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RESEARCH ARTICLE

Life tables under current risk composition based on observed, fixed characteristics

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ABSTRACT We examine how differences in risk composition between the overall synthetic life table cohort versus one that would be living under current mortality conditions influence life table mortality statistics. We propose formulas (i) for adjusting the force of mortality and life table statistics, eliminating heterogeneity introduced by the lagged risk composition of the synthetic cohort based on observed, fixed characteristics; and (ii) for decomposing the difference between two statistics under current risk composition, life expectancy (LE) and average lifespan deprivation (Dep) into the effects of differences in composition and of the summary mortality statistics of the subgroups. We use data on educational attainment in Denmark in 1991–1995 and 2011–2015 to illustrate these methods. The empirical example shows that the difference between the "standard" LE and the one under current risk composition is noteworthy, but the gap for Dep is negligible. Additionally, both the increase in the LEs of the educational groups and the shift in the composition of the population due to educational expansion contributed to the increase in the LE under current educational composition of both sexes. The observed decrease in Dep over the study years for both sexes resulted predominantly from the decrease in Dep of educational groups.

KEYWORDS Lagged risk composition • Compositional bias • Heterogeneity in mortality • Period life expectancy • Educational attainment

Introduction

The period life table describes the survival of a synthetic life table cohort, which is constructed from the mortality rates by age of the cohorts alive in a given period. Such an age-specific mortality rate is the weighted average of the rates for population subgroups with weights equal to the size of the subgroups at a given age. In populations composed of subgroups with very different mortality risks, mortality measures for a synthetic life table cohort differ from those that summarise the survival of a cohort that would live only under the mortality conditions of a given period. The difference between the two measures lies in their differing composition according to these risk subgroups. While the mortality rates of the subgroups reflect period mortality conditions, the subgroup weights do not. This is

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because the risk composition of the cohorts that make up the synthetic life table cohort is predominantly the result of the past, rather than current, conditions that these cohorts were exposed to over their lifetimes. As a result of this lagged compositional bias, life table mortality statistics cannot be interpreted as indicators of survival under period-specific mortality conditions, as those statistics would refer to the survival of a cohort that would live its entire life under these conditions. For this hypothetical cohort, both the subgroup-specific mortality rates and subgroup weights for deriving the total mortality rates must refer to conditions observed in the study period (Vaupel, 2002; Guillot, 2011; Guillot and Canudas-Romo, 2016; Luy et al., 2020). The aim of this study is to propose solutions for the derivation of life tables and their selected summary statistics that take into account the risk composition of a life table cohort by observed characteristics implied by current mortality conditions. The focus is on subgroups based on individual fixed characteristics.

The idea to adjust period mortality statistics for bias resulting from the lagged composition of the synthetic life table cohort was introduced in demography by Vaupel et al. (1979); Vaupel and Yashin (1985), who discussed the effects of unobserved compositional differences. The effect that the lagged composition of the synthetic life table cohort due to unobserved characteristics has on life table statistics has been extensively discussed in demography, starting with the works of Beard (1963); Shepard and Zeckhauser (1975); Keyfitz and Littman (1979). These studies focused on differences in the composition of the life table cohort due to frailty selection, a process by which cohorts are first depleted of their weakest individuals. As a cohort ages, the cumulative effect of mortality over time reshapes its frailty distribution towards the fittest individuals. Under long-term secular improvements in mortality, each cohort that makes up the synthetic life table cohort in a given period has a different frailty composition than the members of a life table cohort of the same age who would live their entire life under current mortality conditions. Specifically, older cohorts, having lived through periods of higher mortality, will tend to be composed of more robust individuals than the life table cohort. As a result, the overall age-specific mortality rates in a given period are lower than those of a cohort that would live only under current mortality conditions (Vaupel et al., 1979; Manton et al., 1981, 1986; Vaupel and Yashin, 1985; Vaupel, 1986).

Essentially, the same phenomenon can occur with a secular change in conditions that affect the composition of cohorts according to characteristics other than frailty, and some of these characteristics can be observed (Vaupel, 2002; Guillot, 2011; Luy et al., 2020). Due to *scarring* in earlier periods, certain cohorts contain a high share of individuals who are particularly susceptible to the mortality conditions of the study period. With the secular improvement in mortality conditions, a life table cohort that would live its entire life under current conditions would have a lower share of these individuals. Some examples of such conditions are childhood exposure to infectious diseases or malnutrition (Elo and Preston, 1992; Barker, 1998; Crimmins and Finch, 2006; Palloni and Beltrán-Sánchez, 2017; Almond et al., 2018); socio-economic and family childhood conditions (Montez and Hayward, 2011); or accumulated tobacco consumption over the cohort's lifetime (Peto et al., 1992; Wang and Preston, 2009). All of these circumstances affect the development of chronic conditions and mortality in later life. An opposite effect on synthetic cohort composition results, for example, from *conditioning*. Conditioning refers to the immunity

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acquired during previous exposure to a disease, whereby those who have been previously exposed are less susceptible to certain period conditions, such as influenza strains (Glezen and Couch, 1997). Unlike frailty composition, differences in the exposure of cohorts to conditions causing scarring or conditioning can be observed. Educational attainment (Zajacova and Burgard, 2013) and race (Das Gupta, 1988) are two further examples of observable factors influencing mortality that make the synthetic life table cohort different from a cohort that would live only through the conditions of a given period.

Research questions concerning the compositional effect of heterogeneity according to observed characteristics on the summary statistics of mortality have often been addressed in demography through the application of various decomposition methods (e.g.,Vaupel and Canudas-Romo (2002); Das Gupta (1991); Torres et al. (2019); Keyfitz and Littman (1979)). However, to our knowledge, bias in life table measures arising from the lagged composition of the life table cohorts by observed characteristics has not yet been addressed. In this study, we propose methods for deriving life tables and summary mortality measures consistent with current mortality conditions when an observed subgroup composition is fixed at the radix age. Although any method that controls for the composition of the population can be used to correct for bias, the difficulty lies in defining a composition of the population that would be consistent with current mortality conditions. In the case of observed characteristics, the composition of a cohort that would live only under current mortality conditions is obtained by (i) partitioning the life table in the radix age; and (ii) following each group's specific mortality over the life course, assuming that each group's specific mortality conditions (the current conditions) remain constant. When, as we discuss, observed characteristics are fixed at the life table radix age, only the current mortality conditions determine the cohort's group composition at ages beyond the radix age.

We illustrate the proposed methods with the example of educational attainment in Denmark in two periods: 1991–1995 and 2011–2015. Generally, educational attainment does not change for individuals above a certain age in young adulthood, and data on the educational composition of the population and mortality are routinely collected, although they are not always readily accessible. As a result of the rapid expansion of education that began in the second half of the 19th century (Baker et al., 2011), coupled with a growing gap in the survival of educational groups (Meara et al., 2008; Brønnum-Hansen, 2017), the educational composition of older and younger cohorts differs dramatically. Therefore, the composition of the synthetic life table cohort and the cohort that would live only under current mortality conditions also differ. We hypothesise that, as educational attainment is an important social determinant of mortality (Mackenbach et al., 2008; Elo, 2009; Hummer and Lariscy, 2011), these compositional differences should result in a notable gap between the life table measures derived via the two approaches, offering a good illustration of the problem raised in this article.

Methods

The mortality rates of the cohorts alive in the study period do not represent current mortality conditions due to their lagged risk composition. *Lagged risk composition* means that the

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proportions of subgroups characterised by different mortality risks in the cohorts in the study period have been determined by the cumulative effects of past conditions affecting mortality. We refer to the mortality statistics for the synthetic cohort of a period life table as *standard*. In contrast, *life table cohort under current risk composition* refers to a cohort in which both the mortality rates of subgroups characterised by different mortality risks and the composition of the population by these subgroups result only from current conditions. This means that the composition of the life table cohort at each age is determined only by the composition at the radix age and the period-specific mortality of each subgroup. In this article, the life table statistics for this cohort are denoted with the index "cc" to distinguish them from the standard life table notations. For brevity, the term *under current risk composition by observed characteristics fixed at the radix age* is shortened to *under current risk composition*. In this study, we generalise and expand on formulas proposed by Keyfitz and Littman (1979) to derive the force of mortality and life table statistics for a cohort consisting of two subgroups. These formulas were previously applied by Das Gupta (1988) to estimate a life table "consistent with life tables for subpopulations", with race as the fixed characteristic defining the population subgroups. The formulas provided in the main text of the article are supplemented by their discrete approximations in Section S2 in the Supplementary material available online at https://doi.org/10.1553/p-4pz2-ce.

By a we denote the life table initial (radix) age. For the ith sub-group ($i = 1,2,\dots n$) of the life table cohort, its proportion at the radix age a is denoted by π_i, such that $1 = \sum_{i=1}^{n} \pi_i$. For fixed characteristics, group membership does not change above age a, and changes in the composition of the life table cohort with age are determined only by attrition within subgroups. The proportion of risk group i at age $x \geq a$ in the life table cohort under current risk composition equals:

$$\pi_{cc,i}(x) = \frac{\pi_i \ell_i(x)}{\sum_{i=1}^{n} \pi_i \ell_i(x)} = \pi_i \frac{\ell_i(x)}{\ell(x)}, \tag{1}$$

where $\ell(x)$ denotes overall survivorship to age x from the radix age a, whereas $\ell_i(x)$ denotes survivorship for the ith risk group.

The number of survivors at age x under current risk composition is the sum of the survivors in each of the risk groups, weighted by the cohort composition by risk groups at the life table radix age:

$$\ell_{cc}(x) = \sum_{i=1}^{n} \pi_i \ell_i(x). \tag{2}$$

The total force of mortality at age x under current risk composition is

$$m_{cc}(x) = \sum_{i=1}^{n} \pi_i(x) m_i(x) = \sum_{i=1}^{n} \pi_i \frac{\ell_i(x)}{\ell(x)} m_i(x), \tag{3}$$

where $m_i(x)$ denotes force of mortality at age x for the ith risk group.

The total death density at age x under current risk composition is given as

$$d_{cc}(x) = m(x)\ell(x) = \sum_{i=1}^{n} \pi_i d_i(x), \tag{4}$$

where $m_i(x)$ denotes death density at age x for the ith risk group.

This implies that life expectancy (LE) at life table radix age a under current risk composition, when the risk composition refers to risk subgroups fixed at the radix age, is

$$e_{cc}(a) = \sum_{i=1}^{n} \pi_i e_i(a), \tag{5}$$

where $e_i(a)$ is life expectancy at age a of the ith risk group of the life table cohort. Detailed steps for deriving this equation are provided in Section S1 in the Supplementary material.

When a symmetric decomposition technique is applied, like in standard methods for decomposing differences between two LEs (see, for example, Kitagawa (1955); Das Gupta (1991); Andreev et al. (2002)), the difference between two values of LE under current risk composition has a straightforward decomposition:

$$e_{cc,2}(a) - e_{cc,1}(a) = \frac{\sum_{i=1}^{n} [\pi_{2,i} - \pi_{1,i}][e_{2,i}(a) + e_{1,i}(a)]}{2} + \frac{\sum_{i=1}^{n} [\pi_{2,i} + \pi_{1,i}][e_{2,i}(a) - e_{1,i}(a)]}{2}, \tag{6}$$

where the first element represents the difference between the two LEs due to compositional differences, and the second element represents the differences in the LEs of the subgroups. We give the derivation of the formula in Supplementary material equation S1.4. The proposed method is analogous to Kitagawa's (1955) method for decomposing a difference between two crude death rates according to a single compositional factor. Based on the similarity of the two methods, we identify additional mortality statistics that can be used in comparative studies of life table cohorts under current risk composition, as discussed in the summary and discussion section of the paper.

In addition to LE, another important life table summary statistic is average lifespan deprivation (Dep). It is commonly derived according to the $e^{\dagger}$ formula, and used as a demographic indicator of inequality in ages at death in a period life table (e.g., Shkolnikov et al. (2011); Aburto and van Raalte (2018); van Raalte and Caswell (2013); van Raalte et al. (2018); Vaupel et al. (2011); Zhang and Vaupel (2009)). This statistic is based on Keyfitz's (1985, pp. 72–73) notion that "everybody dies prematurely" and that upon death an individual is deprived of life expectancy at the given age. Average lifespan deprivation in the life table cohort under current risk composition at life table radix age a is derived as:

$$e^{\dagger}_{cc}(a) = \sum_{i=1}^{n} \pi_i e^{\dagger}_i(a), \tag{7}$$

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where the average lifespan deprivation in the ith subgroup at life table radix age a is measured as:

$$e_i^{\dagger}(a) = \int_{x=a}^{\infty} d_i(x) e_i(x) dx. \tag{8}$$

The above formula is derived in detail in Supplementary material equation (S1.6).

The difference between two values of $e_{cc}^{\dagger}$ statistics has a straightforward decomposition, analogous to the decomposition of the gap between two LEs:

$$e_{cc,2}^{\dagger}(a) - e_{cc,1}^{\dagger}(a) = \frac{\sum_{i=1}^{n}[\pi_{2,i} - \pi_{1,i}][e_{2,i}^{\dagger}(a) + e_{1,i}^{\dagger}(a)]}{2} + \frac{\sum_{i=1}^{n}[\pi_{2,i} + \pi_{1,i}][e_{2,i}^{\dagger}(a) - e_{1,i}^{\dagger}(a)]}{2}, \tag{9}$$

where the first element represents the difference between the two average lifespan deprivation statistics due to compositional differences, and the second element stands for the differences in the $e^{\dagger}$ of the subgroups.

Empirical example

Data and methods

In the empirical application of the proposed method, we estimate life expectancy and average lifespan deprivation under current educational composition and compare it with the corresponding standard statistic. The term *under current educational composition* means that the composition of the population by educational attainment at each age is determined by the composition of the population at the radix age and the survival of the members of the educational groups from the radix age to a given age. As shown in the methods section, to estimate life expectancy or average lifespan deprivation under current educational composition at a given age, it is sufficient to have the relevant statistics by educational attainment and the composition of the population by educational attainment at the life table radix age. Data on life expectancy by educational attainment are widely, but not universally, available from secondary sources. In the main text of the manuscript, we present the statistics by sex for the Danish population in two time periods: 1991–1995 and 2011–2015. Data sources and results concerning life expectancy under current educational composition for other countries are given in the Supplementary material in Table S.2, following Table S.1, which gives the list of data sources used. Data for the $e^{\dagger}$ statistic, i.e., average lifespan deprivation by educational attainment, are not readily available from previous publications. To calculate them, information on mortality rates by age and educational attainment is required. The secondary data used in this empirical example include the information necessary to derive the $e^{\dagger}$ statistics.

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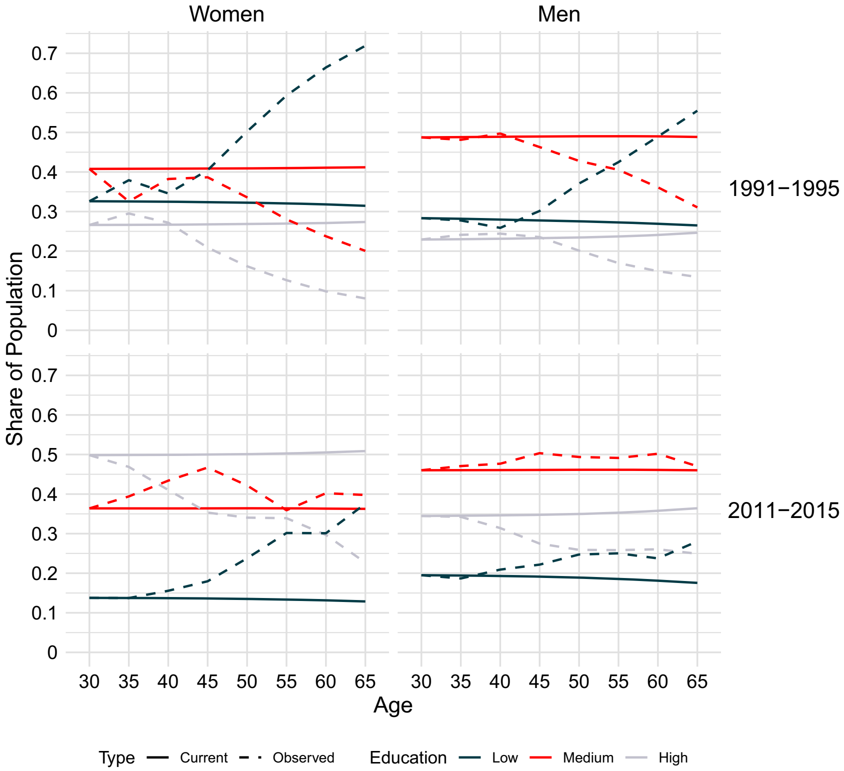
We use 5-year abridged life tables by educational attainment, starting at age 30, in 1991–1995 and 2011–2015, taken from the online supplementary material of Németh et al. (2021). By setting the radix to age 30, we assume that in Denmark, individuals do not acquire any additional educational qualifications after the age of 30. In studies that compare mortality across educational groups, it is generally assumed that individuals have reached their highest level of education by age 30 (or, in some cases, even by age 25). For example, of the eight studies cited in the Supplementary material, Table S.1, only Permanyer et al. (2018) sets the threshold age for completing education at 35. In Denmark, the typical age for completing the lowest level of tertiary education (ISCED 5) was 23–24 years in 1999 and 20–25 years in 2015 (OECD, 1999, 2017). We assume that educational attainment at age 30 is the same as in the 30–34 age interval.

Educational attainment is expressed in three categories based on the International Standard Classification of Education (ISCED): Low, which consists of primary and lower secondary education (ISCED 1–2); Middle, which refers to upper secondary education (ISCED 3–4); and High, which refers to tertiary education (ISCED 5–6). We obtain the distribution by education at the life table radix age, $\pi_i(30)$, from population counts by sex and educational attainment at age 30 from Statistics Denmark (2022). Population counts with no information on educational attainment at age 30 (4% in 1991–1995 and 9% in 2011–2015 for men, 3% in 1991–1995 and 8% in 2011–2015 for women) are redistributed proportionally to the three educational groups.

To match the education-specific life tables, standard life expectancy (LE) comes from abridged life tables with an open age interval of 90+. The $e^{\dagger}$ statistic is also derived from these life tables. We construct these life tables from aggregated death counts and exposures for the years 1991–1995 and 2011–2015 contained in the Human Mortality Database (Human Mortality Database, 2024). The average years lived by those dying in 5-year age groups, ${}_5a_x$, and in the open-age interval are taken from the abridged 5-year life tables for 1990–1994 and 2010–2014 in the Human Mortality Database (Human Mortality Database, 2024). The R code is available at https://github.com/mmuszynskasp/LE_edu.

Figure 1 shows the educational composition of the life table cohort under current educational composition (solid lines) and the synthetic life table cohort (dashed lines) for the Danish population in two periods, 1991–1995 and 2011–2015, for men and women. The composition of the life table cohort under current educational composition, i.e., estimated with the observed educational composition at age 30 modified only by the education-specific survival at ages beyond 30, gives a much more favourable weighting than the actual composition of the synthetic cohorts: lower educational attainment is given far less weight (solid red lines) at older ages than under the observed current composition (dashed red lines). The differences observable in the four panels of the figure reflect dramatic changes in educational attainment across cohorts and a continuing educational expansion in successive cohorts that benefited women more than men. Since individuals with higher levels of education have lower mortality on average, it requires no stretch of the imagination to predict that mortality rates at ages beyond the radix age will be higher for the synthetic life table cohorts than for the life table cohort under current educational composition. On this basis, we expect that the gap between life expectancy under current educational composition and standard life expectancy would be

Figure 1 Educational composition of the life table cohorts* by sex and age in Denmark, 1991–1995 and 2011–2015



Notes: *The two cohort types are: the synthetic life table cohort (Observed) and the cohort aged 30–34 during the study period (Current). The educational composition of the latter is based on its composition at age 30–34, with survival derived from education-specific life tables by sex.
The age range in this figure is limited to 30–69 years, as data for the population by educational attainment (Observed) are only available for this age range.
Source: Authors' estimations based on Statistics Denmark (2022) and Németh et al. (2021).

largest for women and the older cohorts, and in the second period under study. In addition, the increase in life expectancy under current educational composition between 1991–1995 and 2011–2015 would result from both improvements in the life expectancy of educational groups and an increase in the share of those in higher educational groups at age 30, especially among older cohorts and women. No obvious hypotheses can be formulated concerning the effect of the differences in the composition on the gap between the two $e^{\dagger}$ statistics, as they depend on the age pattern of the compositional differences (van Raalte and Caswell, 2013).

For ease of presentation, in the figures, tables and description of results in the empirical illustration of the effect of differences in educational composition, the subscript for

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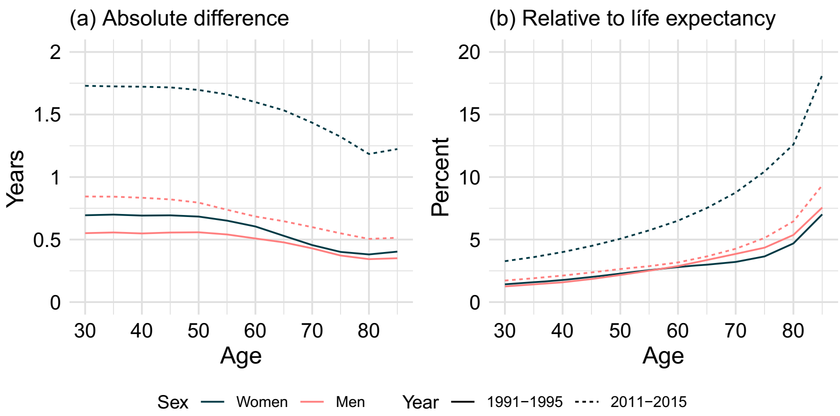
statistics under current risk composition (*cc* in the formulas in Section Methods) is replaced by *edu*.

Results

The first panel (a) of Figure 2 shows that life expectancy under current educational composition (LE_{edu}) is consistently higher than standard life expectancy (LE) for all ages between 30 and 85. The gap between LE_{edu} and LE is of a sufficiently large size that it cannot be ignored. For example, for women aged 30 in 2011–2015, the gap is 1.7 years and the difference in LE between the high and medium educational groups is two years (see Table 1 in Németh et al. (2021)).

Although the absolute difference between LE and LE_{edu} is an easy-to-understand number, the effect of the compositional differences on the gap in life expectancy across the cohorts alive in a study period is better illustrated by the relative differences between the two LEs by age. As shown in the second panel (b) of Figure 2, the older the life table cohort, the larger the difference between the educational composition of the synthetic cohort and the life table cohort under current educational composition, and hence the larger the gap between LE_{edu} and LE relative to LE. This increase with age is most pronounced for women in 2011–2015. This reflects the fact that the dramatic change in the

Figure 2 Difference between life expectancy under current educational composition and life expectancy, by age and sex in Denmark, 1991–1995 and 2011–2015



Notes: Life expectancy under current educational composition (LE_{edu}) refers to the average length of life of a cohort with the composition by educational attainment of those aged 30 in a given period and survival according to education-specific life tables. Life expectancy denotes the standard life table life expectancy (LE) value for a synthetic cohort;
LE and LE_{edu} at age x are conditional on survival to age x.
Source: Authors' estimations based on Németh et al. (2021), Statistics Denmark (2022) and the Human Mortality Database (Human Mortality Database, 2024).

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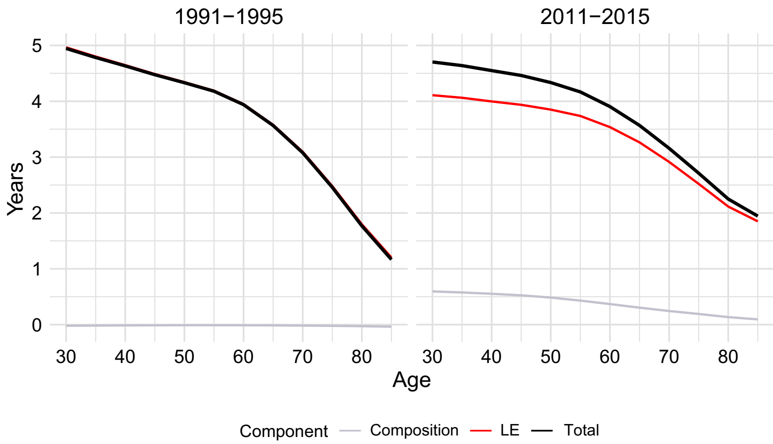
Figure 3 Sex gap in life expectancy under current educational composition by age in Denmark, 1991–1995 and 2011–2015: total gap and contributions of differences in educational composition and life expectancy by education (LE)



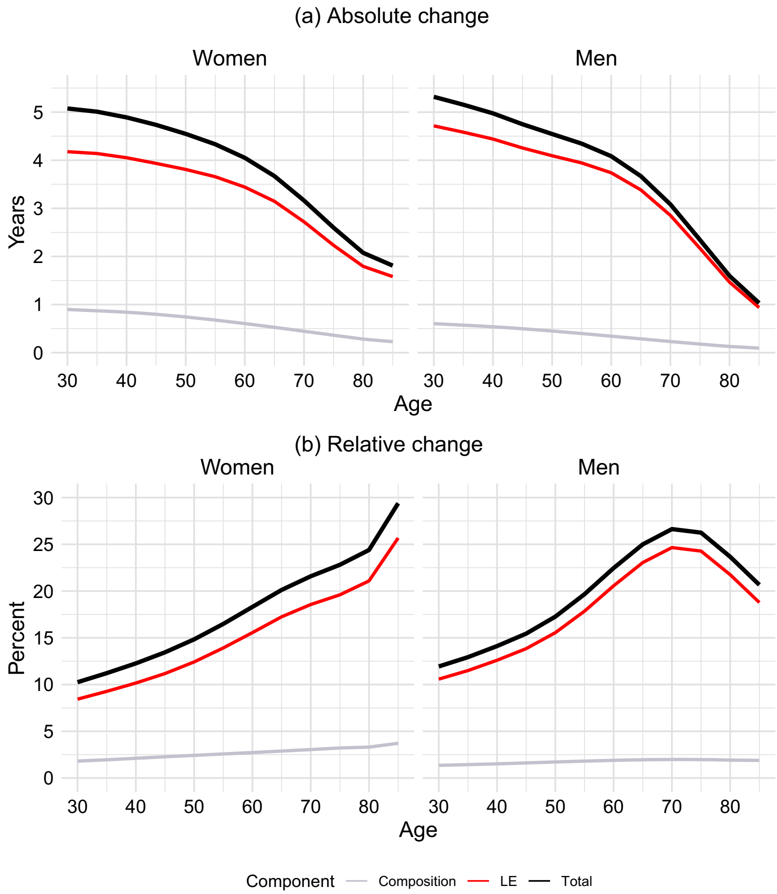
Notes: Life expectancy under current educational composition (LE_{edu}) refers to the average length of life of a cohort with the composition by educational attainment at age 30 in a given period and survival according to education-specific life tables;
LE_{edu} at age x is conditional on survival to age x.
Source: Authors' estimations based on Nàmeth et al. (2021), Statistics Denmark (2022) and the Human Mortality Database (Human Mortality Database, 2024).

educational composition of cohorts and the educational expansion across cohorts have been particularly favourable for women.

The advantage of women over men in LE_{edu} was greater in 1991–1995 than in 2011–2015 for all age groups (Figure 3). In 1991–1995, this advantage was entirely due to women's higher LE across all educational groups. The contribution of this element to the sex gap decreased between the two periods. The composition component played a greater role in women's overall survival, compared to in men's survival, in 2011–2015 than in 1991–1995.

Contrary to our expectations, the increase in LE_{edu} at age 30 between 1991–1995 and 2011–2015 was of a similar magnitude for men (5.3 years) and for women (5.1 years). It resulted from both an increase in the LE of educational groups (an increase of 4.7 years for men and 4.2 years for women) and a change in educational composition (an increase of 0.6 and 0.9 years for men and women, respectively, as shown in Figure 4(a) – numbers not shown in tables). For the older age groups, the increase in LE_{edu} between 1991–1995 and 2011–2015 was greater for women than for men (1.8 years for women and one year for men). The magnitude of the increase in LE_{edu} relative to the LE value in 1991–1995 grows with age for women, while for men, a decrease is observed for the oldest cohorts (above age 70) (Figure 4(b)). Overall, for both sexes and all of the cohorts, the increase in LE_{edu} between 1991–1995 and 2011–2015 was predominantly due to an increase in the LE of educational groups over this period. The contribution of the change in educational composition to the change in LE_{edu} was small.

Figure 4 Change in life expectancy under current educational composition by age and sex in Denmark, 1991–1995 to 2011–2015: total change and contributions of changes in educational composition and life expectancy by education (LE)



Notes: Life expectancy under current educational composition (LE_{edu}) refers to the average length of life of a cohort with the composition by educational attainment of those aged 30 in a given period and survival according to education-specific life tables;
LE_{edu} at age x is conditional on survival to age x.
Relative change is estimated as a percentage of the sex- and age-specific LE_{edu} in 1991–1995.
Source: Authors' estimations based on Nàmeth et al. (2021), Statistics Denmark (2022) and Human Mortality Database (Human Mortality Database, 2024).

The difference between the average lifespan deprivation and the average lifespan deprivation under current educational composition at age 30 ($e^{\dagger}_{edu}$) is negligible (Table 1). Over the study period, a decrease of about 10% in $e^{\dagger}_{edu}$ could be observed for both sexes. This decrease was mainly due to a decrease in the average lifespan deprivation of educational groups, but also to a change in the educational composition. In both study periods, men were

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Table 1 Average lifespan deprivation at age 30 ($e^{\dagger}$) and under current educational composition ($e^{\dagger}_{\text{edu}}$) by sex in Denmark in 1991–1995 and 2011–2015. Sex gap in $e^{\dagger}_{\text{edu}}$, change in $e^{\dagger}_{\text{edu}}$ between 1991–1995 and 2011–2015, and their two components*

	Women			Men			Sex gap in $e^{\dagger}_{\text{edu}}$		
Period	$e^{\dagger}$	$e^{\dagger}_{\text{edu}}$	$e^{\dagger}_{\text{edu}}$-$e^{\dagger}$	$e^{\dagger}$	$e^{\dagger}_{\text{edu}}$	$e^{\dagger}_{\text{edu}}$-$e^{\dagger}$	**Total**	**Composition**	$e^{\dagger}_{\text{edu}}$
1991–1995	8.9	8.8	−0.1	9.2	9.2	0.0	−0.3	0.0	−0.4
2011–2015	8.0	7.9	−0.1	8.5	8.4	−0.1	−0.5	−0.2	−0.3
Change between 1991–1995 and 2011–2015									
Total	−0.9	−0.9	0.0	−0.6	−0.8	−0.2	−0.1	−0.2	0.1
Composition	–	−0.3	–	–	−0.2	–	–	–	–
$e^{\dagger}_{\text{edu}}$	–	−0.6	–	–	−0.6	–	–	–	–

Notes: Average lifespan deprivation under current educational composition ($e^{\dagger}_{\text{edu}}$) at age 30 refers to the average lifespan deprivation of a cohort with the composition by educational attainment of those aged 30 in a given period and survival according to education-specific life tables. $e^{\dagger}_{\text{edu}}$ at age 30 is conditional on survival to age 30.
*Contribution of differences in composition (Composition) and differences in average lifespan deprivation of educational groups ($e^{\dagger}_{\text{edu}}$) to the sex gap in $e^{\dagger}_{\text{edu}}$. Contribution of change in the two components to the total change in $e^{\dagger}_{\text{edu}}$ between 1991–1995 and 2011–2015 by sex.
Source: Authors' estimations based on Nàmeth et al. (2021), Statistics Denmark (2022) and Human Mortality Database (Human Mortality Database, 2024).

characterised by a higher $e^{\dagger}_{\text{edu}}$ than women. In the first study period, 1991–1995, the sex gap resulted from a higher deprivation among educational groups for men than for women, while compositional differences had no effect on the sex gap. Between the study periods, a small increase in the sex gap in $e^{\dagger}_{\text{edu}}$ could be observed, which resulted from an increase in the negative contribution of the differences between the sexes in the composition by educational attainment.

Summary and discussion

In this study, we discuss the importance of a lagged composition of the cohorts that make up the synthetic life table cohort for the mortality statistics of the period life table. We propose formulas that allow period life tables to be derived based on the current long-run composition, taking into account observed subgroups whose proportions are fixed at the life table radix age. We also give formulas for decomposing the difference between two values of life expectancy under current risk composition, or two values of average lifespan deprivation, into a gap due to differences in the statistics of the subgroups and in the composition.

For our empirical example, the observed characteristic that we highlight is educational attainment, which, predominantly due to the enormous educational expansion in the 20th century, yielded a very different lagged risk composition to the one implied by current conditions. We report life expectancy under current risk composition by educational attainment by sex for the Danish population in the periods 1991–1995 and 2011–2015. We show that as a result of the large differences between the educational composition of the life table synthetic cohorts and the current educational composition, the gap between standard period life expectancy (LE) and life expectancy under current educational composition (LE_{edu}) at age 30 is about as large as the LE gap between those with high and medium educational attainment. We demonstrate that although most of the change in LE_{edu} between 1991–1995 and 2011–2015 was due to the higher LE of the educational groups, the favourable change in educational composition between the two periods also contributed to the total increase in LE_{edu}. Differences between average lifespan deprivation and average lifespan deprivation under current educational composition at age 30 were negligible.

In contrast to the period life table, in the life tables calculated in the cohort perspective, the changing mortality conditions and other factors affecting the risk composition of a cohort do not cause a lagged bias. The mortality rates used to construct cohort life tables simultaneously reflect changes in individual mortality risk as the cohort ages and compositional changes in observed and unobserved characteristics over the cohort's life course (Guillot, 2011). Another measure that is free from lagged compositional bias due to observed and unobserved characteristics is the cross-sectional average length of life indicator (CAL). CAL is a summary measure of the mortality conditions to which the cohorts that are alive in the study period, and that make up the synthetic cohort of the period life table, were exposed during their lives (Guillot, 2003, 2008). As it summarises the survival conditions of cohorts, CAL also takes into account the changing composition of those cohorts according to observed and unobserved characteristics that reflect the social and mortality conditions experienced by each cohort over its life course. Although CAL takes into account cohorts alive in a given period, it does not summarise the mortality conditions of a given period, which is what we try to approximate in this study.

Another example of estimating total life expectancy by aggregating group-specific values was discussed by Andreev et al. (1989), who aggregated regional life tables to a country life table. In such a case, the regional subpopulations can exchange members through migration. The problem of aggregating life tables in situations where subpopulations exchange members has also been addressed by Feehan and Wrigley-Field (2021) and Shkolnikov et al. (2001). In this study, however, we present an adjustment of selected life table statistics to a current population composition of risk groups that do not exchange members. This means that for each individual in the cohort, subgroup membership is fixed at the radix age. The proposed formulas are thus simpler than the adjustments required in the studies mentioned above.

In this article, we propose a formula for decomposing the gap between two summary mortality statistics under current risk composition by fixed characteristics into two components: one resulting from differences in the risk composition, and the other resulting from differences in mortality of the risk groups. The current risk composition of a life table cohort allows for a much simpler method for decomposing differences between two mortality statistics than the classic demographic decomposition methods for differences between two standard mortality statistics (e.g, Andreev et al. (2002); Torres et al. (2019); Su et al. (2023); Horiuchi et al. (2008)).

As discussed in the methods section, the decomposition of the difference between two life expectancy values (and average lifespan deprivation values) under current risk composition is based on an equation similar to Kitagawa's (1955) classical decomposition of crude death rate differences between two groups. Kitagawa's method breaks down the total rate difference into two parts: one reflecting the differences in group-specific rates, and the other reflecting the differences in group composition. Applying this idea to life expectancy allows for additional insights to be obtained in comparative studies of mortality based on life table statistics under current risk composition. For simplicity, the discussion here will focus on life expectancy under current risk composition (LE_{cc}), but the same logic applies to other life table statistics as well. From the perspective offered in Kitagawa (1955), LE_{cc} can be seen as a composite index that combines the life expectancies of different risk groups by weighting each group's life expectancy with its proportion at the life table radix age. Following Kitagawa's approach, the difference between two LE_{cc} values can be broken down into two effects on the gap: (i) the effect of differences in life expectancy between risk groups; and (ii) the effect of differences in the risk composition of the populations at the radix age.

In Kitagawa (1955), the first of the two elements resulting from the decomposition of a difference between two crude death rates is a difference between two standardised rates. In our case, this translates into the difference between two "standardised" life expectancies. A standardised life expectancy is derived by weighting the life expectancy of each risk group by the standard composition of risk groups at the radix age. When, as in this study, the decomposition is symmetric, an average of the compositions of the two populations under consideration is used. The resulting composite index of standardised life expectancy can provide a new perspective in comparative studies of mortality, as it summarises in a single figure the differences in mortality between risk subgroups in a population, and controls for differences due to different compositions of the populations at the reference age. The values of such an index can be easily compared between populations and their trends can be analysed, with conclusions being drawn only about differences between populations or changes over time in the life expectancy of specific risk groups.

The second component of the decomposition represents the effect of differences in the radix composition of the two populations on the overall gap in LE_{cc}. It can also be interpreted as a composite index reflecting the difference in the risk composition of the two populations at the radix age, quantified in terms of the life expectancy outcome of that gap. In this case, the average life expectancies of the risk groups in the two study populations are the weights used to construct this composite index.

A limitation of this study is that we assume that the problem of lagged frailty composition goes no further than the subgroups explicitly considered. In other words, using our empirical application as the example, we assume that current mortality conditions are adequately reflected within education-specific life tables, and that unaccounted-for structure is unproblematic. This means that we assume that under current mortality conditions, the observed mortality rates of the educational groups and their resulting life table essentially characterise the educational groups of a cohort that would live under current mortality conditions. From previous studies, however, we know that this assumption is invalid because the within-group frailty composition of the educational groups also changes across cohorts (Zajacova et al., 2009; Dowd and Hamoudi, 2014; Hendi, 2017; Zheng, 2020). The effect of the shift in the within-group frailty composition on the survival of the risk groups, and the effect

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of the latter on life expectancy under current risk composition, should be examined in a follow-up study.

In this article, we argue that life table measures under current risk composition (a term we propose) or under current frailty composition (as proposed by Vaupel et al. (1979)) have the potential to be more accurate measures of period mortality conditions than standard life table measures. We demonstrate a reason for using caution when comparing mortality statistics from period life tables across populations: i.e., the risk composition masked by the standard period life table is the result of past, not present, inter-population differences in conditions that affect mortality. Similarly, caution is needed when interpreting trends in mortality improvement or stagnation within countries, as compositional change is powerful enough to drive or offset a trend. The currently available demographic tools and data are capable of accounting for some, but not all, such distortions. In sum, "demographers should be more careful about distinguishing between life expectancy at current death rates and life expectancy under current mortality conditions" Vaupel (2002, p. 373).

Supplementary Material

Available online at https://doi.org/10.1553/p-4pz2-cebp
Supplementary file 1. Additional derivations (S1), Discrete approximations (S2), Additional empirical examples (S3).

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