

DEBATE

Revisiting within-cohort compositional change to understand mortality inequalities

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ABSTRACT The distribution of social characteristics changes over the life course of cohorts. These cohort compositional changes vary in magnitude across time, across populations and across socioeconomic groups. While this is evident intuitively, it is only rarely made explicit in demographic studies of mortality. In this debate piece, we argue that the classic demographic study of compositional change has become increasingly neglected in the field, as we have shifted towards causal inference of the individual-level determinants of demographic change. Using examples from the USA and Finland, we demonstrate how within-cohort compositional change operates for social characteristics such as education and divorce – a change driven by background and socially selective mortality, migration and changes in the characteristics themselves as the cohorts age. These cohort compositional changes produce non-linear age patterns of difference in the distribution of these social characteristics between Finland and the USA, and across socioeconomic groups, and may thus pose a challenge for the analyses of differential mortality. Ultimately, to understand aggregate, not individual, inequalities in mortality we need to more explicitly investigate how these covariates of mortality are changing in size and importance, and how they interact with indicators of social position over the life of the cohorts.

KEYWORDS Heterogeneity • Mortality selection • Social gradients • Education • Divorce

Introduction

Cohorts are dynamic. New people migrate in, while others die or migrate out. Social characteristics and behaviours change across the life course according to the prevailing opportunities and social norms. As a result of these experiences, the observed social and demographic composition of a cohort changes as it ages. These compositional changes in sociodemographic characteristics over the lifetime of cohorts differ in strength over time; vary across and within socioeconomic groups; and may muddle our classic interpretations of trends in mortality inequalities and other demographic phenomena.

A good example of within-cohort compositional change is seen through the changes in sociodemographic characteristics experienced by two long-running panel datasets in the

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United States. To demonstrate this, Zajacova and Burgard (2013) merged the Assets and Health Dynamics of the Oldest-Old (AHEAD) cohort, born 1900–1923, and the original Health and Retirement Study (HRS) cohort, born 1931–1941, to create the HRS-AHEAD dataset. As the cohorts aged between baseline in 1994 and 2010, the share of female, non-Black, married and never-smoker individuals rose. They additionally experienced increases in median wealth, increases in the average years of education and declines in the mean number of chronic conditions. These cohort compositional changes mainly resulted from the selective mortality of disadvantaged cohort members (Zajacova and Burgard, 2013).

These changes do not require cumulative disadvantage theories, which posit that accumulated risks over the life course increasingly disadvantage low-SES individuals with age (Dupre, 2007; Ross and Wu, 1996), to hold. So long as the population group contains a heterogeneous set of characteristics that impact mortality, the population's social characteristics risk set will change over age to become increasingly dominated by those with the lowest mortality risk set characteristics. The same processes also operate *within subpopulations*. Older low-educated individuals are likely to have experienced far more advantaged life courses than the low-educated individuals of the same birth cohort who died at younger ages.

These tenets are seldom fully explored in mortality inequalities research, even though compositional change has long been a cornerstone of demographic research. Evelyn Kitagawa pioneered her elegant decomposition method in 1955, which, for the first time, allowed researchers to explicitly monitor how a change in who made up the population impacted demographic phenomena (Kitagawa, 1955). Applied to mortality, this approach splits a change in death rates into contributions from “direct changes” (e.g., from medical or public health advances) and “indirect and compositional changes” (e.g., when a lower-mortality group becomes a higher share of the population).

In this debate piece, we demonstrate how compositional changes in time-fixed and time-varying characteristics operate within birth cohorts, and show surprising non-linear patterns of change in cohort distributions of health-relevant characteristics as cohorts age.

We argue that as the population sciences have become more focused on individual-level research and questions of causality, they have lost their core strength in describing how mortality inequalities are shaped by changing population dynamics. We end with a plea to revisit key tenets of compositional change in the interpretation of mortality trends and mortality inequalities.

Time-fixed characteristics and cohort compositional change

Assuming no selective migration, the population distribution of fixed characteristics changes across a cohort as it ages only due to selective mortality. These characteristics include sex, parental social background and race/ethnicity; or, when followed from early adulthood, characteristics that change very little thereafter, such as highest completed education.

But what can be inferred from the changing distributions as a cohort ages? How quickly a cohort experiences compositional change depends on (a) the initial distribution of

characteristics; (b) the mortality gradient associated with the characteristic; and (c) the overall mortality level.

These mechanisms are illustrated in the following examples (Figure 1). Let's imagine that Country A (left column) and Country B (right column) are each made up of two subpopulations with differential mortality (blue = high-mortality disadvantaged subpopulation, red = low-mortality advantaged subpopulation). The subpopulations each experience parallel Gompertz hazards shown in all panels, as depicted by the diagonal blue and red line (right-y axis). Since the disadvantaged blue population experiences higher mortality than the advantaged red population, the blue population's share of the total population (vertical bars – left axis) declines with age. As a result of this declining population share, the aggregate population-level mortality hazard (black line) always bends towards the lower-mortality subgroup hazard – a result shown by Vaupel et al. (1979).

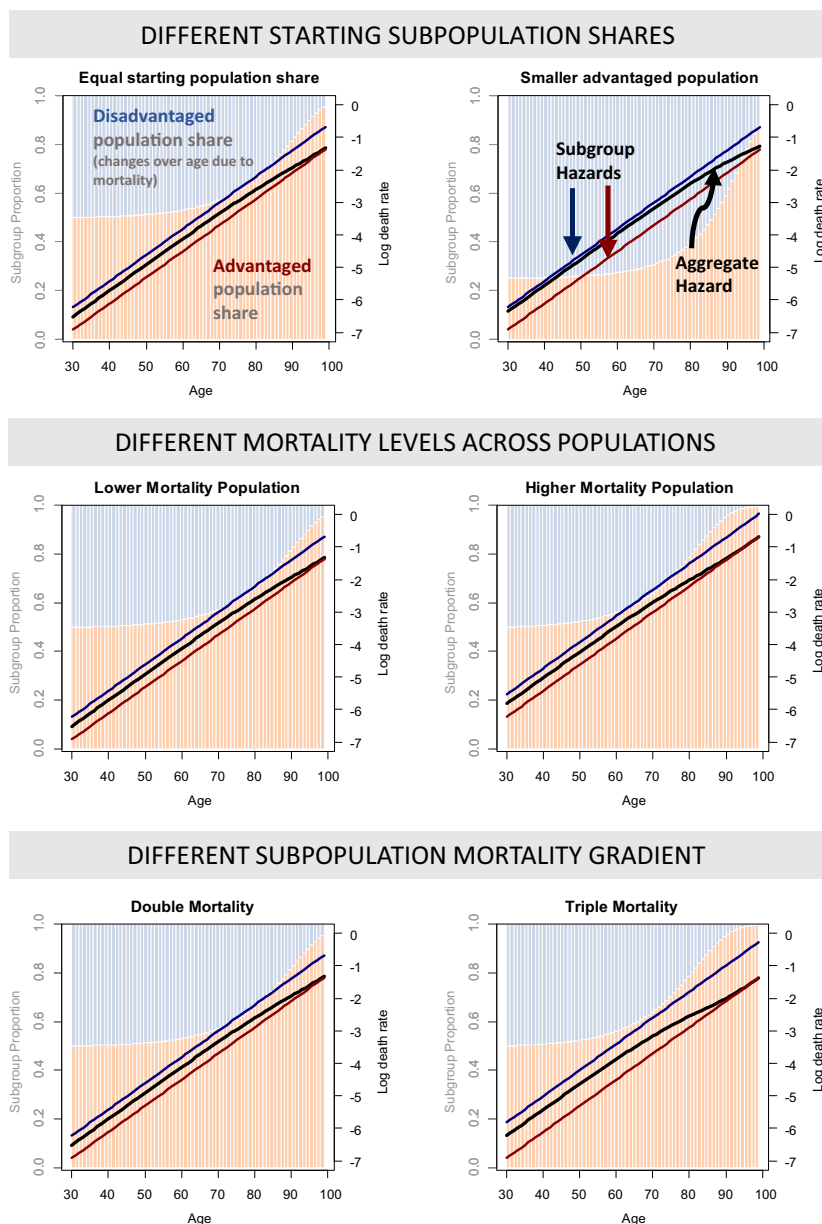
Each row of Figure 1 illustrates scenarios.¹ The first row illustrates a scenario where the subgroup mortality hazards are identical across countries, but the starting distribution differs. The second row shows two populations with the same starting shares and relative mortality gradient (the disadvantaged population experiences double the hazard of the advantaged population at all ages), but in the right column, the hazards are shifted upwards (i.e., mortality is higher overall). The third row shows a scenario with a larger mortality gradient between subpopulations: the disadvantaged subpopulation experiences double (left) or triple (right) the death rates of the advantaged subpopulation at each age.

The key takeaway from Figure 1 is that the population shares change at different speeds over age in Country A compared to in Country B in all three scenarios. Analyses that compare or control for differences in the composition across populations are generally ignoring that these changing compositions over age can be the result of different underlying dynamics. Researchers interested in mortality inequalities at older ages should also be reminded that even if relative mortality inequalities are unchanged over calendar time (for example, between Black and White Americans, or low- and high-educated individuals), we would expect mortality selection based on these characteristics to have less of an impact on the changing population composition over age now compared to in the past due to the overall mortality decline.

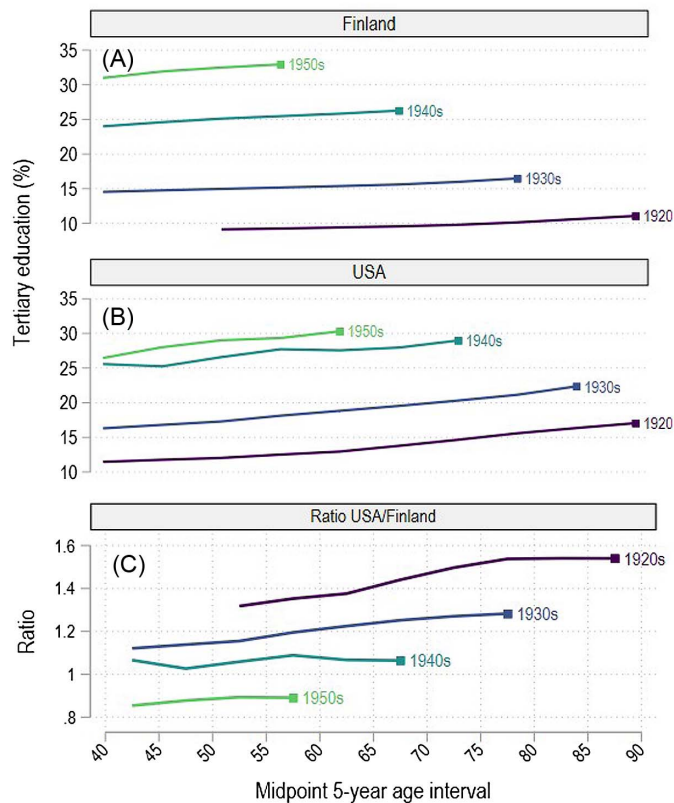
Turning to the real world, it is likely that all of these mechanisms are at play. Panels A and B in Figure 2 show the proportion of tertiary-educated men and women in Finland and the United States across various cohorts as they aged. Since ages below age 40 are excluded and further education after this age is rare (NCES, 2022), within-cohort increases in the proportion of high-educated individuals is mainly driven by the social gradient in premature mortality. Migration could also impact these curves if it is associated with education.²

1 The advantaged population follows a Gompertz hazard with the following parameters ($a = 0.002041075$, $b = 0.080445159$). The disadvantaged population has twice the mortality rate at all ages (three times in the bottom-right panel). For the aggregate population, the hazard was estimated from a life table with the survivors summed across subgroups as input. Calculations were made using the MortalityLaws R Package (Pascariu, 2024).

2 Migration could also impact these curves if it is associated with education. Data on the characteristics of emigrants are generally sparse. However, most migration takes place at younger ages, and an OECD report estimated that the weighted total emigration rate among OECD citizens moving to other OECD countries in 2005/6 was the same for the highly educated group as for all education groups (3.8%) (OECD, 2012).

Figure 1 Scenarios of mortality selection and population composition

Note: Hypothetical examples showing how the rate at which subgroup compositions change because of selective mortality depends on: the initial subgroup composition (first row), the overall mortality level (second row), the mortality gradient (third row). The left axis is the population share (referring to the shaded vertical bars) and the right axis is the log death rate (referring to the diagonal lines).

Figure 2 Percent of the population at each age with a tertiary level of education by birth cohort

Note: Tertiary levels of education are 13+ years in Finland; 4+ years of college in USA. Lines are Loess smoothed. US data are for the native-born only, and come from the publicly available American Community Survey for the years 1970–2022, downloaded via IPUMS USA (Ruggles et al., 2025). Finnish data come from the population register for the years 1970–2020 and cover the whole population.

We reduced the bias by limiting the US data to the native-born and by restricting the figure to ages at which international moves are comparatively rare (Rogers and Castro, 1981; Zagheni and Weber, 2012).

In the US, 12% of 40–44-year-olds from the 1920s birth cohort reported having tertiary education (defined here as at least four years of college). By the time this cohort was aged 85–89, 17% reported having tertiary education. For Finland, the percentage point increase was smaller, rising from 9% to 11%. In both countries, compositional changes resulted from the higher educated dying at a lower rate than the lower educated.

That the average educational level increases over adulthood due to the higher mortality of the less educated is relatively well known. But differences in the extent of within-cohort compositional change across countries are rarely explored, and at this point we have no clear formal explanation as to why compositional change is occurring more quickly

in the USA than in Finland. However, as Figure 1 summarises, the reasons could be: (1) differences in the starting compositions; (2) a higher overall level of premature mortality as these cohorts aged; (3) a larger socioeconomic gradient in mortality in the US; or (4) a combination of all of the above. To make matters even more complex, these changes may be driven by concurrent compositional change in other cohort characteristics. In the Finnish example above, a muted increase in the proportion of the tertiary educated with age in the older cohorts may be associated with the high proportion of men in this category, with men being more affected by selective mortality than women in all educational categories.

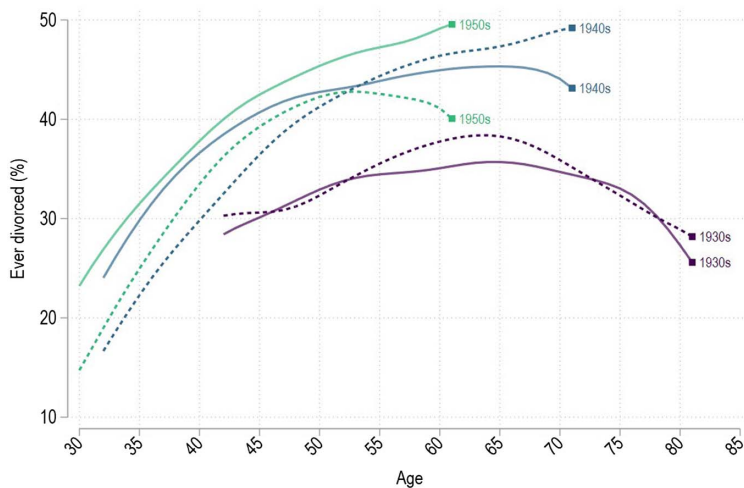
As a result of these differences in mortality-induced educational compositional change in the US and Finland, the ratio of the percentage of individuals who completed tertiary education in the 1920s US cohort compared to in the 1920s Finnish cohort increased from 1.3 at ages 55–59 to its peak of 1.5 at ages 80–84 (Panel C). Our descriptive analyses cannot analytically distinguish the degree to which these patterns are due to the forces presented above. However, the findings are consistent with the idea that the US experienced more education-selective mortality than Finland. Explanations based on higher US levels of background premature mortality may depend on the cohort. The 1920s cohort in the US and in Finland experienced similar mortality through middle adult ages, but the US cohort had lower mortality at most ages above 70 (authors' calculations from cohort mortality data in the Human Mortality Database (HMD, 2025)). By the 1940s cohort, the cohort in Finland had lower mortality over most ages, as depicted in Figure 1.

Meanwhile, although later birth cohorts are more educated, the slopes in both countries mirror those of the 1920s birth cohorts. The USA-to-Finland education ratio declined substantially across cohorts. Within cohorts, this education ratio generally increased with age for a given cohort, but the age increase was weaker among younger cohorts. Although age patterns of mortality gaps between the US and other countries have a myriad of determinants (Ho and Preston, 2010; Palloni and Yonker, 2016; Preston and Vierboom, 2021), a reduction in mortality-induced compositional change at younger ages by education might go some way towards explaining the eroding US mortality advantage at older ages.

Time-varying characteristics and cohort compositional change

Socially selective mortality processes operate beyond fixed characteristics. Compositional changes in time-varying social characteristics also take place within a cohort as it ages. Here, social changes interact with mortality-driven compositional change. An example is divorce. Divorces continuously happen over a cohort's adult life course, and within-cohort compositional change in the percentage ever divorced comes from three sources, assuming no divorce-selective migration and starting from an age at which divorce is zero: (1) levels and changes in first divorces by age (which themselves depend on marriage patterns); (2) the divorce gradient in mortality; and (3) the overall mortality level.

While high-quality longitudinal data on ever divorced status are hard to come by, the US General Social Survey (GSS) has been asking participants for over 50 years whether they have ever been divorced. The results are depicted for different cohorts as they aged in Figure 3. The sample sizes are small (roughly 1000–3000 participants per year), and the

Figure 3 The percent ever divorced by birth cohort, for US men (dashed) and women (solid)

Note: Lines are Loess smoothed.

Source: Unweighted data from the General Social Survey (Davern et al., 2024), 1972–2022.

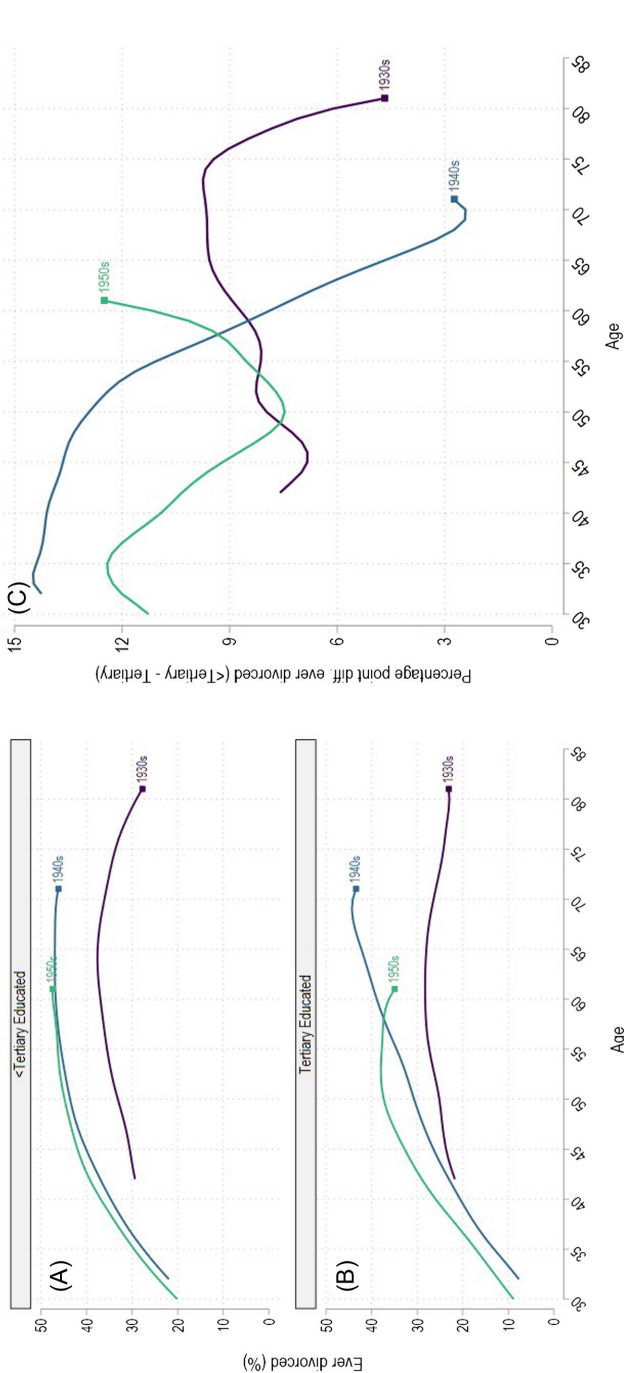
differences between cohorts are not statistically significant. However, the shapes of the curves are what we would expect. New first divorces happen at any age, while the divorced have higher mortality than the non-divorced at all ages. As a result, the percentage of ever-divorced individuals in each cohort rises over age as new divorces outpace divorce-selective mortality. The curves peak, and then fall, once divorce-selective mortality outpaces new divorces.

Looking across cohorts, as divorce has become more socially accepted over calendar time, the curves peak at higher levels for younger cohorts, and at progressively younger ages. The sex difference is surprising: the percent ever divorced curves peaks at younger ages for men than for women of the same cohort (with the exception of the 1940s cohort), despite women being younger than their husbands at marriage and divorce. This might be due to selective mortality impacting men at younger ages (due to higher background mortality or a larger divorce-mortality penalty among men), or to complex period-cohort dynamics related to women of younger cohorts marrying men of older cohorts. Alternatively, it might be a statistical artifact.

Regardless of the veracity of these particular findings, this example illustrates how a plausible interaction of mortality selection and social change in divorce creates nonlinear patterns of the composition of the ever divorced by birth cohort over age. Within-cohort compositional change in the ever divorced is happening at different speeds for different cohorts. It is also likely to differ across countries and to vary in magnitude and in timing. These patterns are a fruitful target for future research.

A final example shows non-linearities in the compositional change by ever divorced status within birth cohorts across educational groups in the USA (Figure 4).

Figure 4 The percent ever divorced by age for various US birth cohorts



Note: The percent ever divorced for those with less than four years of college education (Panel A), and for those with at least four years of college education (Panel B). Panel C shows the percentage point difference between these educational groups.
Source: Unweighted data from the General Social Survey (Davern et al., 2024), 1972–2022.

Panels A and B show the percentage ever divorced for those with and without at least four completed years of college education (for both sexes combined). For both educational groups, divorce is more common among those born in 1940 or later than among earlier cohorts. It is also more common among those with less than tertiary education than among those with tertiary education. For the tertiary-educated group, the age at which selective mortality outpaces first divorces is becoming younger for the most recent cohort. In contrast, it remains unclear whether lower-educated members of the 1940s and 1950s cohorts have yet to reach this inflection point. Among these latter cohorts, rates of first divorce continue to surpass or equal the negative effects of selective mortality, such that the population of ever divorced remains stable until the latest observation age.

Figure 4, Panel C shows the percentage point difference between the curves in Panels A and B. For all cohorts, the percentage point difference starts well above zero, as the uptake of first divorce initially occurs at a faster rate among the non-tertiary-educated group. The difference then declines for the 1940s and 1950s cohorts, presumably due to a combination of the following: (1) the divorce rate difference is narrowing or changing signs between the two educational groups at middle adult ages, which is at least partly explained by different age patterns of marriage entry; and (2) the impacts of divorce-selective mortality differ by age and education. In this second case, the mortality effects of divorce may differ by education. This in turn could relate to changing selection patterns into marriage by level of education (Ruggles, 2015; Torr, 2011; Van Bavel et al., 2018). However, even if the divorce/non-divorced mortality gradient is similar across educational groups, elevated overall mortality among the lower-educated group could still result in larger compositional changes. Following these declines in the percentage point difference in the ever divorced population, the divorce gap increases again for the 1950s cohort, with the same two mechanisms (rates of first divorce, rates of compositional change due to higher mortality of the divorced population) being at play, but changing in strength, and sometimes reversing in direction.

We are less confident in the patterns in the percentage point difference in the ever divorced at older ages because of small cell sizes. To get a sense of how plausible these overall patterns might be, we examined data on the “currently divorced” marital status, which are available from the much larger American Community Survey (ACS) (Supplementary material Figure S.1, available online at <https://doi.org/10.1553/p-7b6f-83c5>).

Age-cohort rises and falls in divorce are also seen, with younger cohorts having higher and earlier peaks. However, the proportion “currently divorced” is lower than the proportion “ever divorced”, and the declines are less pronounced at older ages. As a result, percentage point differences in the currently divorced status between the educational groups vary less over the life course compared to the larger swings seen for the ever divorced status, although nonlinearities remain. Presumably, the different patterns across Figure 4 and Supplementary material Figure S.1 are mostly due to remarriage dynamics, although some difference might result from the small sample size of the GSS.

If we approach these descriptive findings from the point of view of educational differentials in mortality, the contribution of such non-linear shifts in the ever divorced, or in family arrangements more generally, are complex to model. This is because family patterns change dynamically across age, making educational groups observed at the same age somewhat

difficult to compare. To the extent that these social compositional changes differ across countries in terms of timing and intensity, they also challenge our interpretations of why social mortality gradients are steeper in some countries and periods than in others.

While these patterns may be understood intuitively, there has been strikingly little descriptive analysis of how the distribution of sociodemographic characteristics relevant to mortality changes over the life course of cohorts and contributes to mortality inequalities across ages and periods. A recent notable exception is work showing that changing distributions of various characteristics (e.g., SES indicators, region of residence) due to selective mortality do not explain the Black-White mortality crossover at older ages for the 1909–1911 birth cohorts in the US (Breen, 2024).

The patterns of changing social characteristics over the life course, and the variation in these patterns across cohorts, may be understood in terms of a broader set of changing social norms relating to divorce, cohabitation, multi-partner fertility and fertility timing (Ajzen and Klobas, 2013; Lesthaeghe, 2010; Liefbroer and Billari, 2010; Perelli-Harris et al., 2012). At the individual level, there are strong associations between many of these characteristics and mortality (Dupre et al., 2009; Green et al., 1988; Koskinen et al., 2007; Kravdal et al., 2012). However, these individual-level associations are rarely scaled up to the population level.

Cohort compositional changes in social characteristics might be especially problematic when studying SES inequalities in mortality at fixed – but ultimately arbitrary – ages. In Finland, the proportion surviving to ages 65 and 75 has roughly doubled since 1971, with large differences by occupational class (Diaconu et al., 2022). During this period, occupational-class-based inequalities in remaining life expectancies at ages 65 and 75 widened sharply. At the same time, the proportion of the population surviving to the modal age at death was remarkably similar across time and occupational classes. Moreover, occupational-class-based inequalities in the modal age at death were more stable as well.

Implications

A general lack of progress in tackling mortality inequalities, despite decades of research into the social determinants of health, has led to pleas for new narratives (Lundberg, 2020). As we and others have argued, major breakthroughs would require a systematic understanding of compositional differences and compositional change (Hendi, 2024; Martikainen et al., 2007; Montez and Bisesti, 2024; van Raalte, 2021). In our view, such insights have not been forthcoming because of a major shift in the social and biomedical sciences away from providing general descriptions of aggregate trends and towards using causal inference to explain the processes. While this shift has been an important and necessary development, it has also come at a price. Changes in the composition of social groups are less likely to be an outcome of interest than to be regarded as confounders that should be controlled away to obtain causal estimates by using, for example, propensity-score matching, inverse probability weighting or fixed-effects study designs. Such methodologies are critical to understanding the determinants of mortality at the individual level. But at the population level, aggregate trends in social inequalities in mortality can only be

understood with a parallel investigation of how other determinants of mortality are changing in size and importance, and how they interact with indicators of social position.

The economic transformation of the past centuries ushered in enormous changes in work patterns, social structures and gender roles – and, in the process, transformed family structures (Ruggles, 2015). Marriage, divorce and childlessness are all traits that have changed enormously across birth cohorts, and are strongly patterned along socioeconomic dimensions (Furstenberg, 2014; Raymo et al., 2015; Sobotka and Berghammer, 2021). Social gradients for many of these traits have or might plausibly reverse (Esping-Andersen and Billari, 2015; Torr, 2011; Van Bavel et al., 2018). Any observed cohort trajectories of these characteristics over age are thus complex interactions of social change and mortality-selective processes.

One possible reason for neglecting this type of work might be that classic theories of population heterogeneity are based largely on innate, unobserved personal characteristics, fixed at birth, which determine the frailty distribution of the population (Vaupel et al., 1979). As the frail die younger on average, the population will become dominated by less frail individuals at older ages. What we describe here relates instead to compositional changes in social characteristics that may be associated with mortality, and that may change across the life course.

The concept of dynamic heterogeneity³ in ecology comes closer to describing the mortality dynamics that result from these cohort compositional changes. Essentially, it argues that individual life courses are full of forking paths that probabilistically move an individual to/from higher- and lower-risk mortality subgroups (or stages, as the authors refer to them). As such, “different individuals may follow different sequences of stages as they age” (Tuljapurkar et al., 2009, p. 94). The transitions between states are modelled in multistate settings. Because these are usually based on Markov assumptions, where each transition does not depend on either the sequence of state transitions or the duration spent in any state, the direct connection to cohort compositional change over age is not explicit. The outcome of interest from such models is usually the state expectancies, which are averaged across the population (e.g., the average number of years spent in the states of single, married, divorced, etc.), as opposed to the changing state distributions themselves.

This debate piece focused on within-cohort compositional change, demonstrating non-linearities in the proportion of the cohort with various social characteristics that are challenging to predict. To complicate matters further, other types of compositional change, such as *between*-cohort compositional changes, are also operating at the same time. Population subgroups become more or less selected across cohorts as they shrink or grow in size, or as individual characteristics become more or less associated with mortality. One example is the relationship between mortality selection and educational expansion. As educational opportunities grew and the low-educated group shrank in size, the group can be theorised to have

3 This is the term coined by Tuljapurkar et al. (2009) to distinguish it from “fixed heterogeneity”, e.g., the classic models of Vaupel and colleagues (1979). Somewhat confusingly, at around the same time, Caswell (2009) introduced the term “individual stochasticity” to describe a similar phenomenon. The Caswell thinking behind the terminology is that life histories can be understood as a Markov process. In such a world, everyone starting in the same population state (for example, age 30 and unmarried) is subject to identical rates of transitioning to other states (for example, age 31 and married). Any variation in outcomes is stochastic.

become increasingly composed of individuals with serious health conditions or to have come from highly disadvantaged family backgrounds. Such adversities both moderate and mediate the relationship between education and mortality, as the adversities increase mortality risk directly, but also decrease the likelihood of completing more than the basic level of education (Dowd and Hamoudi, 2014; Jackisch and van Raalte, 2025). As a result, mortality inequalities between the now smaller lowest educational group and all other educational groups increase (Hendi, 2024; Hendi et al., 2021; Mackenbach, 2019). How stable these relationships are across contexts is an important avenue for future research.

Conclusion

Changes in cohort composition complicate our analysis of period trends, our field's dominant mode of analysis. As researchers, we may try to reach meaningful conclusions about why socioeconomic mortality inequalities are larger in one country than in another, often linking trends to policy differences. But in any period, the socioeconomic groups themselves have been subject to different patterns of selection and compositional change, and these patterns can differ enormously across countries. Period analyses also blur the potentially important distinction between compositional changes owing to mortality selection versus changing social norms. Based on the tools we currently use in demography, we have little sense of how important changing selection and cohort composition patterns are for producing changing period mortality inequalities, both within and between populations. Mortality theories need to take account of social characteristics in a dynamic way, and population researchers must approach compositional change more explicitly. Ultimately, population health can only be understood if we understand our populations and how they change.

Supplementary material

Available online at <https://doi.org/10.1553/p-7b6f-83c5>

Supplementary file S1. Figure S1



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