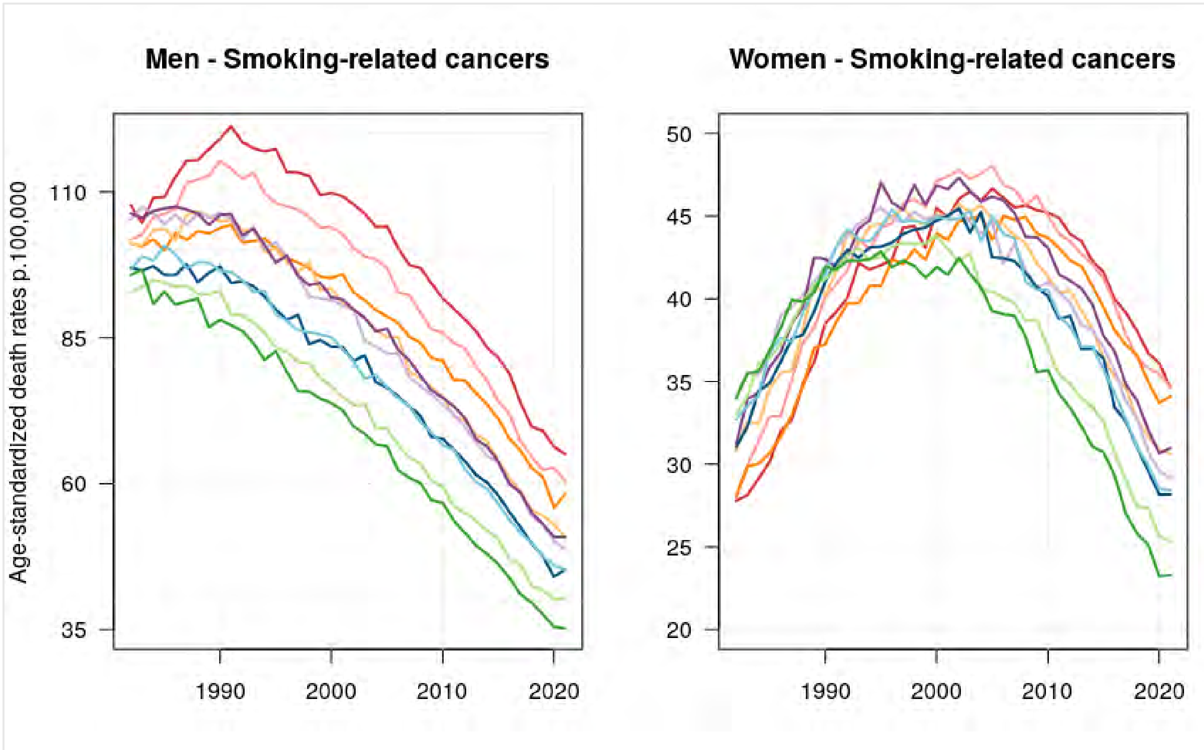
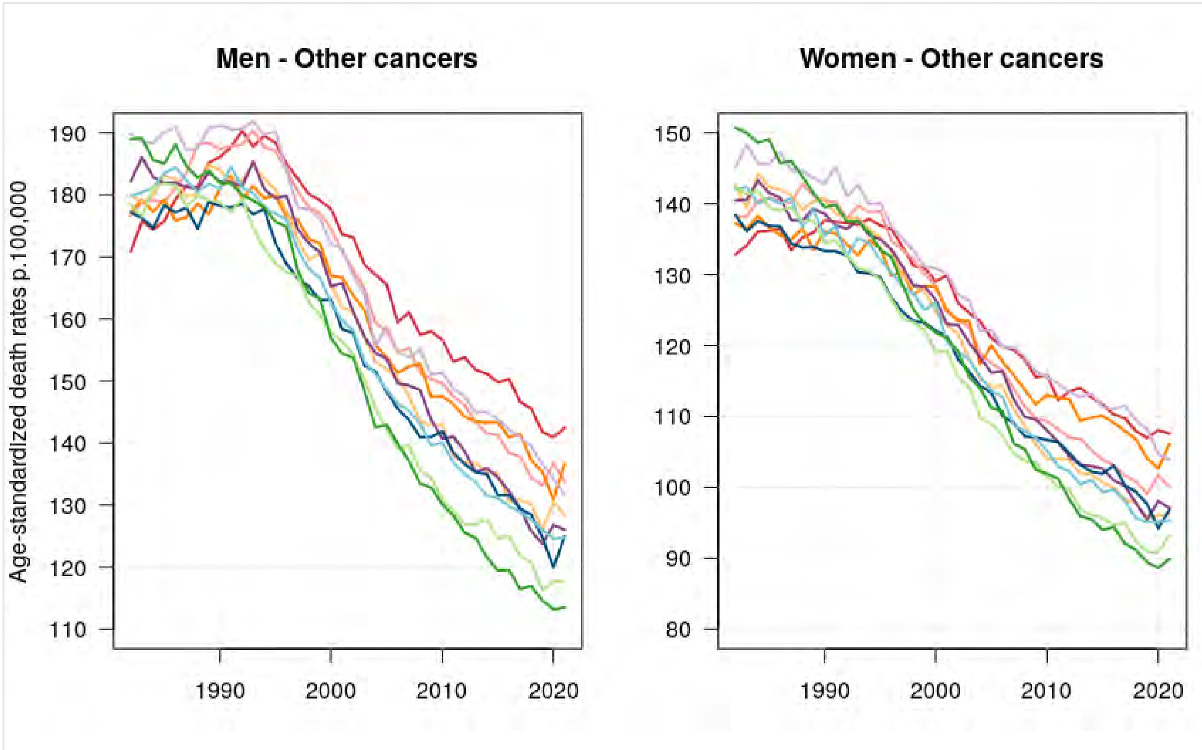


Figure 17

AGE-STANDARDIZED DEATH RATES FROM OTHER CANCERS
BY SIS DECILE AND SEX (USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)



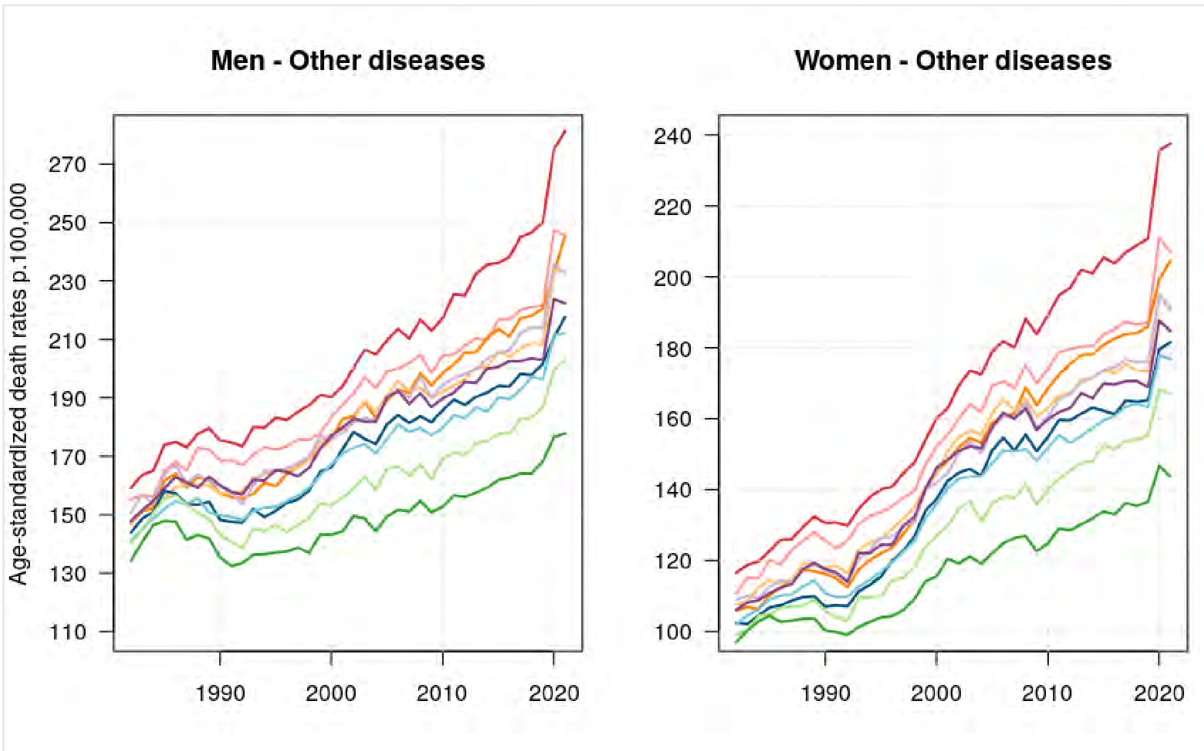
3.4.4 MORTALITY FROM OTHER DISEASES

The rise in mortality from other diseases and conditions was mainly driven by three smaller cause-of-death categories, namely diseases of the metabolism (mostly diabetes mellitus), alcoholism for men, and diseases of the nervous system (half of which are due to Alzheimer's and another quarter to other degenerative diseases of the nervous system) for women mostly. For instance, for males in the top SIS decile, the age-standardized mortality rate from all diseases of the metabolism contributed for more than a third of the increase in mortality from "other diseases" (i.e., 13 per 100,000 of the total excess of 31 per 100,000), followed by alcoholic liver diseases and pancreatitis (5 per 100,000 out of 31 per 100,000). For women, diseases of the metabolism contributed about the same share as for men (11 per 100,000 of the total excess of 27 per 100,000), followed by diseases of the nervous system (5 per 100,000 of 27 per 100,000).

The same causes of death have contributed to the much smaller overall excess of mortality from "other diseases" for the 10% of Americans in the best-off SIS decile so that the mortality gap between the two extreme SIS deciles further increased in 2020 and 2021. While the age standardized death rates from other diseases was 50 percent higher for both men and women in the bottom SIS decile compared with the top decile in 2019, the ratio increased to 60 percent for men and 70 percent for women in 2021.

The increase in mortality from diseases of the metabolism during the pandemic is well documented, especially regarding diabetes mellitus. It is attributed to disruption in the provision of medical care, the contribution of COVID-19 infections to insulin resistance, and an increase in detrimental health behavior, such as less physical activity and more unhealthy food intake (Corrao et al., 2021; Lv et al., 2022). Similarly, increasing mortality from Alzheimer's and other degenerative diseases during the pandemic has been attributed to declines in the quality of care for patients suffering from these conditions and fewer social interactions (Li et al., 2022). COVID-19 is also believed to accelerate the progression of degenerative diseases due to its effects on the brain and on the nervous system among those surviving the infection (Li et al., 2023).

Figure 18
AGE-STANDARDIZED DEATH RATES FROM OTHER DISEASES
BY SIS DECILE AND SEX (USING THE TOTAL U.S. 2000 CENSUS POPULATION AS THE STANDARD)

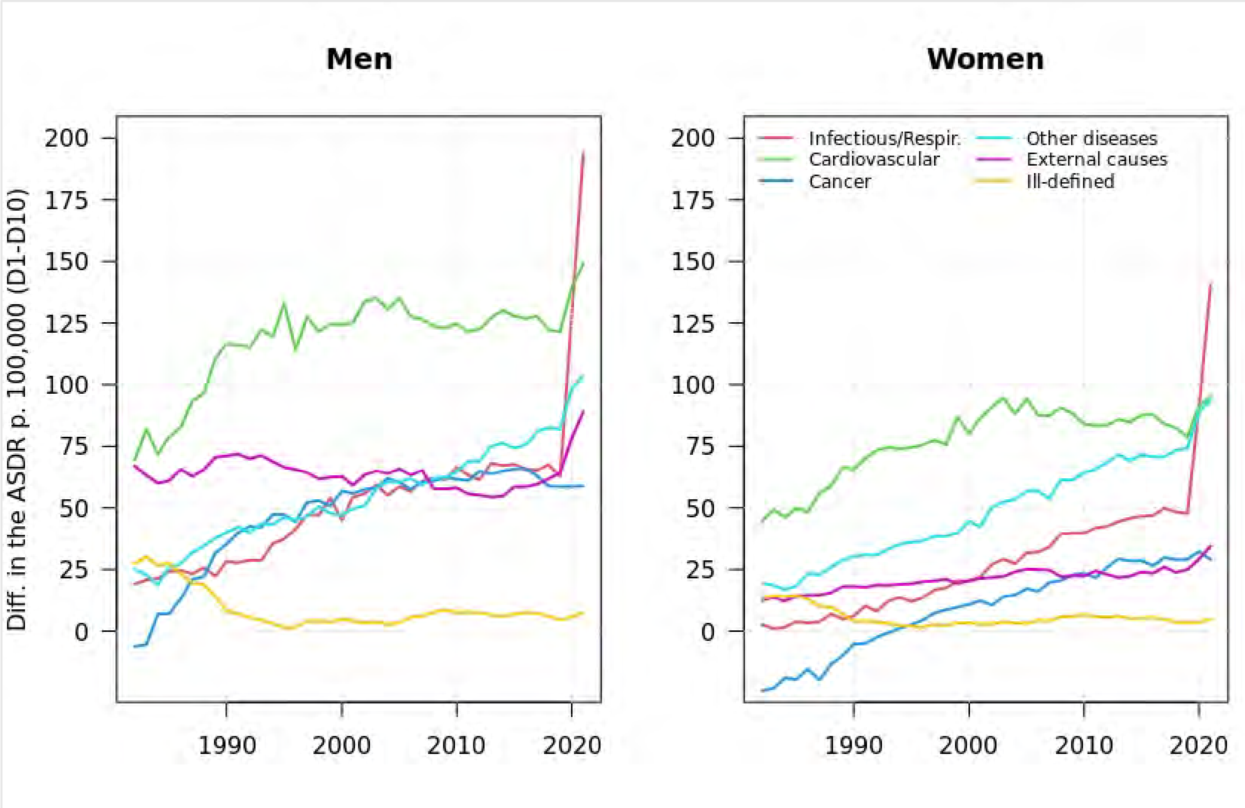


Note that as regards to infectious and respiratory diseases other than COVID-19, there was no significant increases in the mortality rates recorded in 2020 and 2021 in any of the deciles. This is largely due to the lack of a flu epidemic and the reduced activity of other viruses during this period. The remarkable drop in the number of influenza deaths in 2020 and 2021 has been attributed to the precautions taken against COVID-19 which appear to have been particularly effective to control other infectious and respiratory pathogens (Olsen et al., 2021).

The result of the differential trends in cause-specific mortality during the pandemic by SIS decile thus shows an increase in the socioeconomic gradient in all-cause mortality in 2020 and 2021. The increase attributable to a jump in the gap between the top and bottom socioeconomic deciles is the direct impact of COVID-19, but also from the diseases of the cardiovascular system, the residual category of “other diseases”, and external causes. But it is not due to cancer, to infectious and respiratory diseases other than COVID-19, or to ill-defined causes (Figure 19).

Figure 19

DIFFERENCE BETWEEN BOTTOM AND TOP DECILES IN THE AGE-STANDARDIZED DEATH RATES PER 100,000 FOR 6 BROAD CAUSE-OF-DEATH CATEGORIES



Section 4: Conclusions

The COVID-19 pandemic has further amplified the pre-existing socioeconomic gradient in mortality in the United States. Life expectancy at birth has declined in all socioeconomic groups in both 2020 and 2021 except for the 10 percent of men in the most advantaged counties, who recovered in 2021 some of the years of life lost in 2020. Even for them, life expectancy at birth was 1.6 years lower in 2021 than it was in 2019. The loss of life years increases progressively with the degree of disadvantage so that the 10 percent of men in the most deprived socioeconomic decile experienced a level of life expectancy 4.18 years lower in 2021 than in 2019. For women in the same decile, the decline reached 3.25 years. The pandemic thus resulted in a further aggravation of area-level socioeconomic disparities in mortality with an increase in the life expectancy gap between the most advantaged and the most disadvantaged Americans which reached 8.1 years for women and 9.9 years for men in 2021 (from 5.8 years for women and 7.3 years for men in 2019).

The corresponding increase in the age-standardized death rate is mainly attributable to the direct effect of COVID-19 (for 65 to 95 percent, depending on the SIS decile). However, the pandemic was also associated with an increase in mortality from external causes, especially for young adult men, from cardiovascular diseases, and from other diseases. Of those, excess mortality from both COVID-19 and cardiovascular diseases followed a clear socioeconomic gradient. This was not the case for external causes, nor for other diseases, for which the increase in the death rate from 2019 to 2021 was experienced similarly across the socioeconomic spectrum for men and for women alike. For two major groups of diseases, mortality continued its historical decline, namely infectious and respiratory diseases other than COVID-19, due in part to the mitigation measures implemented to reduce the spread of the virus, and cancer (though the latter shows a small uptick in 2021, albeit insufficient to cancel the progress of the previous year).

Though the increase in mortality from external causes is clearly not biologically related to the infection, at least some of the association between the pandemic and cardiovascular or other diseases could be partly due to a either misclassification of COVID-19 (especially at the beginning of the pandemic, when testing was not systematic and little was still understood about the disease) or to some biological effect of the infection, where COVID-19 survivors with pre-existing heart diseases, diabetes, or other chronic conditions were at increased risks of dying. In addition, the pandemic is known to have disrupted or interrupted the management of health care for many of these conditions, leading to a deterioration of patients' health status. This mechanism could also explain the delayed though (so far) small increase in cancer mortality. Finally, the same types of risky behavior that might have induced the increase in mortality from external causes (drug use or alcohol intake for instance) could have accelerated the morbid process for people with cardiovascular or other long-term diseases.

It will be important to continue monitoring changes in cause-specific mortality and their socioeconomic differentials over the coming years as it already appears that the mortality of the most well-off Americans will recover faster than that of the most disadvantaged.

Section 5: Acknowledgments

The authors' deepest gratitude goes to those without whose efforts this project could not have come to fruition: the volunteers 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.

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Appendix 1: Shortlist of the 58 exhaustive cause-of-death categories and associated ICD-8, ICD-9 and ICD-10 codes

No.	Title	Category codes according to		
		ICD-8	ICD-9	ICD-10
1	Intestinal infectious diseases	001-009	001-009	A00-A09
2	Tuberculosis	010-019	010-018	A15-A19, B90
3	Septicemia	038	038	A40-A41
4	Other and unspecified infectious and parasitic diseases	020-037, 039-068, 071-136	020-037, 039-041, 045-066, 071-139	A20-A39 A42-A99, B00-B09, B25-B89, B91-B99
5	HIV disease	--	042-044	B20-B24
6	Viral hepatitis	070	070	B15-B19
7	Malignant neoplasms of lip, oral cavity and pharynx	140-149	140-149	C00-C14
8	Malignant neoplasm of esophagus	150	150	C15
9	Malignant neoplasm of stomach	151	151	C16
10	Malignant neoplasm of colon, rectum and anus	153-154	153-154	C18-C21
11	Malignant neoplasm of pancreas	157	157	C25
12	Other malignant neoplasm of digestive system	152, 155, 156, 159	152, 155, 156, 159	C17, C22-C24, C26
13	Malignant neoplasm of larynx, trachea, bronchus and lung	161-162	161-162	C32-C34
14	Malignant neoplasm of skin	172-173	172-173	C43-C44
15	Malignant neoplasm of breast	174	174-175	C50
16	Malignant neoplasm of uterus	180, 182	179-180, 182	C53-C55
17	Malignant neoplasm of ovary	183	183	C56

No.	Title	Category codes according to		
		ICD-8	ICD-9	ICD-10
18	Malignant neoplasm of prostate	185	185	C61
19	Malignant neoplasm of other genital organs	181, 184, 186-187	181, 184, 186-187	C51-C52, C57-C60, C62, C63
20	Malignant neoplasm of bladder	188	188	C67
21	Malignant neoplasms of kidney and other urinary organ	189	189	C64-C66, C68
22	Leukemia	204-207	204-208	C91-C95
23	Other cancer, including in situ neoplasms, benign neoplasms and neoplasms of uncertain or unknown behavior	158, 160, 163-171, 190-203, 208-239	158, 160, 163-171, 176, 190-203, 209-239	C30-C31,C37-C41, C45-C49, C69-C90, C96-C97, D00-D48
24	Blood diseases	280-289	280-289	D50-D89
25	Diabetes mellitus	250	250	E10-E14
26	Other endocrinologic and metabolic diseases	240-246, 251-279	240-249, 251-279	E00-E07, E15-E90
27	Alcohol abuse	291, 303	291, 303	F10
28	Drug abuse	304-305	304-305	F11-F19
29	Other mental disorders	290, 292-302, 306-315	290, 292-302, 306-319, 331	F00-F09, F20-F99, G30-G31
30	Other diseases of nervous system	320-389	320-330, 332-389	G00-G26, G32-G44, G46-G99, H00-H95
31	Rheumatic heart diseases	390-398	390-398	I00-I09
32	Hypertensive disease	400-404	401-405	I10-I15
33	Other Ischemic heart diseases	410-414	410-414	I20-I25
34	Other heart diseases	420-429	415-429	I26-I52

No.	Title	Category codes according to		
		ICD-8	ICD-9	ICD-10
35	Cerebrovascular diseases	430-438	430-438	I60-I69, G45
36	Other circulatory diseases	440-458	440-459	I70-I99
37	Influenza	470-474	487-488	J09-J11
38	Pneumonia	480-486	480-486	J12-J18
39	Other acute respiratory infections	460-466	460-466	J00-J06, J20-J22, U04
40	Other chronic obstructive pulmonary disease	490-493, 518	490-494, 496	J40-J47
41	Other diseases of the respiratory system	500-517, 519	470-478,495, 500-519	J30-J39, J60-J99
42	Gastric and duodenal ulcer	531-534	531-534	K25-K28
43	Liver diseases	570-573	570-573	K70-K77
44	Other digestive diseases	520-530, 535-569, 574-577	520-530, 535-569, 574-579	K00-K23, K29-K67, K80-K93
45	Diseases of skin and subcutaneous tissue	680-709	680-709	L00-L99
46	Diseases of the musculoskeletal system and connective tissue	710-738	710-739	M00-M99
47	Diseases of genitourinary system	580-629, 792	580-629	N00-N99
48	Complications of pregnancy, childbirth and puerperium	630-678	630-679	O00-O99
49	Certain conditions originating in the perinatal period	760-779	760-779	P00-P96
50	Congenital malformations, deformations, and chromosomal abnormalities	740-759	740-759	Q00-Q99
51	Transport accidents	E800-E845	E800-E848	V01-V99
52	Other accidents	E850-E949	E850-E949	W00-W99, X00-X59, Y40-Y98
53	Suicide and self-inflicted injury	E950-E959	E950-E959	X60-X84

No.	Title	Category codes according to		
		ICD-8	ICD-9	ICD-10
54	Assault	E960-E978, E990-E999	E960-E978, E990-E999	X85-Y09, Y35, Y36
55	Event of undetermined intent	E980-E989	E980-E989	Y10-Y34
56	Senility	794	797	R54
57	Other ill-defined and unspecified causes of death	780-791, 793, 795-796	780-796, 798-799	R00-R53, R55-R99
58	COVID-19	NA	NA	U07

Appendix 2: Actual life expectancies at selected ages by sex and by SIS decile in 2019, 2020, and 2021, and as estimated for 2021 using a variety of methods

In all tables below, the columns correspond to

(1) 2019 actual lifetable
(2) 2020 actual lifetable
(3) 2021 actual lifetable
(4) 2021 COVID-deleted lifetable (with COVID-19 as the underlying cause only)
(5) 2021 COVID-deleted lifetable (with any mention of COVID-19)
(6) 2021 predicted lifetable from 2010-2019 trends in the probabilities of dying (q_x)

Table 3

2019, 2020 AND 2021 ACTUAL LIFE EXPECTANCIES AT AGE 25 YEARS AND ESTIMATED LIFE EXPECTANCIES AT BIRTH FOR 2021 USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	49.21	46.37	45.15	47.38	47.58	49.01	54.51	52.21	51.34	53.39	53.61	54.35
2	50.92	48.62	47.46	49.49	49.68	50.84	55.98	54.14	53.29	55.11	55.30	55.86
3	51.22	49.26	47.76	49.80	49.98	51.01	56.04	54.50	53.50	55.23	55.41	55.86
4	52.37	49.94	49.01	51.07	51.23	52.26	57.21	55.56	54.97	56.60	56.76	57.11
5	51.87	49.63	48.89	50.51	50.67	51.68	56.83	55.32	54.78	56.14	56.31	56.72
6	52.65	50.48	49.80	51.52	51.68	52.51	57.43	55.79	55.39	56.79	56.95	57.28
7	53.12	51.39	50.37	52.02	52.19	53.01	57.70	56.44	55.78	57.09	57.26	57.63
8	53.65	51.97	51.43	52.79	52.93	53.56	58.09	56.87	56.60	57.64	57.78	58.06
9	54.96	53.27	52.79	54.08	54.22	54.87	59.05	57.82	57.74	58.65	58.78	59.03
10	55.95	54.03	54.36	55.43	55.56	56.00	59.85	58.57	58.99	59.77	59.89	59.98
All	52.59	50.48	49.66	51.41	51.57	52.48	57.28	55.73	55.24	56.66	56.82	57.21

Table 4

DIFFERENCE IN LIFE EXPECTANCY AT AGE 25 YEARS BETWEEN THE ACTUAL LIFETABLE FOR 2021 ON THE ONE HAND AND THAT IN THE 2019 AND 2020 ACTUAL LIFETABLES AS WELL AS IN THE LIFETABLE FOR 2021 ESTIMATED USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	4.06	1.22	0.00	2.23	2.43	3.86	3.17	0.87	0.00	2.05	2.27	3.01
2	3.46	1.16	0.00	2.03	2.22	3.38	2.69	0.85	0.00	1.82	2.01	2.57
3	3.46	1.50	0.00	2.04	2.22	3.25	2.54	1.00	0.00	1.73	1.91	2.36
4	3.36	0.93	0.00	2.06	2.22	3.25	2.24	0.59	0.00	1.63	1.79	2.14
5	2.98	0.74	0.00	1.62	1.78	2.79	2.05	0.54	0.00	1.36	1.53	1.94
6	2.85	0.68	0.00	1.72	1.88	2.71	2.04	0.40	0.00	1.40	1.56	1.89
7	2.75	1.02	0.00	1.65	1.82	2.64	1.92	0.66	0.00	1.31	1.48	1.85
8	2.22	0.54	0.00	1.36	1.50	2.13	1.49	0.27	0.00	1.04	1.18	1.46
9	2.17	0.48	0.00	1.29	1.43	2.08	1.31	0.08	0.00	0.91	1.04	1.29
10	1.59	-0.33	0.00	1.07	1.20	1.64	0.86	-0.42	0.00	0.78	0.90	0.99
All	2.93	0.82	0.00	1.75	1.91	2.82	2.04	0.49	0.00	1.42	1.58	1.97

Table 5

2019, 2020 AND 2021 ACTUAL LIFE EXPECTANCIES AT AGE 45 YEARS AND ESTIMATED LIFE EXPECTANCIES AT BIRTH FOR 2021 USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	31.58	29.30	28.50	30.51	30.69	31.44	35.96	33.94	33.41	35.23	35.40	35.84
2	33.02	31.07	30.29	32.15	32.32	33.01	37.18	35.54	34.99	36.62	36.78	37.09
3	33.21	31.66	30.60	32.43	32.60	33.13	37.20	35.88	35.13	36.68	36.84	37.08
4	34.23	32.23	31.64	33.53	33.68	34.21	38.23	36.77	36.36	37.84	37.98	38.19
5	33.91	32.12	31.65	33.15	33.30	33.88	37.94	36.59	36.25	37.49	37.64	37.88
6	34.53	32.78	32.37	33.95	34.10	34.57	38.48	37.06	36.83	38.11	38.25	38.42
7	34.97	33.62	32.86	34.37	34.53	35.00	38.70	37.62	37.13	38.32	38.47	38.70
8	35.38	33.92	33.62	34.88	35.02	35.43	39.00	37.89	37.74	38.70	38.83	39.03
9	36.42	34.99	34.73	35.92	36.05	36.46	39.80	38.70	38.71	39.56	39.67	39.84
10	37.24	35.59	35.99	37.00	37.12	37.40	40.51	39.30	39.78	40.52	40.62	40.68
All	34.43	32.70	32.18	33.77	33.93	34.45	38.30	36.92	36.61	37.91	38.05	38.28

Table 6

DIFFERENCE IN LIFE EXPECTANCY AT AGE 45 YEARS BETWEEN THE ACTUAL LIFETABLE FOR 2021 ON THE ONE HAND AND THAT IN THE 2019 AND 2020 ACTUAL LIFETABLES AS WELL AS IN THE LIFETABLE FOR 2021 ESTIMATED USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	3.08	0.80	0.00	2.01	2.19	2.94	2.55	0.53	0.00	1.82	1.99	2.43
2	2.73	0.78	0.00	1.86	2.03	2.72	2.19	0.55	0.00	1.63	1.79	2.10
3	2.61	1.06	0.00	1.83	2.00	2.53	2.07	0.75	0.00	1.55	1.71	1.95
4	2.59	0.59	0.00	1.89	2.04	2.57	1.87	0.41	0.00	1.48	1.62	1.83
5	2.26	0.47	0.00	1.50	1.65	2.23	1.69	0.34	0.00	1.24	1.39	1.63
6	2.16	0.41	0.00	1.58	1.73	2.20	1.65	0.23	0.00	1.28	1.42	1.59
7	2.11	0.76	0.00	1.51	1.67	2.14	1.57	0.49	0.00	1.19	1.34	1.57
8	1.76	0.30	0.00	1.26	1.40	1.81	1.26	0.15	0.00	0.96	1.09	1.29
9	1.69	0.26	0.00	1.19	1.32	1.73	1.09	-0.01	0.00	0.85	0.96	1.13
10	1.25	-0.40	0.00	1.01	1.13	1.41	0.73	-0.48	0.00	0.74	0.84	0.90
All	2.25	0.52	0.00	1.59	1.75	2.27	1.69	0.31	0.00	1.30	1.44	1.67

Table 7

2019, 2020 AND 2021 ACTUAL LIFE EXPECTANCIES AT AGE 65 YEARS AND ESTIMATED LIFE EXPECTANCIES AT BIRTH FOR 2021 USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	16.79	15.21	15.06	16.33	16.47	16.79	19.63	18.18	18.08	19.24	19.38	19.66
2	17.58	16.16	15.95	17.16	17.29	17.63	20.36	19.11	18.99	20.07	20.20	20.37
3	17.55	16.44	16.01	17.18	17.31	17.55	20.20	19.20	18.92	19.92	20.05	20.20
4	18.19	16.82	16.65	17.88	18.00	18.22	20.93	19.76	19.68	20.69	20.80	20.94
5	18.08	16.82	16.73	17.75	17.87	18.13	20.77	19.65	19.66	20.53	20.64	20.77
6	18.46	17.22	17.16	18.21	18.34	18.56	21.12	19.97	20.06	20.93	21.05	21.13
7	18.68	17.76	17.41	18.40	18.53	18.77	21.22	20.33	20.18	21.00	21.13	21.26
8	18.78	17.74	17.71	18.58	18.68	18.85	21.27	20.35	20.43	21.12	21.24	21.34
9	19.38	18.29	18.33	19.15	19.25	19.41	21.78	20.86	21.02	21.65	21.75	21.82
10	19.80	18.59	19.01	19.75	19.84	19.96	22.26	21.21	21.68	22.26	22.36	22.40
All	18.30	17.06	16.94	18.01	18.12	18.36	20.94	19.84	19.84	20.72	20.84	20.98

Table 8

DIFFERENCE IN LIFE EXPECTANCY AT AGE 65 YEARS BETWEEN THE ACTUAL LIFETABLE FOR 2021 ON THE ONE HAND AND THAT IN THE 2019 AND 2020 ACTUAL LIFETABLES AS WELL AS IN THE LIFETABLE FOR 2021 ESTIMATED USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	1.73	0.15	0.00	1.27	1.41	1.73	1.55	0.10	0.00	1.16	1.30	1.58
2	1.63	0.21	0.00	1.21	1.34	1.68	1.37	0.12	0.00	1.08	1.21	1.38
3	1.54	0.43	0.00	1.17	1.30	1.54	1.28	0.28	0.00	1.00	1.13	1.28
4	1.54	0.17	0.00	1.23	1.35	1.57	1.25	0.08	0.00	1.01	1.12	1.26
5	1.35	0.09	0.00	1.02	1.14	1.40	1.11	-0.01	0.00	0.87	0.98	1.11
6	1.30	0.06	0.00	1.05	1.18	1.40	1.06	-0.09	0.00	0.87	0.99	1.07
7	1.27	0.35	0.00	0.99	1.12	1.36	1.04	0.15	0.00	0.82	0.95	1.08
8	1.07	0.03	0.00	0.87	0.97	1.14	0.84	-0.08	0.00	0.69	0.81	0.91
9	1.05	-0.04	0.00	0.82	0.92	1.08	0.76	-0.16	0.00	0.63	0.73	0.80
10	0.79	-0.42	0.00	0.74	0.83	0.95	0.58	-0.47	0.00	0.58	0.68	0.72
All	1.36	0.12	0.00	1.07	1.18	1.42	1.10	0.00	0.00	0.88	1.00	1.14

Table 9

2019, 2020 AND 2021 ACTUAL LIFE EXPECTANCIES AT AGE 85 YEARS AND ESTIMATED LIFE EXPECTANCIES AT BIRTH FOR 2021 USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	5.86	5.25	5.55	6.00	6.06	5.88	6.87	6.18	6.52	6.90	6.98	6.90
2	5.99	5.34	5.63	6.07	6.14	6.03	7.02	6.36	6.71	7.10	7.17	7.07
3	5.87	5.38	5.49	5.91	5.98	5.88	6.92	6.39	6.59	6.95	7.04	6.95
4	6.15	5.60	5.78	6.23	6.29	6.17	7.25	6.59	6.90	7.29	7.36	7.24
5	6.04	5.44	5.65	6.06	6.12	6.05	7.13	6.47	6.83	7.18	7.25	7.11
6	6.19	5.61	5.90	6.32	6.39	6.20	7.22	6.58	6.94	7.29	7.37	7.23
7	6.27	5.84	5.99	6.37	6.44	6.28	7.23	6.71	6.95	7.27	7.35	7.25
8	6.14	5.62	5.80	6.16	6.22	6.16	7.18	6.63	6.94	7.24	7.31	7.18
9	6.31	5.77	6.00	6.33	6.38	6.31	7.34	6.75	7.10	7.38	7.44	7.29
10	6.36	5.80	6.19	6.52	6.57	6.43	7.53	6.86	7.40	7.68	7.74	7.58
All	6.12	5.57	5.80	6.20	6.26	6.14	7.17	6.55	6.89	7.23	7.30	7.18

Table 10

DIFFERENCE IN LIFE EXPECTANCY AT AGE 85 YEARS BETWEEN THE ACTUAL LIFETABLE FOR 2021 ON THE ONE HAND AND THAT IN THE 2019 AND 2020 ACTUAL LIFETABLES AS WELL AS IN THE LIFETABLE FOR 2021 ESTIMATED USING A VARIETY OF METHODS, BY SIS DECILE, EACH SEX

Decile	Men						Women					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
1	0.31	-0.30	0.00	0.45	0.51	0.33	0.35	-0.34	0.00	0.38	0.46	0.38
2	0.36	-0.29	0.00	0.44	0.51	0.40	0.31	-0.35	0.00	0.39	0.46	0.36
3	0.38	-0.11	0.00	0.42	0.49	0.39	0.33	-0.20	0.00	0.36	0.45	0.36
4	0.37	-0.18	0.00	0.45	0.51	0.39	0.35	-0.31	0.00	0.39	0.46	0.34
5	0.39	-0.21	0.00	0.41	0.47	0.40	0.30	-0.36	0.00	0.35	0.42	0.28
6	0.29	-0.29	0.00	0.42	0.49	0.30	0.28	-0.36	0.00	0.35	0.43	0.29
7	0.28	-0.15	0.00	0.38	0.45	0.29	0.28	-0.24	0.00	0.32	0.40	0.30
8	0.34	-0.18	0.00	0.36	0.42	0.36	0.24	-0.31	0.00	0.30	0.37	0.24
9	0.31	-0.23	0.00	0.33	0.38	0.31	0.24	-0.35	0.00	0.28	0.34	0.19
10	0.17	-0.39	0.00	0.33	0.38	0.24	0.13	-0.54	0.00	0.28	0.34	0.18
All	0.32	-0.23	0.00	0.40	0.46	0.34	0.28	-0.34	0.00	0.34	0.41	0.29

Appendix 3: Comparison of New Update to Existing Update

Figures 20 and 21 illustrate the differences in mortality estimates for ages 80 and over between the new life tables and the existing.

Figure 20

NEW MORTALITY ESTIMATES AS A PERCENTAGE OF EXISTING MORTALITY ESTIMATES BY AGE AND CALENDAR YEAR - FEMALE

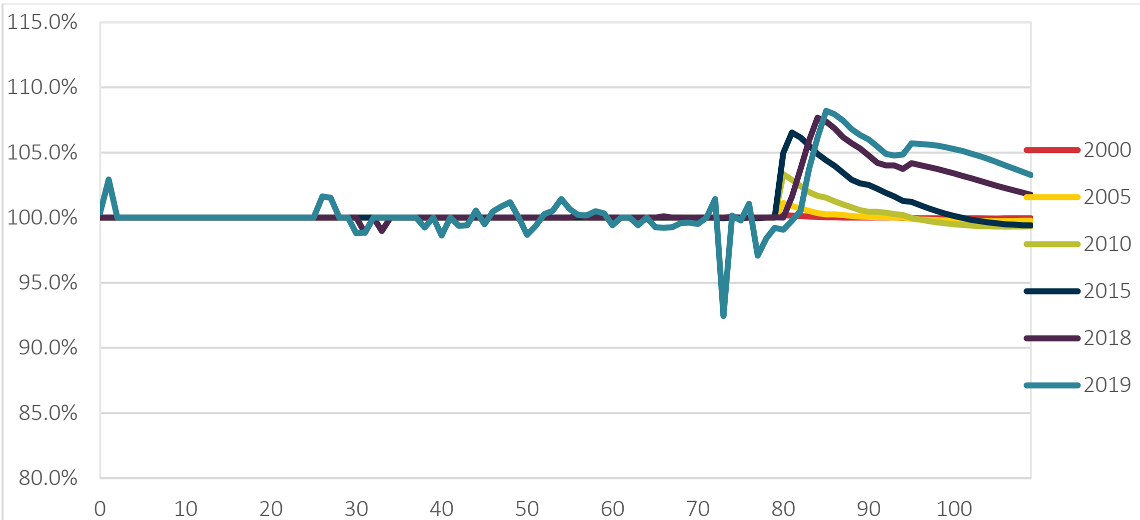
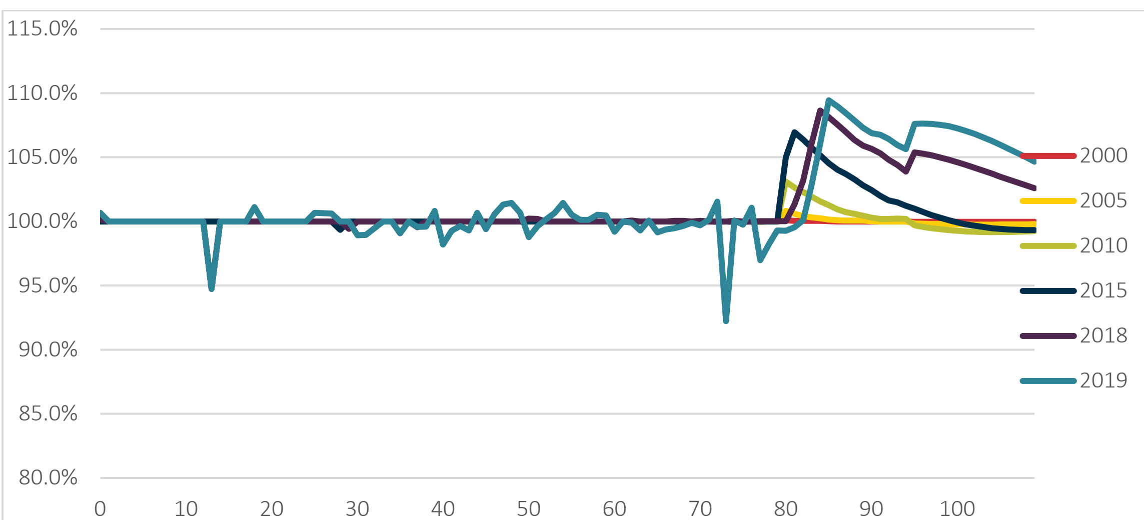


Figure 21

NEW MORTALITY ESTIMATES AS A PERCENTAGE OF EXISTING MORTALITY ESTIMATES BY AGE AND CALENDAR YEAR - MALE



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