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Word count: 5,798

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Abstract

We investigate the contribution of socio-behavioral factors to changes in US adult mortality over the period 1997-2019, using National Health Interview Surveys (NHIS) for years 1997-2018 linked to death records through 2019. The variables studied include alcohol consumption, cigarette smoking, health insurance coverage, educational attainment, mental distress, obesity, and race/ethnicity. We evaluate the contribution of each socio-behavioral variable to mortality change by estimating the mortality risks associated with each variable in a hazards model and applying the risks to changes in the variable's distribution. We find that reductions in cigarette smoking and increases in educational attainment are the largest contributors to recent mortality improvements, accounting between them for 67% of mortality improvements. In a secondary analysis, we compare two subperiods to investigate whether the variables can account for a widely-observed slowdown in the rate of mortality reduction that occurred *within* the period of study. Rising levels of psychological distress, combined with very high risks associated with distress, were responsible for 13% of the slowdown. However, most of the slowdown remains unaccounted for.

Keywords: Mortality, Trends, Health, Smoking, Despair

Introduction

Hundreds of factors affect levels of mortality in every population. Changes in the prevalence or fatality of these factors, and in how they combine, produce changes in a population's level of mortality. These trends in mortality have important implications for quality of life, social and family relationships, and the fiscal viability of age-based programs of economic transfer (Trustees 2022).

There are several approaches to identifying the various factors that influence mortality trends in large populations. One straight-forward approach uses cause-of-death assignments on death certificates (e.g.,Woolf and Shoomaker 2019). Since some underlying causes of death are the product of well-recognized causal processes, e.g., motor vehicle accidents, death in childbirth, and lung cancer, changes in these causes of death contain a causal attribution that may satisfy the standards of the investigator. This approach is less informative for causes of death that are multifactorial and the outcome of many, often overlapping, causal processes. The majority of deaths fall into this category, including deaths from most cancers, cardiovascular diseases, and dementias. Nevertheless, cause of death assignments in these cases are still useful in limiting the range of search for causal factors.

A second approach measures the distributions of various mortality-influencing factors at two points in time. By using information on the mortality risks associated with each factor, the approach can estimate the contribution of changes in the distribution of that factor to mortality change. An analysis may focus on a behavioral risk factor such as smoking or obesity (e.g., Stewart and Cutler 2015) or elements of medical services and medical technology, such as patterns of pharmaceutical use (e.g., Buxbaum et al. 2020). Estimates of prevalence and relative risks are typically made independently and are sometimes based on different data sources, which may introduce biases when different classification systems or sampling strategies are used in the different sources (Flegal et al. 2014). Some studies have been able to derive estimates of mortality trends, prevalence of risk factors, and relative risks from a single data source (Deeg et al. 2012; Preston, Vierboom, Stokes 2018).

In this paper, we use data from a single source, the National Health Interview Survey (NHIS), to identify factors contributing to mortality trends in the US at ages 25-84. The NHIS is the largest national data source on individuals and their health behaviors and circumstances. Our principal goal is to identify the effect of various socio-behavioral factors on trends in mortality during the period 1997-2019. In pursuit of this goal, we identify 1) the *mortality risks* associated with a socio-behavioral factor; 2) changes in the distribution of that factor; and 3) the mortality trend produced by the risk combined with the distributional changes. We also consider changes in the risks that may have occurred during the period of study.

The period 1997-2019 begins with the availability of important variables in the NHIS and ends in the last year for which the surveys have been linked to death reports. Coincidentally, the period ends just before the outbreak of the COVID-19 epidemic in 2020 and the tumultuous mortality changes that it introduced. The period 1997-2010 is one of relatively steady improvements in mortality in the United States (Kochanek et al. 2019: Figure 1), while the rate of mortality improvement during 2010-2019 was considerably slower than during the earlier period (Xu et al. 2021). Official estimates of life expectancy at birth for the nation show a value of 76.5 years in 1997 and 78.7 years in 2010, while rising minimally to 78.8 years in 2019 (Aries and Xu 2022). An additional goal of the paper is therefore to identify factors responsible for the recent slowdown in the rate of mortality advance.

Data and Methods

Data

We use annual waves of the National Health Interview Survey (NHIS) for years 1997-2018, made available by IPUMS (Blewett et al.2017). The NHIS is a cross-sectional survey that is nationally-representative of non-institutionalized civilians of all ages living in the United States. The National Center for Health Statistics has linked respondents from surveys 1997-2018 to death records through 2019, allowing for longitudinal mortality-follow up. For more information, see the survey's website (CDC 2022).

Analytic Approach

Our goal is to assess how population-level changes in socio-behavioral factors contributed to mortality trends between 1997-2019. To achieve this goal, we apply a partial regression decomposition framework that combines information on the changing prevalence of a factor with the relative mortality risks associated with that factor.

$$\text{Annual contribution of change in variable to change in mortality} = \frac{\sum_i(\Delta x_i * \beta_i)}{\Delta_t} \qquad \textbf{Eq 1}$$

where x_i is the proportion of the population in category i of the variable in the national distribution; Δx_i is change in this proportion during the period studied; β_i is the regression coefficient for category i from a Cox proportional hazards model identifying the relationship between a variable and mortality; and Δ_t is the mean duration between observations.

In our Cox models, we specify time since initial participation in the survey as the exposure time. Individuals remain exposed to the risk of death until they are censored by death, by reaching the end of survey linkage to death records on January 1, 2020, or by reaching age 85 (N = 565,092). An additional 45,259 individuals, who are first surveyed at age younger than 25, become part of our analytical sample when turning 25. To reduce imprecision resulting from changes in individual characteristics between survey and period of exposure to the risk of death – for example, some may quit smoking – we censor all individuals after 5 whole years since initial observation. In a sensitivity analysis, we explore the use of an alternative period of censoring.

The regression decomposition approach is applied three times (see Figure 1 for an overview). The broadest application compares changes between the period 1997-2004 (T1) and the period 2012-2019 (T3). The hazard model used for this analytic period is based on the entire set of observations from 1997 to 2019. In order to investigate whether variables in the model are capable of accounting for the slowdown in mortality improvement after 2010, we then divide the full period into thirds and estimate two hazard models, one for the period 1997-2008 and the other for 2008-2019. We apply equation (1) for the first half to mortality change from 1997-2004 (T1) to 2005-2011 (T2) and the regression equation for the second half to mortality change from 2005-2011 (T2) to 2012-2019 (T3). This approach enables us to study changes in the influence of a variable on mortality during the period of study as well as changes in the rate of distributional change.

The sample is limited to adults ages 25-84 who were: 1) eligible for mortality follow-up; and 2) selected by the survey to answer additional health-related questions. We do not exclude individuals based on missingness on key variables. Rather, when a variable has missing values, we add a level for "unknown" to that variable. We use mortality weights for the sample population, called *mortwtsa* in IPUMS. The complete sample includes 610,351adults, and 3,182,710 person-years of follow-up.

Analyses were performed using Stata 17 (StataCorp 2021). Our Stata code is publicly available [citation omitted for blind review].

Variables

We include variables whose associations with mortality have been well established and whose distribution is sufficiently heterogeneous that the variables produce a substantial population attributable risk of death. These include demographic characteristics of age and sex; social characteristics of race/ethnicity and educational attainment; biobehavioral risk factors of smoking, alcohol consumption, and body mass index; a measure of access to health care; and a measure of psychological distress. A calendar year variable is created to identify trends in mortality that are not captured by other variables in the model. Variables are constructed in the following way:

Calendar Year, Age, and Sex: A key variable in our analysis is calendar year. After initial assignment to a particular year at survey, the year variable increases by one year for each year of follow-up. Since the Cox model predicts the natural log of the death rate, the coefficient of the year variable is the estimated annual rate of mortality decline during the period under study. When a model includes only age and year of observation, the coefficient of year is treated as the age-controlled rate of mortality change.

Age measures age at last birthday and, like calendar year, increases by one year for each additional year of observation. We use a logarithmic transformation of age. Assuming that the log of mortality is a linear function of age produces the classic Gompertz curve.

In the NHIS, sex is treated as constant and binary.

Race/Ethnicity: Mortality differentials by race/ethnicity have been widely documented (e.g. Martin and Soldo 1997; Curtin and Arias 2019; Hooper et al. 2020). Some of the differentials are a product of differences in the distribution of socioeconomic and behavioral variables among the groups, while others are a product of specific features of group membership, e.g. discrimination against Black people (Jackson et al. 2011) and processes of migrant selectivity among Hispanics (Markides and Eschbach 2011).

We use a conventional categorization of race/ethnicity: non-Hispanic White ("White"), non-Hispanic Black ("Black"); Hispanic; and Other.

Educational Attainment: Educational attainment has become the most prominent variable representing an individual's socio-economic status in studies of health and mortality (Elo 2009). One advantage of the variable is that data on educational attainment is typically available for all adults, unlike occupation or income. A second is that individuals typically complete their education in young adulthood so that the variable remains stable through life. As a result, it is not highly vulnerable to problems of reverse causation during adulthood. Other socioeconomic variables such as income and occupational status can change as a result of one's health status, creating problems of statistical inference. Survey reporting of educational attainment is more reliable and complete than that of other socio-economic variables (Hummer and Lariscy 2011).

Educational attainment reflects the stock of human capital established relatively early in life that is available to individuals throughout their life course (Elo 2009). That capital may include health-related knowledge, resources, and skills. In their summary of relevant literature, Hummer and Lariscy (2011) and Hummer and Hernandez (2013) identify powerful mortality effects associated with educational attainment.

We use what has become a standard set of categories for educational attainment: less than high school completion; high school diploma; some college; and college completion.

Smoking Status: Following a thorough account of smoking/mortality relations in NHIS (Lariscy et al. 2018), we use the following categories of smoking status: *Current smokers* report smoking 100 or more cigarettes in their lifetime and now smoke every day or some days. *Current smokers* are further disaggregated by number of cigarettes smoked per day (<10, 10–19, 20–39, and 40+ cigarettes). *Former smokers* report smoking 100 or more cigarettes in their lifetime, but none currently. *Never smokers* report smoking fewer than 100 cigarettes in their entire life.

Body Mass Index (BMI): For use in analysis of mortality, an individual's lifetime maximum BMI is preferred to BMI measured at survey because it is less affected by reverse causation resulting from disease-initiated weight loss (Stokes and Preston 2016a, 2016b). However, maximum BMI is not available in NHIS.

Instead, we use a continuous measure of an individual's BMI units above 25.0, the beginning of the "overweight" range. Using continuous measures of BMI produces results that are much less sensitive to the common errors of self-reports than use of a set of categorical variables (Preston, Fishman, and Stokes 2015).

Alcohol Consumption: Mortality attributable to excessive alcohol consumption has been rising (Vierboom 2020). We construct an alcohol variable that attempts to combine lifetime frequency with the frequency of binge drinking in the past year. Lifetime abstainers reporting drinking fewer than 12 drinks in their lifetime, while former drinkers reported more than 12 drinks in their lifetime, but none in the last year. Light/moderate drinkers drank in the last year, and reported fewer than 60 occasions of binge drinking in the last year (binge drinking is equivalent to consuming 5+ drinks for men on a single occasion, 4+ for women). Heavy drinkers binge drank on 60 or more occasions in the last year.

Psychological Distress: Several studies have linked psychological distress to subsequent mortality (e.g. Keyes and Simoes 2012; Gilman et al. 2017). A prominent explanation of rising mortality among middle-aged White people uses cause-of-death assignments to identify rising mortality from "deaths of despair", a category that includes deaths from suicide, drug poisoning, and alcoholic liver disease (Case and Deaton 2017, 2020. 2022). Despair is not a well-recognized psychological construct but it is related to depression and anxiety, for which widely validated scales exist and which have been included in the NHIS since 1997. We use the K-6 scale that combines depression and anxiety to capture "non-specific psychological distress" (Kessler et al. 2002; Lace et al. 2020). Three of the six K-6 questions appear to tap into a layman's concept of "despair": "During the past 30 days, how often did you feel (1) so sad that nothing could cheer you up? (2) hopeless? Or (3) worthless?" With six items, each of which is scored from 0 to 4, the additive K-6 variable takes on scores of 0-24. If a respondent is missing the answer to just one of the six questions, we replace the missing value with the mean of the available five. We then use a conventional scale that trichotomizes the variable: a score of 0-4 indicates little to no psychological distress, 5-12 indicates moderate psychological distress, and 13+ indicates severe psychological distress (Tomitaka et al. 2019).

Access to Health Care: Most of the variables in the NHIS that relate to the availability of medical care combine elements of availability with elements of the respondent's health history, e.g., "In the last 12 months have you needed but couldn't afford medical care?" We seek a measure of health care availability that does not depend on respondent's illnesses, which we would expect to correlate with subsequent survival for reasons unrelated to availability. For this purpose, we use a dummy variable indicating whether an individual has health insurance coverage. Wilper et al. (2009) use hazard models to estimate that 45,000 annual deaths are associated with a lack of health insurance.

Results

Table 1 shows the distribution of population characteristics for adults interviewed in years 1997-2004, 2005-2011, and 2012-2018. We will refer to these periods as Time 1 (T1), Time 2 (T2) and Time 3 (T3) (see Figure 1 for an overview of the years included in each subperiod). The distributions are based on respondent characteristics at baseline and are weighted to be nationally representative (using *mortwtsa* in IPUMS).

The population underwent significant educational upgrading between T1 and T3, with the proportion having a bachelor's degree rising from 25.8% to 34.2%. At the same time, the proportion of people who had ever smoked decreased from 47.9% to 40.9%, alongside a reduction in the proportion of smokers who smoke heavily. A growing proportion of people reported Hispanic ethnicity. The percentage reporting that they had health insurance coverage rose by 1.4 percentage points. The largest change in alcohol consumption patterns was an increase of 4.4 percentage points in the proportion who currently drink but who are not frequent binge drinkers. Mean units of BMI above 25 rose by 0.84 kg/m^2 and mental distress increased.

Table 2 shows the coefficients of the hazard models when all variables are included in a model predicting mortality. We present three sets of results: one for the full period and one for each half-period. In all models, variables are related to mortality in the expected direction. Mortality falls with rising educational attainment and rises with smoking intensity, increased psychological distress, absence of health insurance coverage, and higher BMI. Coefficients of alcohol consumption are more complex. Relative to light/moderate drinkers, former drinkers and current binge drinkers had higher mortality, but so did lifetime abstainers. A J-shaped relationship is commonly found, with the mortality nadir among light drinkers and higher mortality among nondrinkers and moderate to heavy drinkers (Rogers et al. 2013).

The coefficient for "calendar year" can be interpreted as the unaccounted-for annual trend that remains after controlling for changes in the included covariates. With all variables in the model, the coefficient of calendar year for the full period is -0.0045—implying an annual mortality change of -0.45%. With only calendar year and age in the model (to control only the effects of changes in the age distribution), the coefficient of calendar year is -0.0111. In other words, age-standardized mortality on average decreased by 1.11% during each year of the period.

Table 2 enables a comparison of the mortality risks associated with a characteristic in the first and second halves of the period. For the most part, coefficients are relatively stable over time. However, those who attended college or achieved a BA increased their mortality advantage over those who did not, while mortality among Whites deteriorated relative to that of other racial/ethnic groups. The coefficient of calendar year in the full model changed from strongly negative at -0.0162 during the first half of the period (indicating an annual decline in mortality rates attributable to factors outside of the model) to slightly positive, 0.0022, during the second half (indicating increasing mortality attributable to these factors).

Accounting for Mortality Changes during the Full Period, 1997-2019

Table 3 shows changes in the annual rate of mortality change associated with each variable of interest, as calculated by the regression decomposition (Eq. 1). Values below zero indicate that changes in the given variable pulled mortality downwards, while positive values suggest that changes increased mortality. Figure 2 presents these results in graphic form. We begin by examining results for the full period, 1997-2019, before examining possible explanations for the stagnation in mortality improvements during that period.

Results for the overall period are given by the green bar in Figure 2 and the first column of Table 3. By far the largest driver of declining mortality over this period was evolving smoking patterns. Changes in smoking were responsible for an average annual decline in mortality of

0.0047. This value can be compared to the annual rate of mortality decline of 0.0111 in the regression on "year" controlling only age. Changes in the distribution of smoking behaviors therefore account for 42% (0.0047/0.0111) of the age-controlled decline in mortality over this period.

The variable with the second-largest effect on the rate of mortality decline over the entire period was improvements in educational attainment, which contributed an annualized amount of 0.0027 to the decline. This represents 24% of the age-controlled decline of 0.0111 over the period.

Reductions in the prevalence of binge drinking, former drinking and lifetime abstention relative to light/moderate drinking account for 12% (0.0013/0.0111) of the mortality decline. Rapid increases in the proportion of the population which is classified as Hispanic or "other races" (Table 1), combined with large mortality advantages for these groups relative to Whites (Table 2), were responsible for 10% (0.0011/0.0111) of the mortality decline.

Changes in health care coverage, as measured here, had a negligible effect. Two factors contributed to rising mortality during the full period. Increasing levels of psychological distress raised annual mortality by 0.0013 per year while rising BMI increased mortality by 0.0005 per year.

The effect of changes in mortality attributable to factors not in the model can be gauged by the contribution of the calendar year variable, the results of which are given in Table 3. Despite our efforts to control for elements impacting trends in mortality, a substantial annual trend remains, representing 41% (0.0045/0.0111) of age-adjusted mortality change during the full period.

Accounting for the Slowdown in Mortality Improvements

As noted earlier, data from vital statistics showed that the rate of mortality decline slowed during the period. To investigate whether the variables employed in this paper can account for the slowdown, we repeat the regression decomposition to investigate mortality change between T1 to T2 (using the hazard equation estimated on data for 1997-2008) and T2 to T3 (using the hazard equation estimated on data for 2008-2019). Results for these sub-periods are shown by the gray bars in Figure 2 and the last two columns of Table 3.

The age-controlled mortality rate declined by an annual average of 2.01% during the first sub-period, but only 0.68% during the second (see the first row of Table 2). Thus, a slow-down in the rate of mortality decline during the overall period is clearly reflected in NHIS data. The slowdown can therefore be quantified as 1.33% per year (i.e., 2.01%-0.68%).

In Figure 2 and Table 3, declines in smoking are the largest driver of mortality reduction in both sub-periods, while educational upgrading is the second largest. For both variables, the contribution is larger in the second period than in the first, implying that these variables were exerting greater downward pressure on mortality during the second period and were therefore not responsible for the slowdown in the rate of mortality decline.

Notably, the only variable considerably driving mortality upwards more in the second period than the first is mental distress. In the first sub-period, changes in mental distress increased mortality by 0.0003 (Table 3), while changes in the second pulled mortality upwards by 0.0023. By itself, this variable was therefore responsible for 15% of the slowdown (0.0020/0.0133).

The contribution of a variable can differ between periods both because of changes in regression coefficients or differences in rate of change in the distribution of a variable. In the case of mental distress, the source of the variable’s growing role was not the rising mortality risks associated with mental distress, as evidenced by the stable coefficients for the variable in Table 2. Rather, the cause was the growing prevalence of moderate and severe distress (Table 1), combined with the very high mortality penalty associated with these conditions (Table 2).

The main difference in contributions during the second period relative to the first pertains to “calendar year”. It contributed substantially to mortality reduction during the first period but to mortality *increase* during the second period. This change contributes +0.0184 (i.e., 0.0022 + 0.0162) to the actual trend change of +0.0133. Although there are positive and negative contributions from other variables to the change in trend, in this sense the change in trend was essentially entirely attributable to factors outside of our model.

Robustness check

We performed a sensitivity analysis using a death follow-up period of three years since survey, rather than five years. Results were minimally affected by shortening the follow-up period (see Appendix Figure 1).

Discussion

We begin by comparing the mortality trend implicit in the NHIS to that in national vital statistics. Over the full period 1997-2019, the age-controlled rate of mortality change in NHIS was -0.0111 (Table 2). Using data from the official vital statistics published for years 1997 and 2019 (Hoyert et al. 1999; Xu et al. 2021), we find that the annualized rate of change in the age-standardized death rate among people aged 25-84 between 1997 and 2019 was -1.09%[1]. Thus, there is excellent agreement in the estimated pace of adult mortality change over the period between NHIS surveys linked to mortality and official vital statistics. There is also good agreement with the Social Security Administration's annual estimates of age/sex standardized death rates. Based on data in the Trustees (2022) annual report, the average annual rate of change in mortality between 1997 and 2019 was -1.14%.

Vital statistics data on racial/ethnic and educational differentials in mortality and in rates of mortality change are also broadly consistent with our results. Case and Deaton (e.g., 2017, 2020, 2022) show that, during the 21st century, death rates among college graduates have fallen much faster than those of other educational categories. They also show a shrinking White mortality advantage as a result of deteriorating death rates relative to those of other racial/ethnic groups. Both of these trends are apparent in the changes in coefficients between the first and second periods in Table 2. Case and Deaton's data are drawn from aggregated vital statistics data but cognate trends are clearly identifiable in individual-level data in the National Health Interview Survey. When annual surveys are combined in this fashion, the NHIS appears to be a valuable source of information about mortality trends, a use to which it has not previously been put.

The variable making the largest contribution to mortality decline over the full period as well as both sub-periods was cigarette smoking. Smoking is a major risk factor for death while large declines in proportions of the population who smoke make this a very active variable on the mortality landscape. Its role should come as no surprise as demographers and epidemiologists

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[1] This calculation uses the age distribution of the US Census in 2000 to age-standardize death rates in 5-year wide age intervals in 1997 and 2019.

have described its impact on population mortality levels for many years (Preston, 1976; Peto, et al. 1992; National Research Council 2011).

The second most powerful variable contributing to mortality decline is educational attainment. This result is consistent with the very strong relationship between educational attainment and mortality (Hummer and Lariscy 2011; Hummer and Hernandez 2013; Sasson and Hayward 2019; Case and Deaton 2022) and the rapid improvement of the educational distribution of Americans (Table 1). Nevertheless, the result may seem surprising because the variable, often studied as a major factor in cross-sectional mortality differentials, is seldom featured in discussions of mortality trends. An important exception is the work of Wolfgang Lutz, who has used international cross-sections and time series to argue that the dominant factor in global improvement in mortality over the past century is an increase in adult educational attainment (e.g., Lutz and Kebede 2018; Lutz and Skirbekk 2014).

Luy et al. (2019) also found that rising educational attainment contributed to improvements in mortality. They decomposed changes in life expectancy at age 30 in three countries between 1990 and 2010 into effects associated with changes in the educational distribution and effects of mortality change at a given level of educational attainment. In the US, 19% of the gain in life expectancy was associated with educational upgrading. In Italy and Denmark, respectively, 20% and 24% of improvements in life expectancy were attributed to educational upgrading. Luy et al.'s estimated effect in the US is close to our 24% estimate in Table 3 for a somewhat later period.[2]

It should be noted that random measurement error typically biases coefficients towards zero. Such errors would be expected to produce an underestimate of the contribution of variables to mortality change. This concern is particularly worrisome in the case of obesity. Our results regarding obesity contrast with those of Preston, Vierboom and Stokes (2018). Using a similar research design to that of the present paper, they conclude that rising obesity reduced the annual rate of mortality decline by 23% over the period 1988-2011. The principal difference between the studies is that different variables were used to represent obesity. The present study uses NHIS

[2] It should be noted that we are dealing with death rates directly while Luy et al. examine changes in life expectancy. With survival patterns similar to that in the US, the effect of a proportionate change in death rates typically translates into a proportionate effect on life expectancy that is only about one-quarter as large (Keyfitz 1977). So our results are not strictly comparable to theirs.

data on body mass index at baseline while the earlier study used data on lifetime maximum BMI from the National Health and Nutrition Examination Survey. Lifetime maximum BMI is associated with much larger estimated mortality risks than is baseline BMI (Stokes and Preston 2016a, 2016b). A main reason for the difference is that people who develop a major chronic disease lose substantial weight, on average (Vierboom, Preston, Stokes 2018). The inflow of sick individuals into lower weight categories creates large "reverse causation" biases in the relation between BMI and mortality when baseline weight is used. As a result, we believe that the effect of obesity on mortality trends is underestimated in Tables 2 and 3.

Our construct representing alcohol consumption is susceptible to a similar reverse causation bias since ill individuals may forgo alcohol, artificially decreasing the mortality penalty of alcohol consumption for reasons unrelated to alcohol. In addition, alcohol use may be under-reported for reasons of social desirability, another reason why the analysis may underestimate the true contribution of changing drinking patterns to national mortality trends.

To our knowledge, this study is the first to use individual-level observations to analyze the impact of a changing population burden of mental distress on trends in mortality. We document that in the period 2008-2019, increasing mental distress contributed to the stagnation of mortality improvement. Population-level research on mental distress and mortality is only emerging, and it is possible that we are not accurately estimating the impact. The K-6 scale that is available in the NHIS, categorized into three groups, is not uncommon in research on distress (e.g. Tomitaka et al. 2019). However, there is little research on how this construct captures the variable's association with mortality. The sensitivity and specificity of the K-6 construct in detecting an association with mortality remains uncertain.

An additional concern with the present model is that some of the variables may be working through other variables to affect mortality. The presence of these other variables in the model may be blocking some of the effect of a variable on mortality through its multiple pathways. This concern is especially relevant for educational attainment, a variable whose value is typically established relatively early in life and that could plausibly be hypothesized to affect the value of other variables, especially behavioral variables such as smoking and obesity. To illustrate this possibility, we estimate a model containing only age, sex, year, and educational attainment. When the regression decomposition framework is applied to results of this new model over the period T1 toT3, educational attainment was responsible for an annual reduction in the death rate of [-0.0049], compared to a reduction of [-0.0027] in the full model. While results in this paper are based on a conventional hazards model in which hazards are additive, relations among the variables, and their relations to unobserved variables, could be more complex. Such possibilities add uncertainty to our results.

A second possibility of this nature is that mental distress may be, to an important extent, working through patterns of alcohol consumption to influence mortality trends. Removing alcohol consumption from the model had a very small effect on the contribution of mental distress to the rate of mortality change, raising the estimated contribution for the T1 to T3 period from 0.0013 to 0.0014.

Adding up the values in column 1 of Table 3, the socio-behavioral variables in our model accounted for an annual decline in mortality of 0.0080 over the period 1997-2019. This value includes the negative contribution to decline from mental distress and body mass index. These variables in total accounted for 72% of the total age-controlled annual decline of 0.0111. Declining smoking and increasing educational attainment were responsible for virtually all of the explanatory power as other variables had small and largely offsetting effects. We were not able to account for the remaining 28% of the decline. Such a result may be attributable to imprecise measurement or conceptual weakness of socio-behavioral variables. It may also reflect the activity of medical variables that are not represented in our framework or in NHIS. Buxbaum et al. (2020) conclude that improvements in pharmaceutical practices, especially greater use of statins and blood pressure drugs, accounted for 35% of the US mortality decline over the period 1990-2015. Such a fraction would account for much of the trend that we have left unexplained.[3]

We are unable to account for much of the slowdown in rates of mortality decline during the period's second half. Rising levels of mental distress were partially responsible for the slowdown, consistent with accounts that feature a rise in "deaths of despair" (Case and Deaton 2020, 2022). Such explanations based on a generalized deterioration in mental health have been

[3] In addition to a longer period, their study focused on life expectancy at birth and includes infancy and childhood, so results are not strictly comparable to ours. Some of the same variables are considered, including smoking, obesity, and health care coverage. They find that improved "public health", including reductions in smoking and improved traffic safety, accounts for 45% of US mortality decline between 1990 and 2015. They do not consider the role of increased educational attainment.

questioned and explanatory substitutes proposed that involve specific supply and demand factors for illicit drugs (Ruhm 2018, Masters et al. 2018). Our results, empirically linking an individual-level indicator of mental health to rising mortality, provide support for including despair or its surrogates in the explanatory framework.

However, most of the slowdown during our period was attributable to "calendar year", i.e., to factors operating outside of our model to produce trends in mortality. In fact, our results have the effect of deepening the mystery about factors that may be involved, since the age-controlled change in mortality trend was +0.0133 but when all our variables are included it rises +0.0184 (Table 2). The socio-behavioral variables were working to reduce mortality during 2008-2019 but their activity was not sufficient to avert a major slowdown in the rate of mortality improvement. Once their effect is accounted for, the slowdown worsens.

These results add urgency to the search for explanations of the slowdown. Medical variables may be playing a role here as well.For example, it is possible that a levelling-off of trends in the use of blood pressure drugs and statins contributed to the change in trend. Such a hypothesis would be consistent with evidence that the bulk of the slowdown is attributable to stagnation or reversal of declines in mortality from cardiovascular disease (Mehta, Abrams and Myrskyla, 2020). National trends in systolic blood pressure for individuals aged 60+ showed significant declines from 1999 to 2010 but no reductions between 2010 and 2016 (Dorans et al. 2019).

For more than a century, mortality in advanced countries declined steadily, encouraging the idea that future declines could be predicted by extrapolating rates of decline observed in the past (Vaupel et al. 2021). But the declines were not on automatic pilot; they were a result of human activity in many different spheres, including advances in education and social programs to reduce smoking. Better knowledge about the sources of past mortality changes can inform this important chapter of social history. It can also improve projections of future mortality. For example, levels of educational attainment are readily predictable on a birth cohort basis since attainments change little after age 30 (Lutz and Samir 2011). Likewise, the effects of smoking changes on mortality are predictable by observing cohort patterns of lung cancer mortality (Preston et al. 2016). Carefully integrating such factors into mortality projections should help improve their reliability.

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Table 1. Characteristics of the sample, by period of interview.[a]

Characteristic	1997-2004	2005-2011	2012-2018
Mean age in years (std dev)	48.0 (0.1)	48.9 (0.1)	49.9 (0.1)
Male	47.9 (0.1)	48.3 (0.2)	48.2 (0.2)
Race			
NH-White	74.9 (0.3)	70.3 (0.3)	66.5 (0.4)
NH-Black	10.9 (0.2)	11.3 (0.2)	11.7 (0.2)
Hispanic	10.3 (0.2)	13.0 (0.2)	14.8 (0.3)
Other	3.9 (0.1)	5.4 (0.1)	6.9 (0.2)
Educational attainment			
<High school	14.6 (0.2)	12.7 (0.2)	10.3 (0.2)
High school	32.2 (0.2)	29.9 (0.2)	26.5 (0.2)
<4 years college	27.4 (0.1)	28.0 (0.2)	29.1 (0.2)
≥4 years college	25.8 (0.3)	29.4 (0.3)	34.2 (0.3)
Cigarette smoking			
Never	52.1 (0.2)	55.3 (0.2)	59.1 (0.2)
Former	24.6 (0.1)	23.7 (0.2)	24.1 (0.2)
Current (<10/day)[c]	6.4 (0.1)	6.9 (0.1)	6.7 (0.1)
Current (10-19/day)	5.7 (0.1)	5.8 (0.1)	5 (0.1)
Current (20-39/day)	9.0 (0.1)	6.7 (0.1)	4.4 (0.1)
Current (40+/day)	1.6 (0.0)	0.9 (0.0)	0.4 (0.0)
Unknown	0.6 (0.0)	0.8 (0.0)	0.5 (0.0)
Alcohol consumption			
Lifetime abstainer	20.2 (0.2)	19.1 (0.2)	17.1 (0.2)
Former drinker	16.0 (0.1)	15.5 (0.2)	14.8 (0.1)
Light/moderate drinker	59.7 (0.2)	60.8 (0.2)	64.2 (0.2)
Heavy drinker	2.8 (0.0)	2.7 (0.1)	2.6 (0.1)
Unknown	1.3 (0.1)	1.9 (0.1)	1.4 (0.0)
Mean BMI above 25 (st dev)	2.8 (0.0)	3.4 (0.0)	3.7 (0.0)
Health insurance coverage			
Yes	86.4 (0.1)	84.1 (0.2)	87.7 (0.2)
No	13.4 (0.1)	15.7 (0.2)	11.9 (0.1)
Unknown	0.3 (0.0)	0.2 (0.0)	0.4 (0.0)
Mental distress			
None (K6: 0-4)	81.1 (0.2)	80.8 (0.2)	77.7 (0.2)
Moderate (K6: 5-12)	14.6 (0.1)	15.0 (0.1)	16.0 (0.1)
Severe (K6: ≥13)	3.1 (0.1)	3.3 (0.1)	3.5 (0.1)
Unknown	1.1 (0.0)	.9 (0.1)	2.8 (0.1)
Mean calendar yr follow-up (st dev)	2001.5 (0.004)	2008.1 (0.01)	2015.5 (0.01)
N[d]	212,281	159,097	193,714

Source: NHIS. a. Includes adults ages 25-84 at cross-sectional interview. Weighted to be nationally representative using *mortwtsa* in IPUMS. b. % distributions and standard errors in parentheses unless otherwise noted. c. Respondents who report smoking on "some days" classed as smoking <10 cigarettes/day. d. Respondents first surveyed below age 25 become part of the mortality follow-up sample when turning 25. This table, restricted by age at interview, includes 565,092 respondents. Later analyses include people who age into the sample.

Table 2. Coefficients from Cox proportional hazard models predicting deaths per person per year.[a]

Characteristic	**Full Period** 1997-2019		**Subperiods** 1997-2008		**Subperiods** 2008-2019	
	Coefficient	Std error	Coefficient	Std error	Coefficient	Std error
Calendar year (age only)[b]	-0.0111	0.0014	-0.0201	.0045	-0.0068	0.0030
Calendar year (full model)[c]	-0.0045**	0.0014	-0.0162**	0.0052	0.0022	0.0034
Age	0.083***	0.001	0.085***	0.001	0.081***	0.001
Male	0.401***	0.016	0.441***	0.023	0.368***	0.023
Race/Ethnicity						
Non-Hispanic White	ref	ref	ref	ref	ref	ref
Non-Hispanic Black	0.262***	0.022	0.342***	0.031	0.212***	0.031
Hispanic	-0.267***	0.032	-0.162***	0.043	-0.337***	0.045
Other	-0.182***	0.053	-0.098	0.090	-0.229***	0.066
Educational attainment						
<High school	ref	ref	ref	ref	ref	ref
High school	-0.155***	0.020	-0.170***	0.029	-0.159***	0.029
<4 years college	-0.230***	0.023	-0.181***	0.033	-0.260***	0.033
≥4 years college	-0.493***	0.027	-0.422***	0.041	-0.521***	0.037
Cigarette smoking						
Never	ref	ref	ref	ref	ref	ref
Former	0.405***	0.021	0.391***	0.030	0.420***	0.030
Current (<10/day)[d]	0.841***	0.033	0.771***	0.050	0.872***	0.046
Current (10-19/day)	0.831***	0.035	0.816***	0.054	0.823***	0.047
Current (20-39/day)	0.951***	0.030	0.876***	0.040	1.00***	0.043
Current (40+/day)	1.12 ***	0.057	1.16***	0.075	1.090***	0.089
Unknown	0.485***	0.097	0.421**	0.149	0.531***	0.135
Mental distress						
None (K6: 0-4)	ref	ref	ref	ref	ref	ref
Moderate (K6: 5-12)	0.468***	0.020	0.483***	0.028	0.466***	0.029
Severe (K6: ≥13)	0.759***	0.031	0.807***	0.049	0.723***	0.044
Unknown	0.493***	0.054	0.508***	0.079	0.524***	0.079
Body Mass Index (above 25)	0.008***	0.002	0.007*	0.003	0.008**	0.003
Health insurance coverage						
Yes	ref	ref	ref	ref	ref	ref
No	0.015	0.035	0.017	0.049	-0.001	0.048
Unknown	0.030	0.157	0.046	0.206	0.002	0.254
Alcohol consumption						
Lifetime abstainer	0.385***	0.022	0.350***	0.031	0.412***	0.031
Former drinker	0.439***	0.019	0.430***	0.028	0.445***	0.025
Light/moderate drinker	ref	ref	ref	ref	ref	ref
Heavy drinker	0.356***	0.046	0.373***	0.069	0.342***	0.062
Unknown	0.170*	0.075	0.257*	0.106	0.132	0.104

Source: NHIS. a. The sample, which includes adults ages 25-84 at follow-up, is weighted to be nationally representative using *mortwtsa* in IPUMS. b. Coefficient of year in model predicting mortality controlling only year and age. C. Coefficient of year in model predicting mortality when all variables are included. d. Respondents who report smoking on "some days" are classed as smoking <10 cigarettes/day.

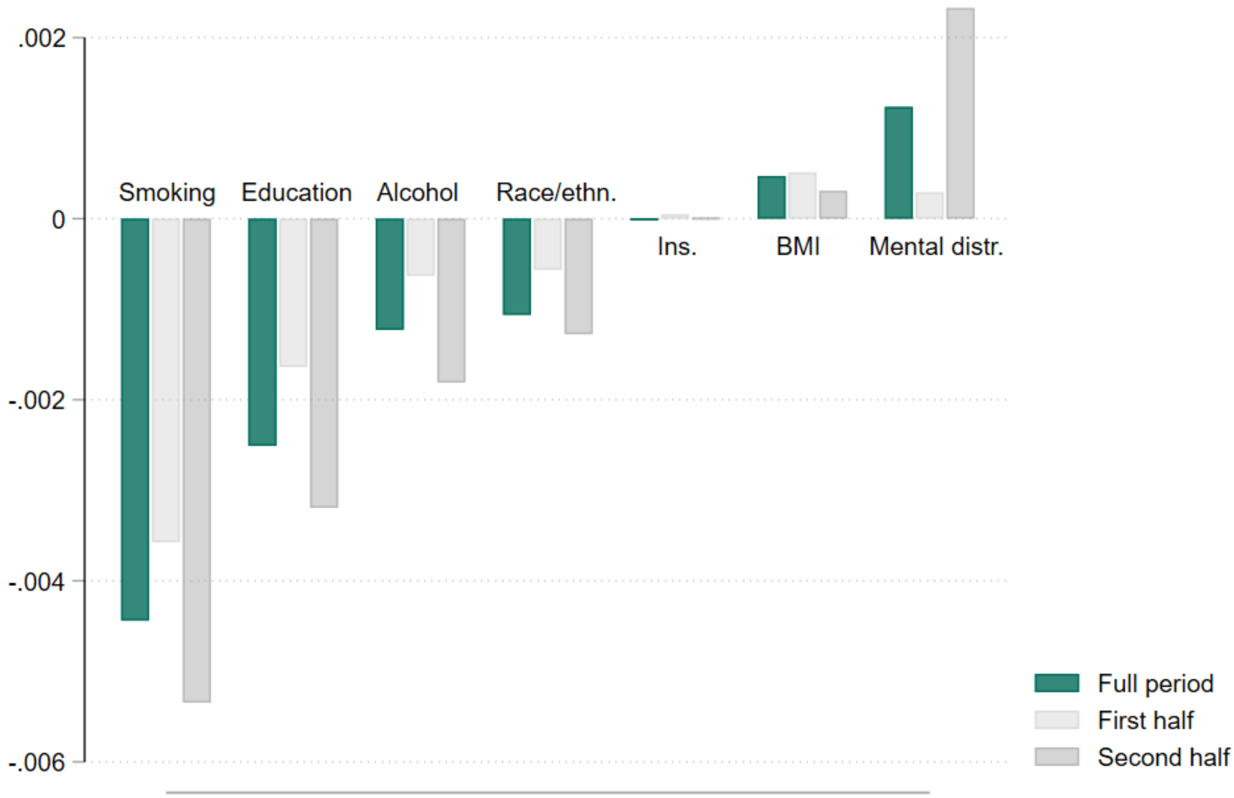
Table 3. Contribution of change in variable to annual change in the death rate.

Variable	Full Period	Subperiods	
	1997-2004 & 2012-2019[a]	1997-2004 & 2005-2011[b]	2005-2011 & 2012-2019[c]
Year	-0.0045	-0.0162	0.0022
Age	0.0119	0.0112	0.0125
Male	0.0001	0.0003	-0.0001
Race	-0.0011	-0.0006	-0.0013
Educational attainment	-0.0027	-0.0019	-0.0032
Cigarette smoking	-0.0047	-0.0041	-0.0054
Alcohol consumption	-0.0013	-0.0007	-0.0018
Body Mass Index	0.0005	0.0006	0.0003
Health insurance coverage	0.0000	0.0001	0.0000
Mental distress	0.0013	0.0003	0.0023

a. Uses regression equation fitted to years 1997-2019.
b. Uses regression equation fitted to years 1997-2008.
c. Uses regression equation fitted to years 2008-2019.

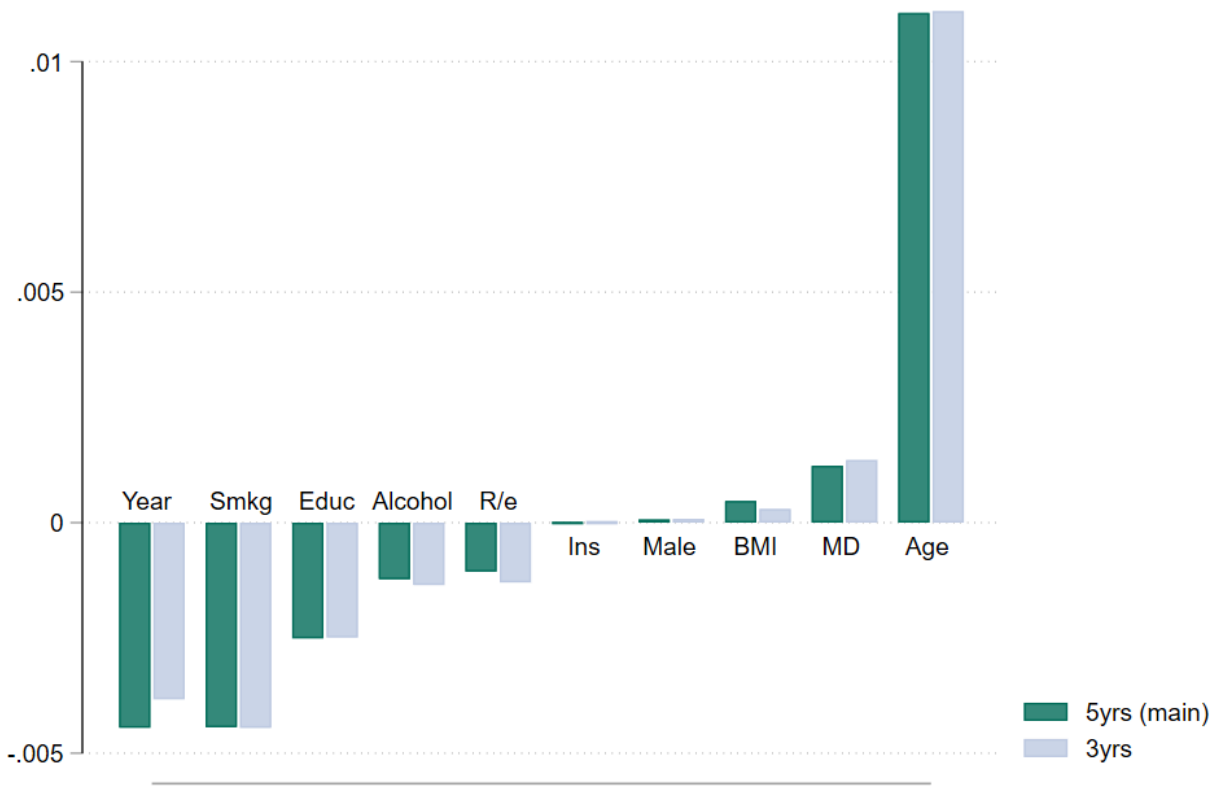
Figure 1. Division of the study period into sub-periods.

Figure 2. The contribution of changes in socio-demographic variables to mortality change, by period.



Source: NHIS
Abbreviations: Smkg: Smoking. Educ: Education. R/e: Race/ethnicity. Ins: Insurance coverage. BMI: Body Mass Index. MD: Mental distress.

Appendix Figure 1. The contribution of changes in socio-demographic variables to mortality change over full period, by length of mortality follow-up.



Source: NHIS
Abbreviations: Smkg: Smoking. Educ: Education. R/e: Race/ethnicity. Ins: Insurance coverage. BMI: Body Mass Index. MD: Mental distress.