Mortality Inequality and Its Implications for Retirees

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A thesis submitted for the degree of

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Abstract

This thesis presents four studies on mortality inequality which advance the knowledge of how lifespans differ across social groups and the implications for retirees. The first two studies are based on the concept of distributional differences and propose new methods to study mortality inequality. Specifically, Chapter 2 introduces a statistical distance index to capture the stratification of lifespans among social groups. Empirical evidence from Finland demonstrates its utility and reveals new dimensions of mortality inequalities that traditional measures obscure. Chapter 3 proposes a novel method for investigating the factors that contribute to total lifespan inequality. It finds that in the United States, while racial/ethnic differences in life expectancy contribute little to total-population-level lifespan variance, distributional differences across race/ethnicity explain one fifth of the total lifespan variance. The next two studies explore the implications of mortality inequalities for retirees. Chapter 4 models dynamic work trajectories of older US adults and presents major results of gender and educational inequalities in the United States. It shows that less-educated older adults spent less time working, which compensates for their lower longevity when compared to their more-educated counterparts. Nonetheless, educational inequality in retirement lifespan is substantial and persistent. Chapter 5 looks at how education and preretirement earnings relate to lifetime pensions from age 60 onward, as well as how mortality affects the distribution of lifetime pensions in Sweden. The results show that the greater longevity of socially advantaged groups accounts for up to one quarter of lifetime pension inequality. Chapters 4 and 5 both highlight the importance of social differences in mortality and advocate for greater emphasis on the role of mortality in high-level discussions on old-age policies.

Contents

List of Figures

List of Tables

1 Introduction

Our world is witnessing two major demographic trends: mortality decline and population aging. The former relates to the rise in longevity and constitutes one of the most significant population changes of the twentieth century. The world average life expectancy at birth increased from 32.0 years in 1900 to 72.8 years in 2019 (Roser et al., 2013), marking a tremendous improvement in human welfare. The latter trend, population aging—characterized by an increasing share of older adults in populations, is partly a result of mortality decline. Currently, a number of high-income countries have more than 20% of their populations aged 65 and older. Yet, population aging is not limited to high-income countries—low- and middle-income countries are experiencing the fastest rates of population aging (United Nations, 2019).

Situated in the context of these two demographic trends, the primary theme of this doctoral thesis is an examination of inequality in the processes of mortality decline and population aging. To achieve this, the thesis poses several guiding questions: Against the backdrop of increasing life expectancy, how are lifespans distributed unequally? What insights can we gain regarding mortality inequality from alternative measures? For older adults, how does mortality inequality shape their lifetime in retirement? What are the implications of lifespan inequality for aging policies, especially pension policies? To address these questions, the four studies included in this thesis utilize vital statistics, longitudinal surveys, and linked register data from Finland, Sweden, and the United States. Besides applications of advanced demographic and statistical methods, such as the multistate life table and decomposition techniques, I propose new methods for assessing mortality inequality. The results of this thesis will help us more accurately and comprehensively understand patterns of mortality inequality. The examination of mortality inequality related to retirees will inform policymakers about how to design equitable pension and healthcare systems. This introduction serves as a background and provides an overview of the thesis.

1.1 Life Expectancy, Lifespan Inequality, and the Importance of New Measures

Life expectancy at birth is a widely used measure of the average age at death of a cohort of newborns. It had been increasing globally for decades until the year 2020. Despite this overall trend, life expectancy varies both across and within nations. Within nations, gender, socioeconomic status, race, and place of residence, as among the most studied contributors to inequalities in life expectancy (Chetty et al., 2016). Understanding how and why lifespans differ across individuals and social groups is of paramount importance to public health. For one thing, reducing mortality inequality is a key component for future advancements in human longevity as a whole. For another, studying lifespan inequality can indicate how resources are unequally distributed. It is a desirable policy goal to ensure that everyone has an equal opportunity to live a healthy and long life. Hence, an accurate and comprehensive picture of mortality inequality can help policymakers to better allocate resources to address the root causes of such disparities.

There are two types of lifespan inequality that are interrelated but distinct. The first type, known as *population-level* lifespan inequality, refers to the variation in lifespan across all members of a population. Essentially, it relates to the dispersion of a lifespan distribution and can be quantified using measures such as the interquartile range, variance, and Gini coefficient. The second type of lifespan inequality is *group-level* inequality, which examines how group memberships stratify lifespans. For example, how many years do individuals with a college degree on average outlive those without a college degree? This group-level inequality is an inherent component of total population-level inequality. Understanding both population-level and group-level lifespan inequality is critical to identifying and addressing disparities in longevity and promoting equitable access to healthcare.

In demography, an important literature is dedicated to developing new measures and methods for analyzing population data. Especially, recent developments in alternative measures of mortality have outlined a promising landscape of mortality research. An important feature of this thesis is its methodological innovations in measuring inequality. In particular, I argue that conventional measures such as life expectancy are insufficient when it comes to detecting lifespan inequality. Measures and methods that take into consideration the full range of lifespan distributions can help improve our knowledge of both population- and group-level inequalities. Such distributional approaches relate mortality inequality to sociological concepts, provide novel empirical evidence, and open up exciting new directions.

1.2 Inequality among Older Adults: Mortality, Retirement, and Pension

While reductions in mortality among infants, children, and young adults contributed the most to life expectancy gains in the first half of the twentieth century, declines in old-age mortality have been the major driver for the more recent improvement in life expectancy (Cutler and Meara, 2001). Hence, a closer look at old-age mortality as well as the inequality in it is of great importance for understanding the future development in human longevity. Moreover, population aging means that older adults are an increasingly important part of populations around the world. Given this, it has become ever more important, especially from a policymaking perspective, to study inequality later in life.

The second half of this thesis, therefore, zooms into the older population. However, instead of solely examining mortality inequality, I seek to understand the impact of differences in age at death across older adults on the equity in retirement lifespan and pension accumulation. In contemporary welfare states, policymakers have long been aware that understanding the development of mortality is crucial when designing sustainable pension and healthcare systems. The inequality in mortality, however, has received little attention in high-level debates on pension reforms. Meanwhile, there is a lack of empirical research on how mortality inequality is related to older people's social and economic life. Newly available longitudinal aging surveys and administrative records offer an excellent opportunity for rigorous research on old-age inequalities. The second part of this thesis is dedicated to filling this gap by presenting novel evidence from the United States and Sweden, and it demonstrates that not only mortality, but also mortality disparities, is important for old-age policies.

1.3 Overview of the Studies

Overall, this thesis aims to contribute to the literature on inequality in aging and mortality through its methodological innovations as well as novel empirical findings. Broadly speaking, the thesis addresses two questions. First, what insights can we gain about mortality inequality through innovations in measures and methods? Second, what is the impact of mortality inequality on older adults with regard to equity in the length of retirement life and lifetime accumulated pensions?

Specifically, the first two studies answer the first research question. Traditionally, mortality differences are measured by comparing life expectancy or mortality rates. Little is known about how distinct overall lifespan distributions are. Chapter 2 proposes a simple way of quantifying distributional differences in lifespan which also captures the sociological concept of stratification. Chapter 3 presents how the idea of distributional difference can be used to better understand sources of population-level lifespan inequality. The next two studies address the second question. They focus on the old-age population and explore how mortality inequalities are related to inequalities in retirement life. For older adults, mortality determines how much time they spend in retirement and are eligible for receiving pensions. Chapter 4 examines inequalities in retirement lifespan by education and gender in the context of the United States where returning to work after initial retirement is common. Chapter 5 focuses its attention on Sweden, a country with relatively lower mortality and generous social welfare. It examines how much of the inequality in lifetime pensions by socioeconomic status (SES) is due to the fact that high-SES individuals live longer.

2
A Distributional Approach to Measuring Lifespan Stratification

2.1 Introduction

Mortality reduction and longevity extension are progressing unequally at the global, regional, national, and subnational levels. In 2018, life expectancy at birth was 63 years among low-income countries, 18 years lower than in high-income countries (World Bank, 2021). Numerous studies have documented that even within high-income countries, differences in life expectancy between socio-economic groups can be strikingly large. In the United States (US), for instance, men in the top 1 per cent of the income distribution lived 14.6 years longer on average than those in the bottom 1 per cent during the period 2001–14 (Chetty et al., 2016). Large gaps in life expectancy between socio-economic groups have been reported in many

This chapter is co-authored with José Manuel Aburto, Lasse Tarkiainen, Pekka Martikainen, and Alyson van Raalte. Materials from this chapter has been published as Shi, J., J. M. Aburto, P. Martikainen, L. Tarkiainen, and A. van Raalte. (2023). "A Distributional Approach to Measuring Lifespan Stratification." *Population Studies*, 77:1, 15-33.

other countries and at different times (e.g. Brønnum-Hansen and Baadsgaard, 2012; Mackenbach et al., 2018; Martikainen et al., 2014).

The reduction of mortality inequalities arguably constitutes one of the major public health challenges and is important for further advances in human longevity as a whole. To date, a large segment of the literature examining between-group differences in longevity has focused on the comparison of group averages, such as age-standardized mortality rates and life expectancies. While life expectancy is undoubtedly a powerful mortality indicator, other important facets of between-group differences in longevity can be hidden if life expectancy alone is studied.

To better the understanding of between-group differences in longevity, we introduce and quantify a new concept: lifespan stratification. Measuring lifespan stratification belongs to an approach that has been taken less frequently—comparing the distance and non-overlap between lifespan distributions—and which is conceptually different from conventional approaches of comparing central tendencies (e.g. life expectancy) or variabilities. We show that the non-overlap index we use operationalizes the long-standing sociological concept of social stratification and reveals the extent to which society is divided into unique social strata when individual longevity is the outcome variable. Our empirical example of lifespan stratification between Finnish income groups illustrates that this new measure reveals new inequality patterns. Hence, our measure is a useful addition to the demographer's toolbox of analysis on mortality differences.

2.2 Conventional Approaches to Measuring Mortality Differences

Measurement of differences in lifespan distributions between population subgroups has generally been approached in one of the following ways: (1) by comparing measures of central tendency (e.g. mean, median, mode); (2) by comparing the spread or prematureness of mortality (e.g. variability, years of life lost [YLL]);

or (3) by comparing overall distributions using statistical distance measures (e.g. Kullback–Leibler divergence [KLD]). Here we review the first two approaches, before focusing on statistical distance measures in the next section.

2.2.1 Comparing Central Tendencies

Earlier work on social differences in mortality has tended to compare age-standardized mortality rates between social groups using rate ratios (Duleep, 1989; Kitagawa and Hauser, 1973; Logan, 1954; Whitney, 1934). Rate ratios show the relative difference between groups, while rate differences show the actual size of the inequality. Life expectancy has also long been used by prior studies to examine group differences in mortality (Antonovsky, 1967; Brønnum-Hansen and Baadsgaard, 2012; Chetty et al., 2016). It is the mean value of the lifespan distribution from the life table, and a comparison of life expectancies can be used to indicate the average number of years by which a group of individuals outlives another group. Other measures of central tendency, such as the modal and median age at death, have long been included in mortality analysis and have enriched demographers' understanding of the evolution of human longevity (Canudas-Romo, 2008, 2010; Cheung and Robine, 2007; Cohen and Oppenheim, 2012; Horiuchi et al., 2013; Kannisto, 2001; Lexis, 1879; Ouellette and Bourbeau, 2011). Recent research on mortality differences between population subgroups has started to incorporate these additional central tendency measures beyond the traditional comparisons of life expectancy (Brønnum-Hansen and Baadsgaard, 2012; Diaconu et al., 2022; Zarulli et al., 2012).

Like mortality rates, central tendency measures can also be compared using ratios or differences. In practice, life expectancy ratios are less frequently reported than life-expectancy differences. Absolute and relative measures yield the same patterns of inequalities when population subgroups are examined at a given time, when the aim is to understand whether group A is performing better than group B. However, absolute and relative measures may contradict each other when the goal is to examine how the magnitude of mortality difference between A and B varies across time or place: for example, when seeing whether the sex difference in life expectancy is larger in one country than in another. Adding a dimension of time or place to social differences in mortality complicates the comparison of central tendency measures. For illustration, we compare life expectancies at birth for men in three countries. In 2018, life expectancies for men in Nigeria, Pakistan, and Hong Kong were 53, 66, and 82 years, respectively (World Bank, 2021). Consider two comparisons: (1) difference in life expectancy between Nigeria and Pakistan; and (2) difference in life expectancy between Pakistan and Hong Kong. The mean difference between Pakistan and Nigeria was 13 years and between Hong Kong and Pakistan was 16 years, suggesting that mortality difference was larger between Hong Kong and Pakistan than between Pakistan and Nigeria. However, life expectancy for men in Pakistan was 1.25 times that of Nigeria, while life expectancy for men in Hong Kong was 1.24 times that of Pakistan, suggesting that mortality difference was more similar between Hong Kong and Pakistan than between Pakistan and Nigeria. Therefore, monitoring life expectancy inequalities using differences and ratios can yield inconsistent results. Similarly, slope and relative indices of inequality when examined on mortality rates often lead to different conclusions about the direction of changes in inequalities (e.g. Mackenbach et al., 2018).

In summary, assessing whether the longevity gap has been growing or diminishing and whether policies have been successfully narrowing the gap can depend on whether absolute or relative measures are used (Carter-Pokras and Baquet, 2002; Harper and Lynch, 2017). The potential inconsistency in the two types of measures is perhaps a limitation of this approach.

2.2.2 Comparing Variabilities

A recent strand of research has shifted the attention from group differences in means to group differences in variabilities (Brønnum-Hansen and Baadsgaard, 2012;

Edwards and Tuljapurkar, 2005; Permanyer et al., 2018; van Raalte et al., 2018). Lifespan variability measures the within-group heterogeneity in ages at death. It also captures the degree of lifetime uncertainty that a random individual from that group faces. For individuals, lower uncertainty conditional on the same expected lifespan means greater security, which, as economists have argued, people would rather gain at the expense of losing a few years of expected life (Edwards, 2013). A wide range of variability measures are available, due to the well-researched area of income inequality. Lifespan variability measures include the interquartile range, Gini coefficient, coefficient of variation, and standard deviation. In demography, metrics such as the life table entropy (H) and life disparity ($e^{\dagger}$) have been introduced due to their useful interpretations (Goldman and Lord, 1986; Keyfitz, 1977; Leser, 1955; Vaupel, 1986; Vaupel and Romo, 2003).

The theory of mortality compression predicts that as mortality reduction continues, lifespans tend to be concentrated around the mean age at death and thus the survival curve evolves towards a more rectangular shape (Fries, 1980; Myers and Manton, 1984). Indeed, research has shown that rising life expectancy was historically often coupled with falling lifespan variability (Smits and Monden, 2009; Vaupel et al., 2011). Cross-sectional data have shown that lower socio-economic groups tend to exhibit larger lifespan variability in addition to lower life expectancy (Brown et al., 2012; Edwards and Tuljapurkar, 2005; van Raalte et al., 2011). These findings point to the so-called 'double burden' (van Raalte et al., 2018) among people of lower socio-economic status (SES); that is, compared with high-SES individuals, low-SES individuals not only live shorter lives on average but also face greater uncertainty about the timing of death.

The theoretical prediction and the empirical associations between life expectancy and lifespan variability seem to challenge the motivation for including lifespan variability in research on between-group differences in mortality. However, recent evidence has suggested that for some populations or population subgroups (e.g. lower-SES individuals), increasing life expectancy has been associated with stagnating or increasing lifespan variability (Aburto and van Raalte, 2018; Brønnum-Hansen, 2017; Permanyer et al., 2018; van Raalte et al., 2018). Hence, comparing lifespan variability between social groups is helpful for detecting additional dimensions of inequalities.

2.3 Comparing Distributions

Unlike the approaches of comparing central tendency measures and lifespan variabilities, our approach takes into account differences in the whole range of lifespan distributions (i.e. by measuring statistical distance).

2.3.1 Statistical Distance

How big is the difference between two lifespan distributions? This question relates to the concept of *statistical distance*. Measures of statistical distance can quantify the distance between two populations or two probability distributions, and they capture how much 'effort' is needed to transform one lifespan distribution into another. Statistical distance measures have been widely used in many disciplines, including biology, chemistry, information theory, mathematics, mechanical engineering, and statistics (Cha, 2007).

All distance metrics need to fulfil four conditions (Deza and Deza, 2009). Consider a distance metric $D(A, B)$ where A and B are two distributions. The four conditions are expressed as follows:

1. $D(A, B) \geq 0$ (non-negativity);
2. $D(A, B) = 0$, if and only if A and B are identical (identity of indiscernibility);
3. $D(A, B) = D(B, A)$ (symmetry);
4. $D(A, B) + D(B, C) \geq D(A, C)$ (triangle inequality).

A related concept to statistical distance is *divergence*, based on the idea of entropy that originated in information theory (Shannon, 1948). Unlike distance metrics, divergence need satisfy only conditions (1) and (2), although the term divergence is sometimes used interchangeably with statistical distance (Ullah, 1996). A well-known divergence measure is the KLD (Kullback and Leibler, 1951).

The distributional approach using measures of distance and divergence offers new research opportunities for the analysis of mortality differences, beyond summary measures such as mean, mode, and variance. Numerous distance and divergence measures (see an overview in Cha [2007]) can be used to answer the question of how big the difference between two lifespan distributions is. Thus far, only a few studies have taken this distributional approach. Sasson (2016) used the KLD to examine the divergence in age-at-death distributions between educational groups. (Note that throughout this chapter, 'age-at-death distribution' refers to the life table dx, rather than the observed deaths, Dx.) Edwards and Tuljapurkar (2005) and d'Albis et al. (2014) also used the KLD to compare country-specific lifespan distributions. As a divergence measure, the KLD does not satisfy the symmetry and triangle inequality conditions.

2.3.2 Conceptualizing Stratification

Different distance and divergence measures have unique properties that provide different information. We use a distance metric to quantify the concept of *stratification* of lifespan. In sociology, stratification is defined as the phenomenon of society being divided into *hierarchically layered strata*, characterized by historical, cultural, and economic distinctions (Mann, 2009). Social class, education, and income are among the most common social stratifiers of a society (Harper and Lynch, 2014). The use of terminology in the existing literature is wide-ranging. The stratifier is often inserted before the term 'stratification', for example gender in 'gender stratification'. It is also common use to insert the outcome before 'stratification'; for instance, 'income stratification' has been used in prior research where income is the outcome (e.g. Allanson, 2014; Yitzhaki and Lerman, 1991; Zhou and Wodtke, 2019). In our study, lifespan is the outcome and income is the stratifier. We use the terms 'lifespan stratification' and 'the stratification of lifespan' interchangeably.

In a broad sense, stratification is often a synonym of *inequality*, yet Yitzhaki and Lerman (1991) argued that stratification is conceptually different from inequality, the latter often being measured by the distance between group means. Social stratification emphasizes the formation of *observable layers* based on group characteristics (Lasswell, 1965). Put differently, stratification reflects the extent to which social groups form *unique* strata but does not show how big the differences in group means are. According to this rationale, life-expectancy difference between social groups is a good measure of inequality but is not suitable for measuring stratification. When we discuss stratification, it is strictly this narrower phenomenon of distributional distance that we are referring to. The emphasis of stratification on distinguishable strata and noticeable boundaries coincides partly with the concept of statistical distance. Both stratification and statistical distance relate to the phenomenon of two distributions being distinct.

Prior research using the narrow definition of stratification has focused almost exclusively on outcomes such as income and wealth, and little is known about the stratification of lifespan. Admittedly, unlike income, lifespan cannot be redistributed across individuals. But unequal lifespans arise partly from unequal distributions of both monetary and non-monetary resources (Link and Phelan, 1995; Lynch et al., 2000; Marmot, 2005; Phelan et al., 2010). Examining the stratification of lifespan can therefore inform us how health-related resources are stratified between social groups and can shed new light on research into mortality differences.

2.3.3 Conceptualizing Stratification

Consistent with prior research on the stratification of income (Zhou and Wodtke, 2019), we propose to quantify the stratification of lifespan by the proportion of non-overlap of two lifespan distributions. This measure relates to the Jaccard index, originally used by ecologists to measure similarity in flora between districts (Jaccard, 1912), and the Tanimoto index (Tanimoto, 1958), a measure widely used in chemical research to quantify molecular similarity. The Jaccard and Tanimoto similarity metrics are mathematically equivalent. They are calculated as the ratio of the intersection to the union, that is, $(A \cap B)/(A \cup B)$ (i.e. overlap/total). The Jaccard (Tanimoto) distance is calculated as $1 - Jaccard(Tanimoto)$ similarity. For probability distributions, the Jaccard (Tanimoto) distance is also equivalent to the Wave Hedges index (Cha, 2007). (We agree with Prasath et al. [2017] that the name 'Wave Hedges' is questionable, as the formula for the Wave Hedges index cannot be traced to the original paper by Hedges [1976] as cited in Cha [2007]). Due to the inconsistent naming of this measure, we refer to it as the *non-overlap index*, with notation S_{ij}, for the stratification of lifespan between (sub)populations i and j. Note that here i and j can be two subpopulations or any two populations where the comparison is substantively meaningful (e.g. United States vs Japan). S_{ij} is calculated as follows:

$$S_{ij} = 1 - \frac{\int_{\alpha}^{\omega} \min\{d_i(x), d_j(x)\}}{\int_{\alpha}^{\omega} \max\{d_i(x), d_j(x)\}} \tag{2.1}$$

where α is the starting age, ω is the maximum lifespan, and $d_i(x)$ and $d_j(x)$ are life table age-at-death distributions for (sub)populations i and j, respectively.

S_{ij} reaches the maximum of one when two age-at-death distributions do not overlap (maximum stratification) and the minimum of zero when two distributions are identical (no stratification). Stratification increases monotonically as S_{ij} increases from zero to one. It can easily be proved that this index satisfies the four aforementioned conditions of a distance metric (Kosub, 2019). This is an advantage as compared with the asymmetric measure KLD used in earlier research (e.g. Sasson, 2016); it is arbitrary whether the KLD between groups A and B is measured from A to B or from B to A. The non-overlap index is not just a distance measure but also captures the sociological concept of stratification, which makes it easier to interpret than other distance measures.

Furthermore, a larger proportion of non-overlapping lifespans means a greater likelihood that a random individual in the group with lower life expectancy will die earlier than another random individual from the group with higher life expectancy. This concept is closely related to the outsurvival probability (Bergeron-Boucher et al., 2022; Vaupel et al., 2021). Stratification and the outsurvival probability both rely on the topological relationship between two lifespan distributions. Yet unlike the outsurvival probability, which focuses interpretations at the *individual* level, stratification reflects the unequal distributions of lifespans at the *societal* level.

Although the non-overlap index always captures the extent to which two distributions *differ* from each other, it is not designed as a measure of the tendency for values from one distribution to be *higher* (or *lower*) than those from the other. Thus, the non-overlap index is not suitable for measuring lifespan stratification, unless x and $\frac{d_i(x)-d_j(x)}{d_i(x)+d_j(x)}$ are strongly correlated. This way, lifespan distributions can be seen as hierarchically layered. Panel (a) in Figure 2.1 shows an example where two distributions do not fulfil this condition. However, for human populations, x and $\frac{d_i(x)-d_j(x)}{d_i(x)+d_j(x)}$ tend to be strongly correlated, because human populations follow similar patterns of lifespan distribution and because the central tendency and the dispersion of a lifespan distribution are generally negatively correlated, both cross-sectionally and over time. It is worth mentioning that the same value of the non-overlap index may result from scenarios where the skewness and location (age) of the distributions differ. In Figure 2.1, panels (b) and (c) show the same proportions of non-overlap as each other (around 2/3), but panel (b) displays a situation where the two distributions occupy a wider range of lifespans. In panel (b) no individuals from the shorter-lived group survive to ages above 85, where a big part of the non-overlap from the longer-lived group lies. Consequently, compared with panel (c), the two distributions in panel (b) arguably occupy more unique

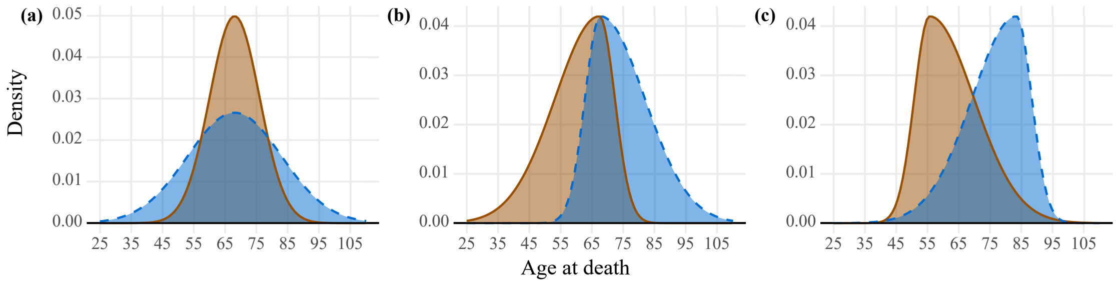

Figure 2.1: Special cases where the non-overlap index cannot perform well. *Source*: Authors' own.

strata and thus their stratification is higher. In such a case, the non-overlap index would not be an appropriate metric of lifespan stratification. Again, these cases are unlikely to be observed in human populations.

To illustrate the conceptual differences and the possible links between stratification and the two conventional approaches, we show four hypothetical scenarios of the stratification of lifespan in Figure 2.2(a)–(d). In panels (a) and (b), the life expectancies of the two social groups are 70 (left) and 75 (right); thus, the life-expectancy difference between the two groups is five years. As the two groups in Figure 2.2(a) exhibit low standard deviations and the two groups in Figure 2.2(b) show high standard deviations, the stratification levels in the two panels are different, with moderate stratification for panel (a), and low stratification for panel (b). In Figure 2.2(c) and (d), there is a 10-year difference in life expectancy between the two groups. Panel (c) displays a higher level of lifespan stratification than panel (d) due to its low standard deviations in both groups. If we examine these panels vertically—comparing Figure 2.2(a) with (c) or Figure 2.2(b) with (d)—the standard deviations of the two groups are the same, but as life-expectancy differences increase, stratification also increases. Therefore, stratification can be affected by differences in both life expectancy and standard deviation.

Our stylized examples suggest that the relationships between stratification and the other two types of measure of between-group differences are unclear. The three indicators may respond differently to mortality changes at different locations

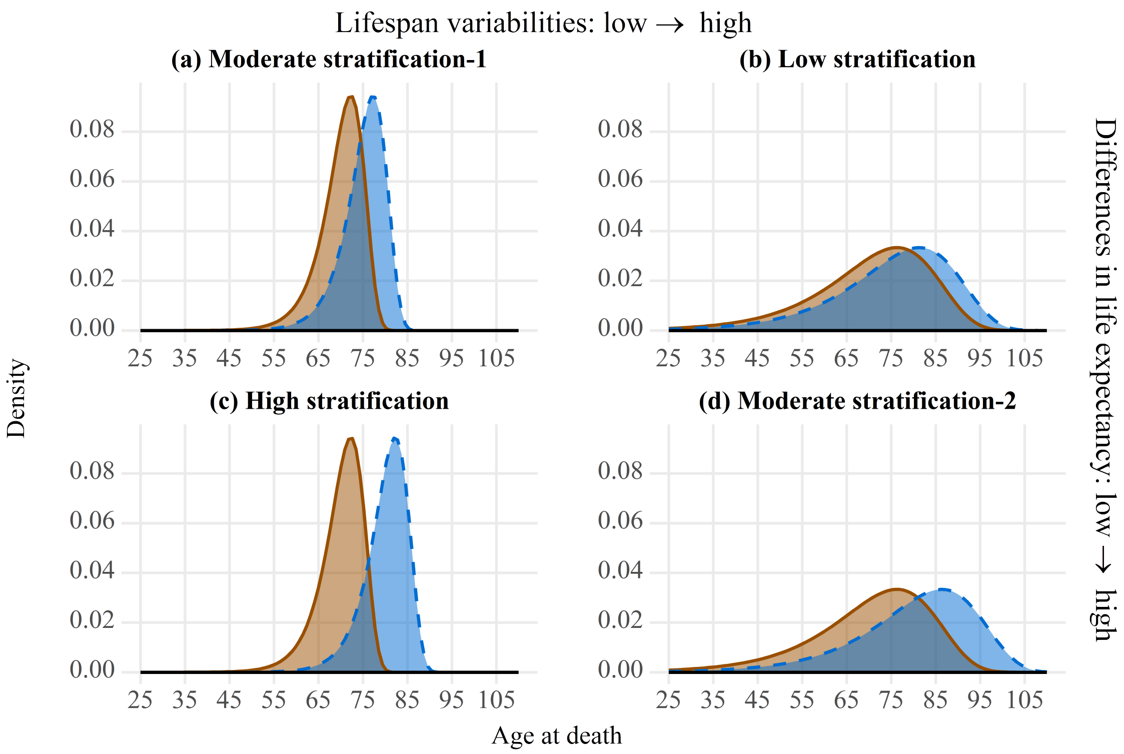

Figure 2.2: Hypothetical scenarios of age-at-death distributions in two groups. *Source*: Authors' own.

(ages) in the distributions; thus, over time, they may produce different or even conflicting trends, as has been observed for the stratification of other types of social goods (Zhou and Wodtke, 2019). For instance, in the high-stratification scenario depicted in Figure 2.2(c), individuals in the lower-mortality group all survive to middle age, whereas no one from the higher-mortality group survives to old age. If the oldest people in the lower-mortality group were to live longer, or if those individuals in the higher-mortality group who die at young ages were to die at an even younger age, differences in life expectancy would increase, while stratification would remain invariant.

Unlike the two conventional approaches that comprise both absolute and relative measures, the non-overlap index for the stratification of lifespan is a relative measure and does not have an absolute counterpart. As a non-parametric index, the value of S_{ij} is not dependent on actual lifespan values but on the relative location of the two distributions. A monotonic transformation of the lifespans of all individuals (by adding/subtracting some years or including a scaling factor) will not change the value of S_{ij}.

2.3.4 Multigroup Stratification

Calculation of the stratification index becomes less straightforward if we are interested in comparing multiple groups. Constructing a stratification index for multiple groups involves several considerations. First, we need to decide whether interest lies in *overall* stratification or in stratification with regard to a reference group. We propose to measure overall stratification, S_{Total}, by a weighted sum of all pairwise comparisons:

$$S_{Total} = \frac{\Sigma_{1 \leq i < j \leq N}^{N} w_i w_j S_{ij}}{\Sigma_{1 \leq i < j \leq N}^{N} w_i w_j} \tag{2.2}$$

where N denotes the total number of (sub)populations, and w_i and w_j are the sizes of (sub)populations i and j, respectively (when $i = j$, $S_{ij} = 0$). It is essential to include all pairwise comparisons, as the two-group stratification is not transitive, that is, one combination of S_{AB} and S_{AC} can lead to different values of S_{BC}. See Figure A.1 in Appendix A.2 for an example.

An alternative is to calculate stratification with regard to a reference group (e.g. the highest SES group or the best-performing group). We propose to measure the reference-based stratification as a weighted sum of all comparisons in which one group is always the reference group, R:

$$S_R = \frac{\Sigma_{1 \leq i \leq N}^{N} w_R w_j S_{Rj}}{\Sigma_{1 \leq i \leq N}^{N} w_R w_i} \tag{2.3}$$

where S_R denotes the multigroup stratification with a reference group R, and w_R and w_i are the sizes of (sub)populations R and i, respectively (when $i = R$, $S_{Ri} = 0$). The selection of a reference group may involve normative judgments (Harper et al., 2010) and has implications for interpretation. Choosing the best-performing group as the reference group quantifies the extent of mortality inequality that could be eradicated if lifespans of those in the disadvantaged groups could be extended to those enjoyed by the lowest mortality group. Alternatively, we could use the population average as the reference group. This would imply that reducing the lifespan of the longer lived is one way to achieve low stratification. However, this is unlikely to be acceptable, even to egalitarians, and does not recognize that lifespans are not directly transferable.

Lastly, the choice of weights also has consequences for interpretation. Weights based on population size may be considered to reflect the public health relevance of lifespan differences. However, if a socially disadvantaged group comprises a small number of individuals, should we care less about them? We might argue that each group is equally important (Harper and Lynch, 2017). Such justification may lead to giving all groups being compared equal weights.

2.4 An Empirical Example of Lifespan Stratification Between Income Groups in Finland

In this section, we present an empirical example of the stratification of lifespan between Finnish income groups. Finland is used because it benefits from an exceptionally long time series of full population data by income percentile and shows mortality inequalities comparable with countries and regions such as the US and western Europe (Elo et al., 2006; Mackenbach et al., 2005; Mortensen et al., 2016). The results are based on period life tables by sex, year, and income quintile (measured in the year prior to exposure). Only individuals aged 25 and above are included, meaning that all reported measures in the example are conditional on surviving to age 25. From these life tables we calculated the remaining life expectancy (hereafter life expectancy), remaining lifespan variation (hereafter lifespan variation), and stratification indices. See an overview of the data set in the Appendix A.1.

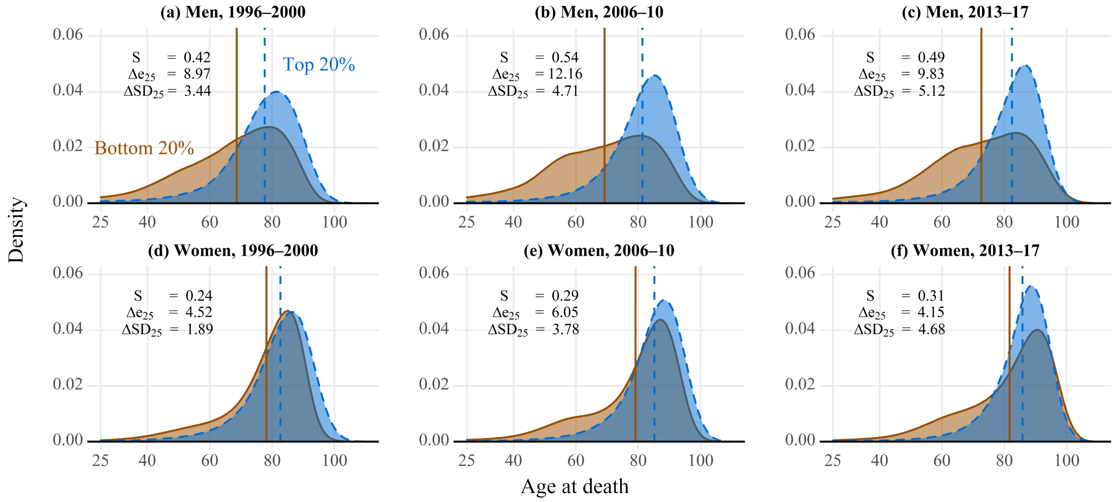

Figure 2.3: Lifespan distributions for highest and lowest income quintiles by sex: Finland, 1996–2000, 2006–10, and 2013–17. *Notes*: Dashed lines show the values of mean age at death. S refers to lifespan stratification; Δe_{25} refers to the difference in life expectancy at age 25; ΔSD_{25} refers to the difference in the standard deviations. *Source*: Authors' calculation based on Finnish register data.

2.4.1 Lifespan Distributions

We first investigate how the age-at-death distributions have evolved differently for those in the lowest and highest income quintiles (20 per cent income groupings). Figure 2.3 shows the distributions for three periods: 1996–2000, 2006–10, and 2013–17. The vertical lines mark the mean ages at death for the two distributions in each panel. From 1996–2000 to 2013–17, there was a general pattern of mortality moving toward older ages for both women and men regardless of income group, which resulted in increases in life expectancy. However, mortality evolved differently in the lowest and highest income groups at certain ages. For men in the lowest income group, there were early 'humps' in the age-at-death distributions across ages 55–70 for 2006–10 and 2013–17. Accordingly, life-expectancy differences between low- and high-income men rose from 9.0 years in 1996–2000 to 12.2 years in 2006–10 and then dropped to 9.8 years in 2013–17. Similarly, stratification increased from 0.42 in 1996–2000 to 0.54 in 2006–10 and then dropped to 0.49 in 2013–17. We find that lifespan-variability differences (measured by standard deviation differences) increased in both 2006–10 and 2013–17.

Similar to the findings for men, a less pronounced hump in deaths at around retirement age also emerged for low-income women. From 1996–2000 to 2006–10, the life-expectancy difference increased from 4.5 to 6.1 years, and stratification increased from 0.24 to 0.29. In 2013–17, low-income women caught up with their high-income counterparts in the proportion of deaths occurring at ages above 90. However, a large number of low-income women were still dying at relatively younger ages. It seems that among low-income women, the improvement at older ages more than compensated for the apparent stagnation at younger ages, leading to a counter-intuitive result: life-expectancy difference between the two income groups decreased to 4.2, while stratification increased to 0.31. Similar to the results for men, we find that lifespan-variability differences increased in both 2006–10 and 2013–17.

2.4.2 Trends in Life Expectancy and Lifespan Variability by Income

How did life expectancy and lifespan variability in Finland evolve for each income group? Before turning to our analysis of lifespan stratification, we investigate the two most commonly used health indicators. Figure 2.4 presents the trends in life expectancy at age 25 and lifespan variability, by income quintile and sex from 1996 to 2017. As expected, there was a persistent income gradient in life expectancy for both men and women; the differences were larger among men than women. At the beginning of our study, life expectancy for men aged 25 ranged between 43.6 and 51.8 years for different income quintiles, whereas life expectancy for women aged 25 hovered between 53.3 and 57.5 years. Over the years, life expectancy increased for both sexes in all five income groups, with slight fluctuations in certain years. By 2017, life expectancy had risen to 48.2–57.9 years for men and to 57.3–60.9 years for women.

We find that those groups with higher life expectancy tended to display lower lifespan variability. Women showed lower lifespan variability than men, and higher

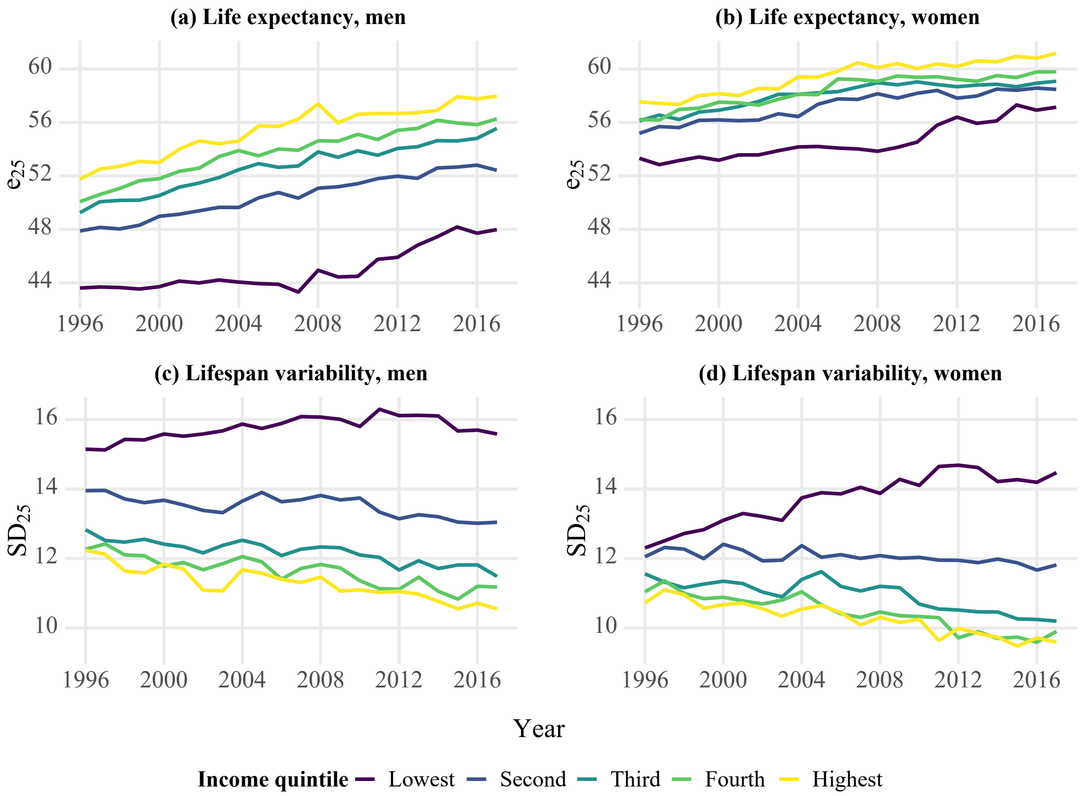

Figure 2.4: Trends in life expectancy and lifespan variability at age 25, by income quintile and sex: Finland, 1996–2017. *Notes*: e_{25} refers to life expectancy at age 25; SD_{25} refers to lifespan variability at age 25, as measured by the standard deviation. *Source*: Authors' calculation based on Finnish register data.

income groups showed lower lifespan variability than lower income groups. However, unlike life expectancy trends, lifespan variability trends diverged across different income groups, especially for women. Lifespan variability decreased for the top four income quintiles, but increased for the lowest quintile.

2.4.3 Trends in Lifespan Stratification and in Life-Expectancy and Lifespan-Variability Differences

We proceed by displaying in Figure 2.5 the trends in lifespan stratification and in the other two measures of differences between the lowest and the highest income quintiles, respectively. The overall lifespan stratification across all five quintile groups shows very similar trends to the one we present here (see Figure A.2 in Appendix A.2). Figure 2.5(a) shows that lifespan stratification between the richest

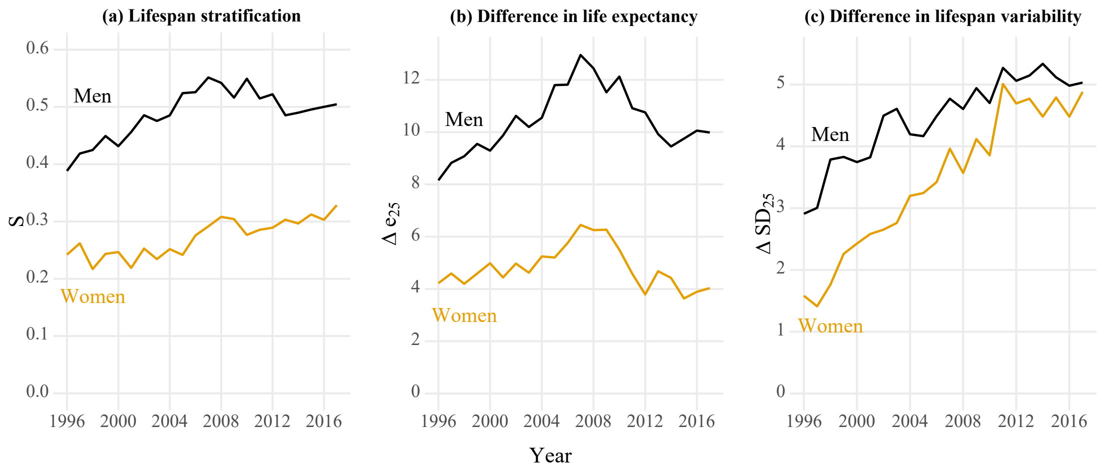

Figure 2.5: Trends in lifespan stratification and differences in life expectancy and lifespan variability at age 25 between the lowest and highest income quintiles, by sex: Finland, 1996–2017. *Notes*: S refers to lifespan stratification; Δe_{25} refers to the difference in life expectancy at age 25; ΔSD_{25} refers to the difference in the standard deviations. *Source*: Authors' calculation based on Finnish register data.

and the poorest 20 per cent (for convenience, hereafter referred to as 'lifespan stratification') increased from 1996 to 2017 for both men and women. Lifespan stratification among men increased from 0.39 in 1996 to 0.55 in 2007 and then decreased to 0.50 in 2017, while lifespan stratification among women increased by 36 per cent, from 0.24 in 1996 to 0.33 in 2017. In more recent years, stratification continued to increase for women, whereas it decreased slightly for men.

Figure 2.5(b) indicates that for both men and women, life-expectancy differences increased over the first decade but decreased between 2008 and 2017, and life expectancy ratios generally show the same pattern (see Figure A.3 in Appendix A.2). The trends for men and women are highly consistent, except that the life-expectancy differences for women fell to a lower level in 2017 (4.0 years) than their initial level in 1996 (4.2 years). For both lifespan stratification and life-expectancy difference, we find that men showed larger values than women. Comparing trends in life-expectancy difference with trends in lifespan stratification, we observe that the two trends were similar for men but also, interestingly, that the trends were different for women in the most recent years: their life-expectancy difference dropped, whereas their lifespan stratification continued to rise.

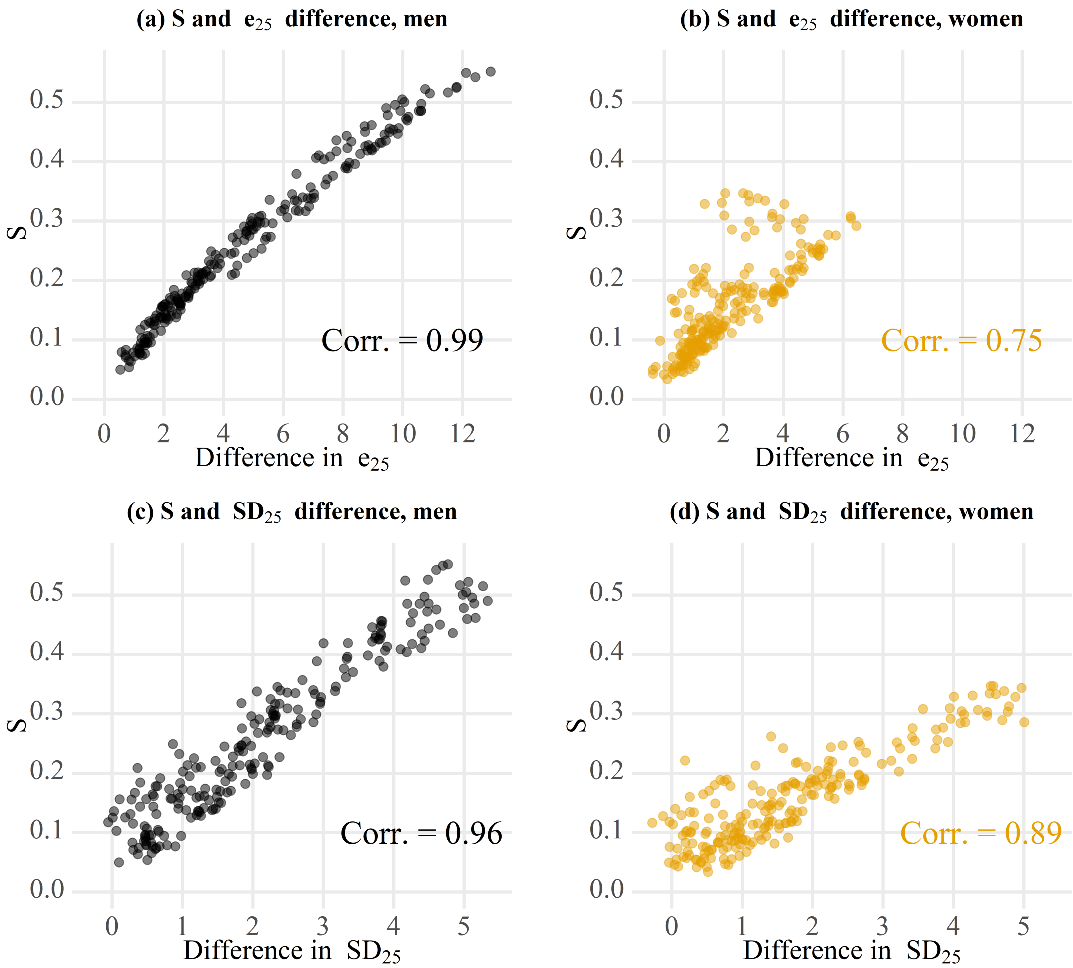

Figure 2.6: Pairwise associations between lifespan stratification and two other measures (life-expectancy differences and lifespan-variability differences), by sex: Finland, 1996–2017. *Notes*: Each point refers to a comparison between two income groups (e.g. the lowest and the second lowest income quintile groups, or the third and the highest income quintile groups) in a given year. The colour becomes darker when multiple data points overlap. S refers to lifespan stratification; Δe_{25} refers to the difference in life expectancy at age 25; ΔSD_{25} refers to the difference in the standard deviations; Corr. is the Pearson correlation coefficient. *Source*: Authors' calculation based on Finnish register data.

From Figure 2.5(c), we find that the absolute differences in lifespan variability increased consistently over the whole period for both men and women. The trends in relative difference in lifespan variability are very similar (see ratios in Figure A.4, Appendix A.2). Yet in contrast to findings in Figure 2.5(a) and (b), which show that the differences in the indicator remained more or less at the same level for men and women, in Figure 2.5(c) we see a convergence in lifespan-variability difference for men and women. Whereas lifespan-variability differences were much larger for men than for women in the earlier years, this gap had almost disappeared by 2017, especially for lifespan variability ratios (Figure A.4, Appendix A.2).

To determine how different age groups contributed to the divergent trends we observe, we can either conduct a decomposition analysis or simply inspect the age-at-death distributions at different periods. Looking back at Figure 2.3, we note that for the low income group, faster mortality improvements at more advanced ages raised life expectancy and compensated for the lack of improvements at younger ages. However, the excessive deaths at pre-retirement ages (the hump) among the low income group increased their lifespan variability as well as the lifespan stratification. How was lifespan stratification associated with life-expectancy and lifespan-variability differences? Figure 2.6 shows these associations using all pairwise comparisons between each two income quintiles (for each year, there are 10 different pairs of five income groups for both men and women). Life-expectancy and lifespan-variability differences were strongly associated with lifespan stratification for men; however, the associations were much weaker for women. Put differently, for women, there was a large range in lifespan stratification, given the same levels of life-expectancy or lifespan-variability differences. Among women, lifespan stratification was more closely correlated with the lifespan-variability differences than with life-expectancy differences.

2.4.4 Year-on-year Changes

On its own, Figure 2.6 cannot tell us how the indices were connected to each other over time. An interesting question is whether the direction of change in lifespan stratification was consistent with the direction of change in the life-expectancy or lifespan-variability differences. For this reason, Figure 2.7 shows the association between yearly changes in stratification and yearly changes in life-expectancy differences (panels (a) and (b)) and lifespan-variability differences (panels (c) and (d)), using all of the pairwise comparisons, as in Figure 2.6. Panels (a) and (b) show

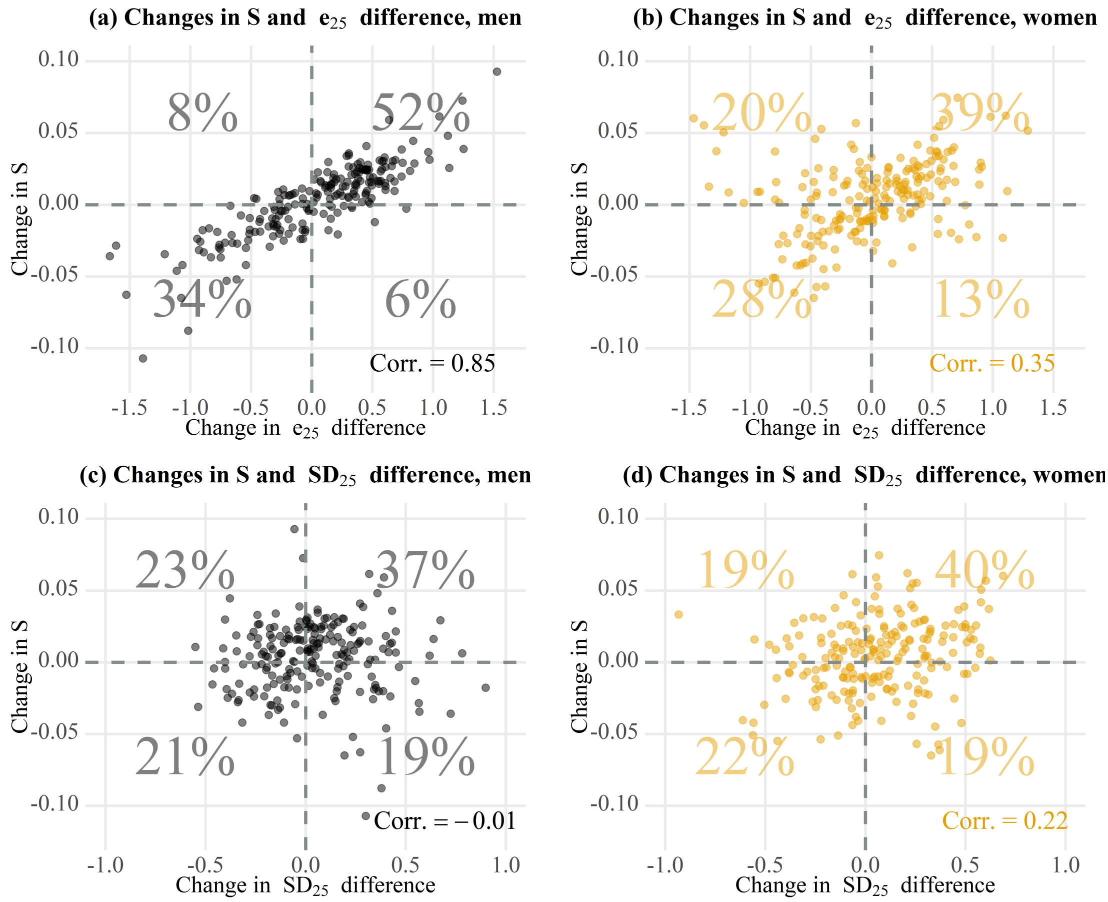

Figure 2.7: Pairwise associations between year-on-year changes in lifespan stratification and year-on-year changes in two other measures (life-expectancy differences and lifespan-variability differences), by sex: Finland, 1996–2017. *Notes*: Each point refers to a comparison between two income groups (e.g. the lowest and the second lowest income quintile groups, or the third and the highest income quintile groups) in a given year. The colour becomes darker when multiple data points overlap. S refers to lifespan stratification; Δe_{25} refers to the difference in life expectancy at age 25; ΔSD_{25} refers to the difference in the standard deviations; Corr. is the Pearson correlation coefficient. *Source*: Authors' calculation based on Finnish register data.

that changes in stratification were more consistent with changes in life-expectancy differences for men ($r = 0.85$) than for women ($r = 0.35$). For men, both these changes simultaneously increased 52 % of the time and simultaneously decreased 34 % of the time. An increase in stratification coupled with a decrease in life-expectancy differences occurred only 8 % of the time (upper-left quadrant) and the other way around just 6 % of the time. For women, desirable changes (i.e. decreases in both indicators, lower-left quadrant) occurred 28 % of the time, while increases in both indicators occurred 39 % of the time. It is notable that around 20 % of the time, lifespan stratification increased while life-expectancy differences decreased (upper-left quadrant). Interestingly, changes in lifespan-variability difference (panels (c) and (d)) were not associated with changes in lifespan stratification for men ($r = -0.01$), and the association for women was weak ($r = 0.22$).

2.5 Discussion

In this chapter, we introduced the concept of lifespan stratification and demonstrated how to measure it. The non-overlap index reflects the extent to which individuals' lifespans are stratified by their social characteristics, and it also captures the distance between two lifespan distributions. Monitoring stratification can uncover between-group differences that go unnoticed in the two conventional approaches—comparing life expectancy or lifespan variability—and can help to link these two lines of research. Our empirical application to Finland showed that income has come to play an increasingly important role in the stratification of lifespan in Finland, while life-expectancy differences have decreased in recent years.

Our contribution is mainly methodological. From a mathematical perspective, the vast majority of research on between-group mortality differences has focused almost exclusively on only two moments of distributions: mean and variance. Measuring distributional differences is conceptually different from comparing central tendency measures or lifespan variabilities. We could argue that because of the strong regularity of the age pattern of mortality, knowing the life-expectancy difference can inform the overall distributional distance. This is only partly true. Given two life expectancies, the range of stratification is relatively predictable. However, how they change over time is much less so. It is possible for distributional distance to diverge when life expectancies converge. This point was clearly illustrated by our empirical examples (see Figure 2.3(d) and (f), and the upper-left quadrants in Figure 2.7(a)–(b)). Further, although showing similar trends, lifespan-variability difference is conceptually different from our distributional approach, because comparing lifespan variability does not take the location of the distributions into account. As the distance and stratification depend on the life expectancy and lifespan variability of two distributions, our approach links these two lines of research nicely. Lastly, many regression-based inequality indices, such as the relative index of inequality (Regidor, 2004), can only be applied to ordinal independent variables. Thus, our index is of particular use when the stratifier is not ordinal, for example in the case of marital status or region, variables which are of great interest in health inequality research.

Thus far, only a few previous studies have taken the approach of measuring distributional dissimilarity, using the KLD (d'Albis et al., 2014; Edwards and Tuljapurkar, 2005; Sasson, 2016), which is asymmetric and less easy to interpret. The non-overlap index has several advantages. First, as a distance metric, it has a simple graphical representation and interpretation: the more overlap between two lifespan distributions, the smaller the distance. Second, it reflects the sociological concept of social stratification, which focuses on the process of clear boundaries forming between social strata in a society. The majority of prior stratification research that emphasizes the geometric distance between two distributions has focused on the distributions of economic outcomes (e.g. Yitzhaki and Lerman, 1991; Zhou and Wodtke, 2019). To date, little is known about how lifespan distributions are stratified.

The non-overlap index for the stratification of lifespan should be included in the toolkit for future analysis of mortality inequality, along with existing metrics, such as differences in life expectancy, lifespan variability, YLL, cross-sectional average length of life (CAL), and other CAL-family measures (Brouard, 1986; Canudas-Romo and Guillot, 2015; Guillot, 2003; Nepomuceno et al., 2022; Sauerberg et al., 2020). This is because we need an array of measures to reflect different dimensions of mortality inequalities. For example, for the low income group in our data, a mid-life mortality hump emerged over the follow-up, while old-age mortality declined and approached that of the high income group. Together these trends resulted in an increasing distance between the two lifespan distributions, which was captured by our index. As alcohol-related mortality is prominent at the ages around this mortality hump in the low income group (Tarkiainen et al., 2012), we postulate that changes in alcohol consumption may have played an important role in driving the recent increase in stratification. Diverging health behaviours may be explained by changing access to health-related information and technology or important social networks (Glied and Lleras-Muney, 2012; Link and Phelan, 1995; Montgomery et al., 2020). With survey data, future work could examine whether these factors correlate with lifespan stratification.

A growing literature has documented widening gaps in life expectancy between socio-economic groups in high-income countries over the last few decades (e.g. Brønnum-Hansen and Baadsgaard, 2012; Chetty et al., 2016; Meara et al., 2008; Permanyer et al., 2018; Sasson, 2016; Sasson and Hayward, 2019; Tarkiainen et al., 2012). Our empirical example showed that for the Finnish population, income-group differences in life expectancy increased over the period 1996–2008 and then decreased during 2008–2017. Yet average lifespans do not tell the whole story. First, stratification increased even during periods in which life-expectancy differences remained stable or decreased, particularly for women. The correlations between yearly changes in lifespan stratification and yearly changes in the other two measures were weak, indicating that life expectancy comparisons did not fully capture the developments in mortality inequalities that occurred during the last decade. Second, although the trends in lifespan-variability differences and stratification were similar for men and women, lifespan-variability differences by income level were approximately the same for men and women in recent years, whereas lifespan stratification was noticeably higher for men than for women. Sex differences in the stratification of lifespan by income were relatively stable over time, a pattern similar to the results for life-expectancy differences. Further decomposition between men and women (Figure A.5, Appendix A.2) showed that temporal mortality changes at older ages accounted for much of the convergence in lifespan-variability differences, whereas they played a much less important role in driving the sex differences in the other two indices.

Previous work has shown that the ages and causes of death that drive differences in population-level life expectancy in high-income countries are not the same as those that drive differences in population-level lifespan variability (Seligman et al., 2016). Lifespan variability is generally more sensitive to mortality change at younger ages than life expectancy (van Raalte and Caswell, 2016). In contemporary low-mortality settings, mortality change at young adult ages is particularly important in driving trends in lifespan variability (Aburto et al., 2016; van Raalte et al., 2014), whereas life expectancy trends tend to be driven by mortality change at ages where the death density is higher, that is, older ages (Rau et al., 2018; Vaupel, 1986). Yet, little is known about the age patterns that drive trends in mortality disparities between socio-economic groups. We conducted supplementary analyses to disentangle the total change in the three metrics between the lowest and highest income groups from the first to the last of the five-year periods (i.e. the same periods that we showed in Figure 2.3; results can be found in Figure A.6, Appendix A.2) into age-specific components. These analyses indicated that the age patterns are distinct in the three metrics. The overall age pattern of stratification is more similar to that of life-expectancy differences, but is more concentrated in ages 50–74. Older ages are much more important in driving the trends in lifespan-variability differences than in the other two metrics.

The most prominent causes of death for ages 50–74 are circulatory system diseases and neoplasms (GBD 2016 Causes of Death Collaborators, 2018). Alcohol-related causes may also play an important role, especially at pre-retirement ages. Indeed, much of the stagnation in life expectancy in the lowest income quintile during the 2000s and the subsequent increase in 2010s was attributable to changes in alcohol-related mortality at pre-retirement ages (Tarkiainen et al., 2012; Tarkiainen et al., 2017). Thus, one policy implication is that efforts should be made to reduce alcohol- and smoking-related deaths among low-income individuals in the middle and early old age groups (Martikainen et al., 2014; Tarkiainen et al., 2012; Tarkiainen et al., 2017). Reducing such deaths would not only increase life expectancy and reduce lifespan variability for the low-SES group but would also lead to a declining trend in lifespan stratification. However, the roles of alcohol consumption and smoking in contributing to life-expectancy differences by income vary by country. Their relevance is particularly strong in Finland (Östergren et al., 2019); thus, policies tackling them are particularly called for.

When lifespan is highly stratified in a society, disadvantaged individuals are not only more likely to die earlier, but they also tend to experience more premature deaths among members of their social and kinship networks over their life course (Daw et al., 2016; Umberson et al., 2017). This becomes more important at older ages, when lower-SES individuals have fewer strong ties. Research has shown that bereavement and lack of social support are critical determinants of poor health and mortality (Berkman, 1995; Cohen and McKay, 1984; Holt-Lunstad et al., 2015; Kawachi and Berkman, 1999; Stroebe et al., 2007; Unger et al., 1999), and such mortality burden is heavier in the lower socio-economic strata (Martikainen and Valkonen, 1998), further contributing to lifespan stratification. In addition, there are sex differences in the effects of bereavement on health and mortality; men are at greater risk of dying than women after experiencing spousal death (Stroebe et al., 2007). This may partly explain the higher lifespan stratification among men than women.

Growing stratification of lifespan can also have negative societal consequences. It calls into question the efficacy of social systems in reducing health inequalities. Even in the absence of empirical data, we might reasonably speculate that when lifespan stratification increases, this can cause stress among individuals who belong to higher-mortality strata. Like other types of social stratification, growing lifespan stratification may trigger social unrest and chaos. While the increasing divergence in health behaviours may be an important explanation, designing better social policies to tackle mortality inequalities has considerable merit.

Finally, increasing stratification of lifespan has further implications. It means that policies targeting people uniformly across SES and age groups are increasingly consequential. For instance, universal state pension ages in many countries are increasingly unfair for people in higher-mortality strata, as individuals from this group will spend less time in retirement (Shi et al., 2022a) and benefit less from the pension system (Shi and Kolk, 2022). However, such inequalities within a population are difficult to detect when only life expectancies are compared. Even pegging retirement age to group-specific remaining life expectancies, a touted solution for reducing pension inequalities (see discussion in Alvarez et al. [2021]), might not be appropriate in highly stratified settings where there are large differences in survival up to such an age.

There are potential extensions to our research. First, recent work has developed estimation methods for significance tests for the non-overlap index (Chung et al., 2019; Rahman et al., 2014). Future research could examine the utility of these tests when applying the index. Second, a large number of distance and divergence measures have been extensively used in other disciplines (Deza and Deza, 2009). Some of these might also be good candidates for measuring lifespan stratification. It is unclear if other measures will lead to similar patterns. Third, we used a period perspective in our empirical example, so the results pertained to hypothetical cohorts who experienced the age-specific mortality rates of a given year. The stratification index itself is not a period measure; hence, future work could examine lifespan stratification from a cohort perspective. Researchers may also extend this work to analyse stratification of truncated lifespan distributions or to incorporate a perspective of multiple cohort experiences, similar to the work by Canudas-Romo and Guillot (2015).

2.6 Conclusion

Life expectancy trends demonstrate that on average, living a long life is increasingly becoming the domain of the rich and privileged. The rising stratification of lifespans is perhaps an even clearer indication of growing mortality inequalities than traditional indicators, such as life-expectancy or lifespan-variability differences. This is because despite diverging life expectancies, a substantial proportion of the disadvantaged groups could nevertheless be experiencing tremendous progress in longevity on a par with that of the most advantaged groups. Our approach takes the divergence in the full age-at-death distribution into account and gives a clearer signal that social groups are effectively experiencing different survival ages. To the extent that individuals surround themselves with others of a similar income level, the poor will enjoy fewer connections to healthy and long-lived adults, while the wealthy will experience less premature death within their immediate social networks. For these reasons, we argue that policymakers should be monitoring the stratification of lifespan alongside other mortality indicators.

3 A Distributional Approach to Decomposing Lifespan Variance

3.1 Background

There has been an increasing interest in lifespan inequality in recent demographic and population health research (e.g., Edwards and Tuljapurkar, 2005; Engelman et al., 2010; van Raalte et al., 2018; Wilmoth and Horiuchi, 1999). Lifespan inequality is arguably the most fundamental inequality as all other inequalities such as education and income inequalities are conditional upon being alive. Therefore, reducing lifespan inequality should be one of the most important public health goals. To achieve this goal, it is crucial to understand the sources of lifespan inequality. Genetic endowment, unobserved frailty, gender, socioeconomic status, race/ethnicity, and place of residence, to name a few, are among the factors that may contribute to population-level lifespan inequality.

At the national level, a generally promising picture has been presented: as life expectancy increases, lifespan inequality decreases (Aburto et al., 2016; Colchero et al., 1999; Edwards, 2011; Permanyer and Shi, 2022; Smits and Monden, 2009; Vaupel et al., 2011). This is consistent with scholars' prediction in the 1980s that the survivor curve will become increasingly rectangularized as human longevity approaches its upper limit (Fries, 1980; Myers and Manton, 1984). It is less promising when taking a look at the subnational level. Life expectancy and lifespan inequality differ by gender, education, occupation, income, race/ethnicity, geographic location, etc. For instance, lower socioeconomic status has been consistently found to be associated with lower life expectancy and higher lifespan inequality (Brønnum-Hansen et al., 2021; Permanyer et al., 2018; Sasson, 2016; van Raalte et al., 2014). What is more worrisome is that lifespan inequality has been increasing or stagnating for lower socioeconomic groups while decreasing for higher socioeconomic groups (van Raalte et al., 2018). The dynamics of mortality within population subgroups make it important to gain a thorough understanding of the sources of population-level total lifespan inequality.

One useful approach to understanding what is causing lifespan inequality is to decompose total inequality in lifespan into *between* and *within-group* components, based on inequality measures such as the variance. Typically, the between-group component captures the contribution of between-group differences in the mean, i.e., life expectancy, whereas the within-group component—the weighted mean of the variance across groups—is assumed to be the part of the variation that is not explained by the grouping variable. Using this approach, van Raalte et al. (2012) found that the between-group component of educational attainment only contributes 0.6%–2.7% to the total lifespan variation across Western European countries. Such a small share of variation explained by education is in sharp contrast to the commonly known wide educational gap in life expectancy. It suggests that the majority of the inequality is within groups that cannot be explained by education.

In this study, We argue that the conventional variance decomposition framework underestimates the importance of the grouping variable because it does not capture between-group differences in distributions that also contribute to total lifespan inequality. The aim of this study is to provide a new variance decomposition approach that further disentangles the conventional *within-group* component into two parts: one explained by between-group differences in distributional shapes, and one that is remaining (i.e., unexplained by the grouping variable). U.S. mortality data by race/ethnicity from 2006 to 2018 are used to illustrate this approach.

3.2 Hypothetical Examples

Population subgroups differ not only in their mean outcomes but also in overall distributions such as location, dispersion, skewness, etc. In conventional decomposition analysis, distributional differences are not taken into account. To illustrate this, consider a population with two subgroups. In the Panel A of Figure 3.1, the two groups have the same mean lifespan of 70 years but have different levels of dispersion and skewness. Performing a conventional variance decomposition analysis would lead to a between-group component that is zero, and the total variance is entirely within-group. However, it is inappropriate to conclude that the groups do not play a role in determining overall lifespan variation. For instance, increasing the share of the "blue" group will lead to an increase in total lifespan variation as the "blue" group has a larger dispersion; yet the between-group component remains zero.

Panel B in Figure 3.1 shows another scenario where two distributions have almost no overlap. The "within-group" component gives no information about the shapes of the two lifespan distributions. Individuals from the "yellow" group cannot reach lifespans as long as those from the "blue" group do. In the analysis of income inequality, Liao (2016) refers to such a phenomenon as the "glass ceiling" effect. Similarly, the "glass floor" effect describes the situation where individuals from the advantaged group (blue) tend not to have very low levels of lifespan as individuals from the disadvantaged group (yellow) do. These two hypothetical examples reflect that distributional differences between population subgroups should be considered when analyzing lifespan inequality.

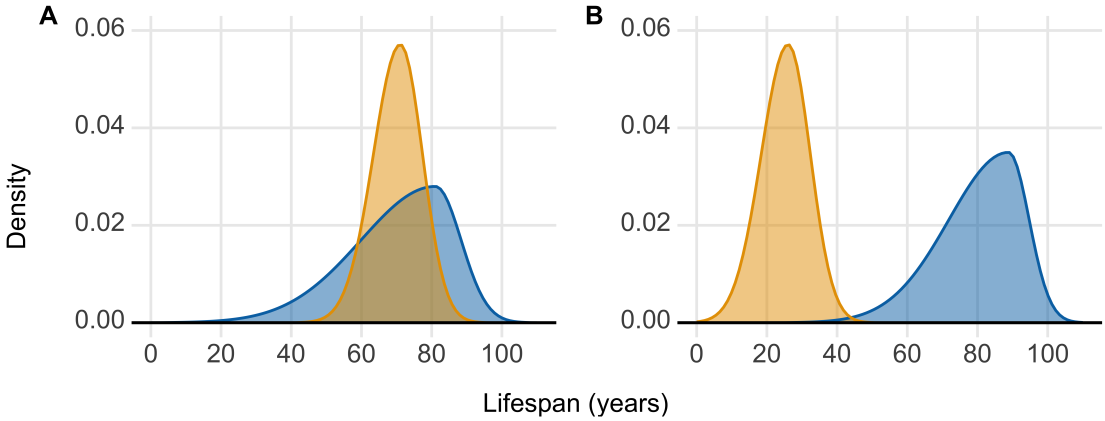

Figure 3.1: Hypothetical lifespan distributions of a population with two subgroups. *Source*: Authors' own.

3.3 The Method

Variance has been widely used to quantify the absolute inequality in the lifespan distribution (e.g., Gillespie et al., 2014; Tuljapurkar and Edwards, 2014; van Raalte and Caswell, 2016). An advantage of variance is its decomposability. In prior research, the variance of lifespans of a population has been decomposed into between- and within-group components based on variables such as area-level deprivation, education, and US state (Seaman et al., 2019; van Raalte et al., 2012; Xu et al., 2021). Also, the global lifespan variation has been decomposed into between- and within-country components (Permanyer and Scholl, 2019). Using life table notations, the variance of a lifespan distribution (V) is given as:

$$V = \frac{1}{l_0} \sum_{x=0}^{\omega} d_x (\bar{x}_x - e_0)^2 \tag{3.1}$$

where l_0 is the radix of a population (e.g. 1), ω is the last age interval, d_x is number of deaths in the age interval $[x, x+1]$ and e_0 is life expectancy. In the conventional framework of variance decomposition, the between-group component (B) can be seen as the weighted sum of the squared distance of the group mean from the population mean. It is calculated as:

$$B = \sum_{i=1}^{n} w^i (e_0^i - e_0)^2 \tag{3.2}$$

where w^i denotes the share of population subgroup i, e_0^i is the life expectancy for group i, and n is the total number of groups. The within-group component (W) is the weighted sum of variance of each group:

$$W = \sum_{i=1}^{n} w^i V^i \tag{3.3}$$

where V^i denotes the variance of group i.

To quantify the role of distributional differences to the total variance, We rely on the concept of a "shared distribution". Suppose we have two population subgroups. The degree of overlapping area in the corresponding two lifespan distributions is a measure of distributional similarity (Shi et al., 2023). When two distributions overlap perfectly, they are identical. The larger the overlap, the larger the distributional similarity. A shared distribution can be seen as the segment of a population that is not explained by the grouping variable. Therefore, the variance of this shared distribution is in some way the "true" within-group component. Similarly, the non-overlapping area of the two distributions is the proportion of the population that is due to the grouping variable. Based on the extent of overlapping, we can further split W into two parts, an unshared within-group component ($W_{unshared}$) that is explained by distributional differences, and a shared within-group component (W_{shared}) that is remaining (i.e., explained by differences in distributional shapes).

Let k_x^i denote the part of the group i that goes into the shared distribution in the age interval $[x, x + 1]$. It is calculated as:

$$k_x^i = \frac{\min\{d_x^i\}}{d_x^i} \tag{3.4}$$

where d_x^i is a vector of group-specific death density in the age interval $[x, x + 1]$, and $\min\{d_x^i\}$ gives the minimum value in d_x^i. Accordingly, $1 - k_x^i$ quantifies the part of the group i that goes into the unshared distribution. Applying k_x^i and $1 - k_x^i$ as weights to Eq. 3.3, we get $W_{unshared}$ and W_{shared} as follows:

$$W_{shared} = \sum_{i=1}^{n} \sum_{x=0}^{\omega} w^i k_x^i d_x^i (\bar{x}_x^i - e_0^i)^2 \tag{3.5}$$

$$W_{unshared} = \sum_{i=1}^{n} \sum_{x=0}^{\omega} w^i (1 - k_x^i) d_x^i (\bar{x}_x^i - e_0^i)^2 \tag{3.6}$$

It can be easily proved that the shared and unshared within-group components sum up to the within-group component in the conventional approach (Eq. 3.3).

3.4 Empirical Example: The Contribution of Race/ Ethnicity to Lifespan Inequality

In this empirical example, We show how racial/ethnic differences in mortality contributed to total lifespan inequality in the United States from 2006 to 2018. Life tables by race/ethnicity, sex, and year were obtained from the Centers for Disease Control and Prevention, National Center for Health Statistics (2021). Exposures by race/ethnicity, sex, and year were retrieved from the Surveillance, Epidemiology, and End Results (SEER) Program, National Cancer Institute (2021). Analyses were restricted to three racial/ethnic categories: non-Hispanic Whites, non-Hispanic Blacks, and Hispanics, and were performed separately by sex.

Figure 3.2 shows life expectancy and the variance of lifespans by race/ethnicity and sex between 2006 and 2018. Hispanics had the highest life expectancy and lowest variance, whereas non-Hispanic Blacks had the lowest life expectancy and highest variance. Life expectancy of non-Hispanic Whites was almost identical to population-level life expectancy. Over the study period, the differences in life expectancy between racial/ethnic groups were fairly stable. In particular, the differences between Hispanics and non-Hispanic Blacks were 5.6–6.8 years for females and 6.8–8.6 years for males.

Population-level lifespan variance was also relatively stable. It ranged between 232.9 and 246.7 years squared for females, and 283.4 and 305.3 years squared for males. For males, lifespan variance declined slightly in the first half of the period and bounced back to the initial level in the second half. Yet these changes were relatively small in magnitude given the high level of lifespan variance in absolute

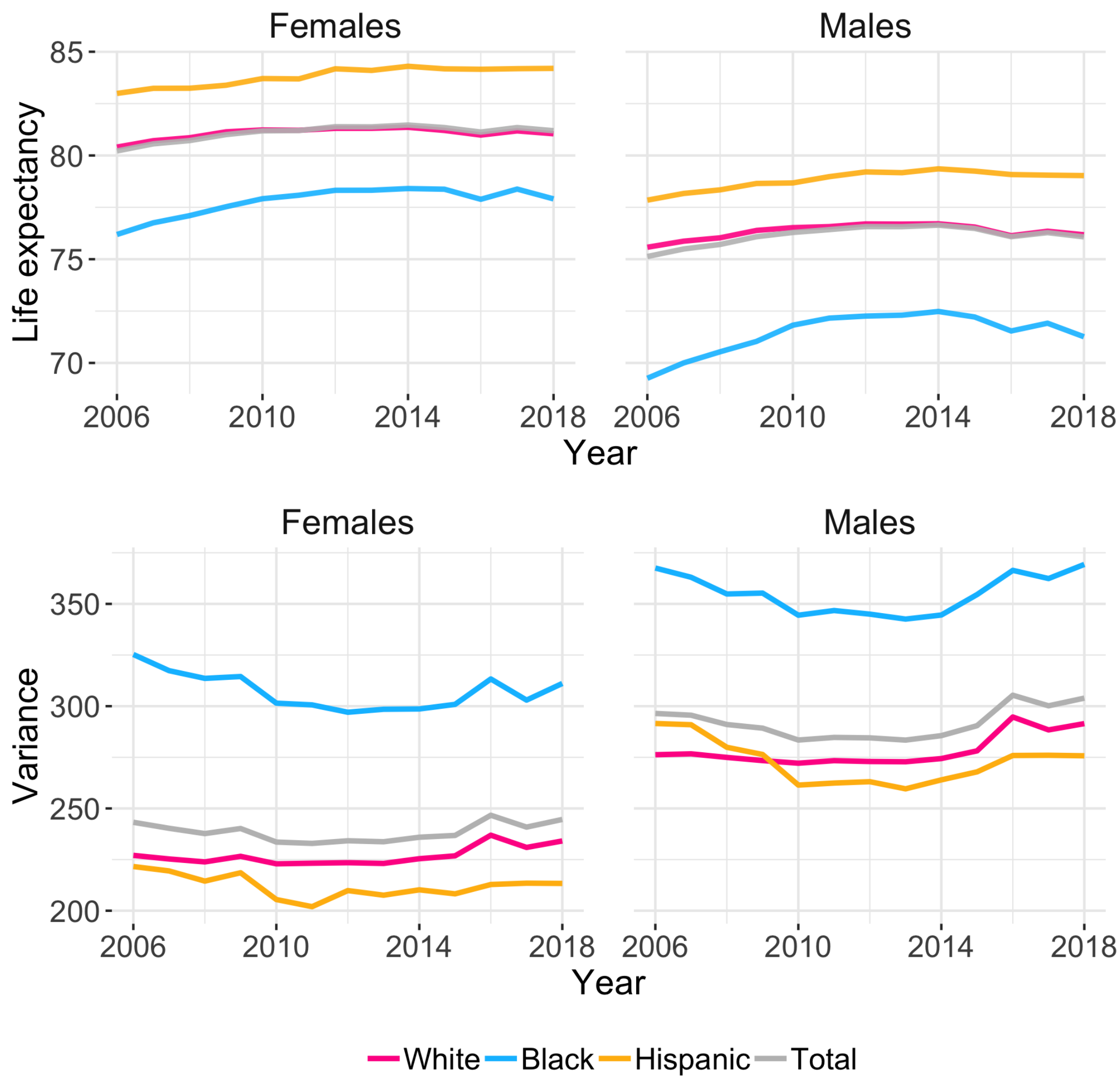

Figure 3.2: Life expectancy and the variance of lifespans by sex and race/ethnicity: United States, 2006–2018. *Source*: Author's calculation based on data from the Centers for Disease Control and Prevention, National Center for Health Statistics (2021), and the Surveillance, Epidemiology, and End Results (SEER) Program, National Cancer Institute (2021).

terms. Trends in lifespan variance by race/ethnicity were different. For both males and females, the lifespan variance of non-Hispanic Whites was stable up to the year 2015 and increased slightly afterward. On the other hand, for Hispanics and non-Hispanic Blacks, the variance decreased in the first half of the study period and increased thereafter. The U-shaped pattern was more pronounced among males.

The large differences in life expectancy suggest that race/ethnicity may play an important role in population-level lifespan variance. Similarly, as the within-group variance is substantially larger among non-Hispanic Blacks who constitute an important proportion (13.4–14.1% over the study period) of the U.S. population, we also expect that race/ethnicity is important to overall lifespan inequality.

To gain a deeper understanding of the role of race/ethnicity in population-level lifespan variance, We show the decomposition results in Figure 3.3 using the proposed method. The upper panels show the absolute contributions of different components and the lower panels show the relative contributions (as proportions). Note that the sum of the “unshared within” and “shared within” equals the within-group contribution in the conventional variance decomposition framework. Although the between-group differences in life expectancy were large, their contribution to total variance was negligible, in both absolute and relative terms. The unshared-within component, i.e. variance explained by distributional differences, was around 50 years squared for both females and males and was stable over time. The relative contribution of the unshared-within component was also similar for females and males and was around 20%.

Meanwhile, the shared-within component—the part that cannot be explained by either between-group mean differences or distributional differences—is the dominant factor that determines population-level lifespan variance. It explained around 80% of the total variance for both females and males. In absolute terms, the shared-within component was larger for males than for females, but in relative terms they were similar. This is why the total variance was larger among males than among females.

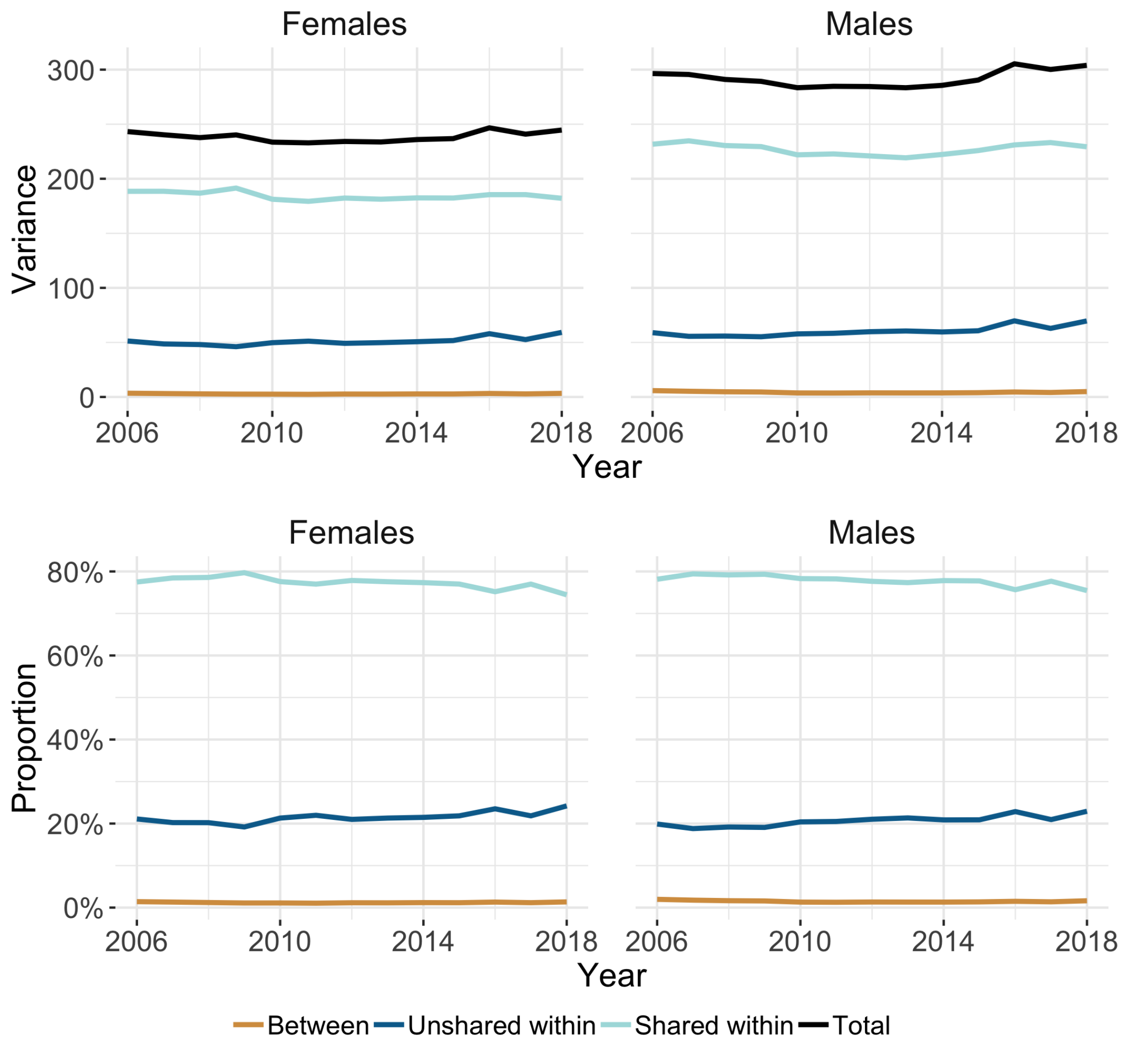

Figure 3.3: Decomposition of the variance in lifespan: United States, 2006–2018. *Source*: Author's calculation based on data from the Centers for Disease Control and Prevention, National Center for Health Statistics (2021), and the Surveillance, Epidemiology, and End Results (SEER) Program, National Cancer Institute (2021).

3.5 Discussions

In summary, this study introduces a novel decomposition approach to disentangle population-level lifespan variance into components that are explained and not explained by a grouping variable. This approach is built on the conventional variance decomposition framework (within- vs. between-group components) and further splits the within-group component into two parts: one that is explained by differences in distributional shapes and the other one that is "truly" within.

Thus, we gain a deeper understanding of how population subgroups play a role in population-level lifespan inequality.

The approach is especially motivated by the fact that (sub)populations differ not only in averages, i.e., life expectancy, but also in their overall distributions, including the median, mode, variance, skewness, kurtosis, etc. To account for overall distributional differences in lifespans between (sub)populations, metrics of statistical distance have been increasingly used by demographers (d'Albis et al., 2014; Edwards and Tuljapurkar, 2005; Sasson, 2016; Shi et al., 2023; Vaupel et al., 2021). In particular, the degree of distributional non-overlap has been used as a simple measure for the distance/dissimilarity between lifespan distributions (Shi et al., 2023).

The aforementioned approaches are essentially *group-level* approaches, capturing inequalities between groups. A distinction of this chapter is that the proposed method is a *population-level* approach. Its goal is to explain the overall lifespan inequality across individuals of an entire population by contributing factors concerning population subgroups. Hence, more accurately speaking, the new approach here is a population-level approach that incorporates group-level inequalities.

This way, we are able to describe how much of the total lifespan variance is attributable to (1) between-group differences in life expectancy, (2) an unshared-within component, i.e. within-group component owing to distributional non-overlap, and (3) a shared-within component, i.e. within-group variance owing to distributional overlap. The shared-within component can be seen as the part of the lifespan variance of the population that is not explained by between-group differences in life expectancy or distributional shapes.

Lifespan is variable even given a set of fixed age-specific mortality rates experienced by everyone in a population (Hartemink et al., 2017). In demographic research, it is still unclear how much of the observed total lifespan variation reflects the (irreducible) randomness in mortality. Likewise, it remains unknown how much variation is due to unequal distribution of resources and reducible. In this new decomposition framework, the overlapping part of lifespans (the shared-within component) may be interpreted as the sum of the ultimate random component of mortality and its variation over time, with the latter being constrained by current medical conditions. Thus, this new decomposition approach brings us closer to the notion of the irreducible randomness in mortality.

In the empirical application, We showed how racial/ethnic differences in life expectancy and overall distributions contribute to total lifespan inequality in the U.S. Not surprisingly, the contribution of between-group differences in life expectancy is negligible in both absolute and relative terms, though between-group differences in life expectancy themselves were large. In the traditional decomposition framework, this would lead to the conclusion that the vast majority of population-level lifespan inequality is within-group and not explained by the grouping variable. As shown earlier, between-group differences in lifespan distributions explained about 20% of the total variance for both sexes. Compared to the traditional variance decomposition, the new method give additional insights into how racial/ethnic differences in the shape of lifespan distribution are related to overall population-level lifespan variation.

Lifespan variance is considerably larger among males than females. We find that this is almost entirely explained by sex differences in the shared-within component. In other words, sex differences in total lifespan variance cannot be explained by race/ethnicity. Whether this is true for other variables such as socioeconomic status is yet to be found out. Future research may conduct a similar analysis to future explore sex differences in lifespan variance.

The minimal role of between-group differences in life expectancy is consistently found in prior research that focuses on different types of subpopulations such as education and area (Seaman et al., 2019; van Raalte et al., 2012; Xu et al., 2021). For example, a recent study shows that in the U.S., differences in life expectancy at birth between states only explain less than 1.3% of the total U.S. lifespan variance at birth (Xu et al., 2021). The rest would be assumed to be within states and unexplained by state differences. An important lesson is that between-state differences in life expectancy are unimportant for national-level lifespan variance. But how important state differences in overall lifespan distributions are is still unknown. The proposed decomposition method can be easily applied to answer this question.

A caveat of the proposed method, like other decomposition methods, is that it does not reveal the true pathways between race/ethnicity and lifespan. Racial/ethnic differences in education, income, health behaviors, and other dimensions of social life may be mechanisms. Incorporating more variables in a more complex decomposition may help to some extent and can let us quantify the net contribution of racial/ethnic differences in lifespan distributions to total variance. One limitation of such aggregate analysis is that the grouping variable has to be categorical (although the original variable may not be categorical). Regression-based decomposition methods may be more flexible to incorporate more variables, whether categorical or not. Despite these limitations, the proposed decomposition approach is a novel addition to demographers' toolbox of analyzing lifespan inequality and makes important contributions to a deeper understanding of the sources of lifespan inequality.

4

Inequalities in Retirement Lifespan in the United States

4.1 Introduction

Retirement is a stage in life where individuals have more control over both the pace and the content of their lives (Ghilarducci and Webb, 2018). Thus, living a long life in retirement is a desirable goal of many people. As mortality reductions at ages 65 and older have been the main driver of life expectancy (LE) gains since the mid-20th century (Rau et al., 2018), people are expected to live longer in retirement now than in the past.

The lifetime spent in retirement is determined by more than just the timing of death (Crimmins et al., 2018; Kibele et al., 2013). Two other factors shape retirement lifespan: first, the variation in the time of withdrawal from the labor

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force (Bernheim, 1989); second, labor force reentry after a phase of retirement (Cahill et al., 2015). Over the period 1992–2004, half of the U.S. men and women had exited the labor force by ages 63 and 61, respectively, and one third of the population returned to work after an initial exit from the labor force (Warner et al., 2010). The actual time spent in retirement is far from self-evident due to the uncertainty in these three factors.

The age at death, the age at initial retirement, and the usage of labor force reentry are known to vary across individuals with different characteristics. First, women tend to live longer and retire earlier than men (Hanson and Wapner, 1994). Second, education not only affects lifespan but also retirement patterns (Hayward et al., 1994). Because of these differences, separate analyses of retirement lifespan by gender and education are required.

In this study, we investigated gender and educational differences in retirement lifespan using data on synthetic cohorts from the Health and Retirement Study (HRS) spanning over two decades (1992–2016). Retirement lifespan is the variable defined as the time spent in retirement beyond the age of 50 years. Discrete-time event history analysis and multistate life tables were used to model career transitions. We focused on several dimensions of inequalities, including the average lifetime spent in retirement, or "retirement expectancy," and the variation in retirement lifespan, or "retirement lifespan variation," and examined how they vary by gender and education.

Within-group variation has largely been overlooked in the context of retirement lifespan, although it has been actively studied in mortality research under the label of lifespan variation. Complementary to LE, variation metrics have gained increasing attention among researchers, particularly for studying educational differences in mortality (Brown et al., 2012; Sasson, 2016; van Raalte et al., 2014; van Raalte et al., 2018; van Raalte et al., 2011). Variation metrics capture how much individuals of the same group differ in their lifespans, that is, the within-group heterogeneity in survival.

Similarly, variation metrics can be used to capture within-group inequalities in retirement lifespan. For policymakers, if ensuring fairness in the length of life in retirement is a desirable goal, the within-group variation is another dimension of policy fairness in addition to the average retirement lifespan. Monitoring variation is also useful for policies that aim to distribute resources for the retired population because knowing the average needs is insufficient. Furthermore, variation indicates the level of uncertainty for individuals from a probabilistic perspective (Courgeau, 2012), potentially affecting individual decisions in saving, consumption, and investment.

We contribute to the literature in three ways. First, inequalities in retirement expectancies (RE) have rarely been directly measured, despite mounting concerns that pension reforms could exacerbate current inequalities in years of retirement (Beach and Bedell, 2019). Second, in contrast to earlier literature that focuses on LE at Social Security full retirement age, we measure retirement lifespan more accurately by considering all transitions: retiring, returning-to-work, and dying. Third, we are the first to apply the concept of variation to the study of inequalities in retirement length, bringing together two previously independent strands of literature: research on lifespan variation and research on retirement transitions. Our research is fully reproducible; we provide R codes (Shi et al., 2022b), making it straightforward to apply our concepts to other data.

4.2 Background

4.2.1 Retirement Onset and Labor Force Reentry in the United States

Inequalities in the time spent in retirement have often been gauged by differences in remaining LE at age 65 (LE_{65}; Kibele et al., 2013; Majer et al., 2011). Yet the actual age of initial retirement varies across individuals, especially in the United States. The official Social Security full retirement age in the United States increased from 65 to 66 years for cohorts born in 1943–1954, and it will increase further for cohorts born in 1955 and later (Behaghel and Blau, 2012). The youngest age at which Social Security pension benefits can be claimed is 62 years. The actual ages at which individuals retire are often below the upper threshold, and sometimes even below the first claiming threshold (Warner et al., 2010).

On average, women retire earlier than men; this observation is consistent across time, yet gender differences in retirement age have narrowed more recently (Quinn et al., 2011). Gender differences in retirement patterns can be partly explained by family circumstances, as women more often quit paid work to take on unpaid domestic and care work (Fisher et al., 2016).

Research across the world has consistently found an effect of education on retirement timing. The self-expectation of working beyond the age of 65 was higher among higher-educated people than among the lower-educated (Mermin et al., 2007; Szinovacz et al., 2014). This matches the observed patterns where lower education is associated with earlier retirement, while higher education is associated with later retirement (Damman et al., 2011; Zickar, 2013). In the United States, Venti and Wise (2015) found that lower-educated people claimed Social Security benefits earlier than higher-educated people. One explanation is that higher income and better work conditions attract higher-educated people to work longer (Potočnik et al., 2009). Ill health has also been found to contribute to the association between low education and early retirement (Jung et al., 2020; Lawless et al., 2015). It is also possible that higher-educated people delay their retirement to compensate for later career onset and to recoup their earlier investment in education (Fisher et al., 2016).

The association between education and retirement may vary over time. During the 2008–2009 Great Recession, the probability of being retired at age 65 increased for both men and women, as older workers were pushed out of the labor market

(Dudel and Myrskylä, 2017), but the impact of the recession varied greatly by education, affecting those with less education disproportionately (Hale et al., 2021). Labor force reentry after initial retirement is another key factor shaping retirement lifespan. Reentry is a common phenomenon in the United States (Cahill et al., 2015; Warner et al., 2010). Skoog and Ciecka (2010) showed that work history predicted one's propensity to return to work. A 65-year-old man who was still active in the labor market was unlikely to reenter after the initial exit from the labor force, whereas a man who was inactive at age 65 was much more likely to reenter after his initial retirement (Skoog and Ciecka, 2010). As gender and education are associated with work history, they may influence the probability of reentering the labor force. In general, women were less likely to engage in postretirement work than men (Maestas, 2010; Pleau, 2010). Hayward et al. (1994) showed that, among all the retirees, lower-educated men were more likely to take part-time jobs after initial retirement than higher-educated men.

4.2.2 U.S. Older-Adult Mortality: Life Expectancy and Lifespan Variation

In addition to the timing of (un)retirement, mortality is another key component determining the retirement lifespan. After a long period of gradual increase, LE in the United States plateaued in recent years (Dyer, 2018), prior to the coronavirus disease 2019 (Covid-19) pandemic. This trend has been explained by increasing overdose mortality over younger-adult ages and slow declines in mortality related to circulatory diseases at middle to older ages (Mehta et al., 2020). The worrisome trend of LE in the United States is also partly attributable to divergent developments in mortality across socioeconomic groups, as studies have found that individuals with lower education and income have experienced declining LE since 1990 (Chetty et al., 2016; Meara et al., 2008; Sasson, 2016; Sasson and Hayward, 2019).

In population health research, variation metrics have been increasingly used to examine group differences in within-group lifespan inequality. Researchers find that men and individuals with lower socio-economic status (SES) tend to have larger lifespan variation in the United States in addition to their shorter LE. This occurs when looking at the variation over the full range of adult ages (Sasson, 2016; Sasson and Hayward, 2019). It is also the case when comparing expectancies and variation in ages at death above the mode (Brown et al., 2012). In other words, the health of men and lower SES groups are more heterogeneous than it is for women and higher SES groups. The lifespan variation from a fixed old-age threshold onward has been found to follow an upward trend for the entire population (Engelman et al., 2014; Myers and Manton, 1984). For SES-specific trends in old-age lifespan variation above age 65, findings are mixed across countries, gender, and education (Zarulli et al., 2012).

4.2.3 Hypotheses

Men and more educated individuals tend to retire later, and men and lower-educated individuals are more likely to return to work. Therefore, we expect that men have shorter retirement lifespans than women, whereas the relationship between education and retirement lifespan is unclear. On the one hand, more educated people tend to live longer, which can lead to longer retirement lifespans. On the other hand, they are more likely to postpone their retirement (Venti and Wise, 2015), thus reducing their retirement lifespans. As divergence in adult lifespan variation has been driven by diverging mortality in working ages (Sasson, 2016), it is less clear whether retirement lifespan variation has diverged across educational groups, particularly given the unknown labor force dynamics at older ages and the potential differences by gender and education.

4.3 Data and Methods

4.3.1 Data

We used the Health and Retirement Study (HRS), a biennial cohort-based panel since 1992 that contains a representative sample of noninstitutionalized individuals aged 50 and older in the United States. We created yearly work trajectories using 1996–2016 waves. Analyses were restricted to individuals aged between 50 and 100 at the time of the interview, including respondents and their age-eligible spouses (N = 32,228).

4.3.2 Outcome Variable

We classify individuals into three mutually exclusive states below the Social Security full retirement age: (a) "employed," (b) "retired," and (c) "out of the labor force (but not retired) or unemployed" (i.e., not employed, not retired [NENR]), using self-reported information (Dudel and Myrskylä, 2017). Figure 4.1 presents possible transitions between states. "Employed" includes self-employed individuals and those who are either working or on temporary leave such as sick leave or holiday. The classification follows this procedure: first, if individuals report themselves as employed, they are classified as "employed." Second, for individuals who report themselves as not employed, they are classified as "retired" only if they report themselves as retired. Third, those who are left from the first two procedures are classified to the state NENR. For ages above cohort-specific Social Security full retirement ages, people are either "retired" or "employed". Those who report themselves as not employed and not retired are automatically classified as retired.

4.3.3 Predictors

We measure education by the highest degree obtained; it has three levels: below high school diploma; a high school diploma or a GED; and a college or university degree.[1] Other key predictors include gender, the employment state in the preceding year, and period dummy variables for 2000–2003, 2004–2007, 2008–2011, and 2012–2015 (with the period 1996–1999 as the reference group). Age is included using a smoothing spline (Debón et al., 2006; Yee and Wild, 1996), together with three dummy

[1] We did not further divide the last category (as some other studies may have done) due to the small samples of earlier birth cohorts that we study.

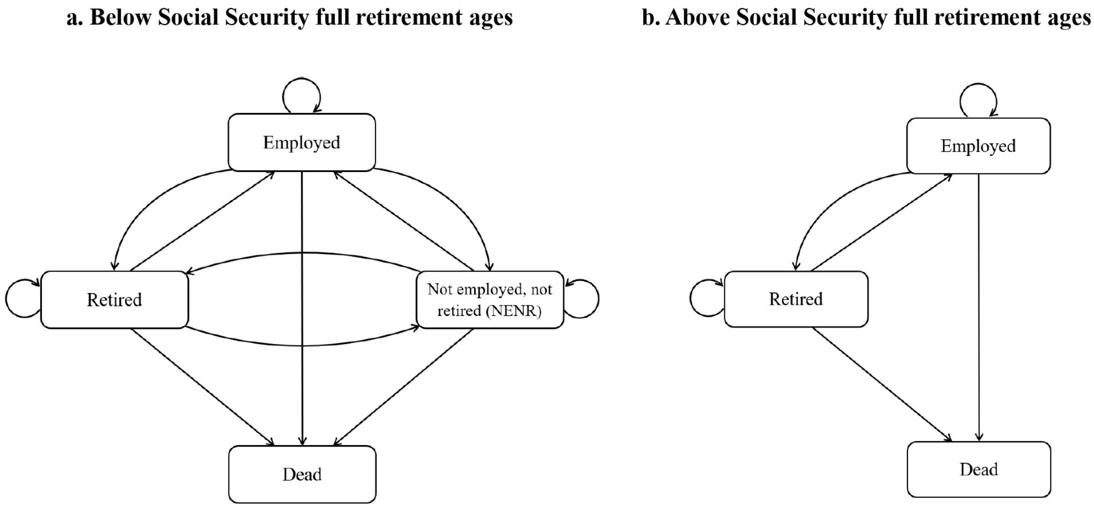

Figure 4.1: Transitions between states between age 50 and cohort-specific Social Security full retirement ages (panel a) and above Social Security full retirement ages (panel b). *Note*: When below cohort-specific Social Security full retirement ages, individuals who are unemployed or out of the labor force but do not identify themselves as retired are classified as "not employed, not retired (NENR)." *Source*: Authors' own.

variables for Age 62–64, Age 65, and Age 66 capturing institutional retirement entry, and one dummy variable Age 67+ to capture older-age retirement entry.

4.3.4 Statistical Analyses

Ideally, we would be interested to observe complete later-life work-retirement histories. However, complete cohort data where everyone has died is rarely available. A solution is to use the synthetic cohort approach—a method that is commonly used by demographers. In this approach, the conditions of a given period, such as a year or a few years are assumed to prevail throughout the lives of members of an artificial cohort. One advantage of this approach is that it reflects temporal changes in mortality and retirement behavior, and provides provisional answers to timely important questions. This synthetic cohort approach has been used by many previous studies on old-age labor market activities and health transitions (Leinonen et al., 2018; Skoog and Ciecka, 2010; Warner et al., 2010; West and Lynch, 2021). Our synthetic cohorts each correspond to one of the five periods mentioned earlier.

First, we use multinomial logistic regression models to estimate the probabilities of transitions between states. Besides the predictors mentioned earlier, the interaction terms between education and period and between education and age dummies are also included. Survey weights are used. All models are estimated separately for men and women. The survival probabilities resulting from these models are adjusted such that they match the survival probabilities provided by the Human Mortality Database (HMD, 2022).

Subsequently, for each period–gender–education combination, we use the predicted year-to-year transition probabilities to analytically derive (a) probabilities of dying without retiring and (b) distributions of state occupation time (Dudel, 2021). This assumes that transitions between states follow the Markovian processes, that is, transition probability from time (age) t to time $t + 1$ only depends on the state at time t, not prior transition histories.

Retirement expectancy (RE) is calculated as the average of the distribution of time spent in the state "retired." We use both absolute and relative inequality measures for retirement lifespan variation. Absolute inequality is translation-invariant (i.e., inequality remains invariant when all individuals gain the same number of years of life in retirement), whereas relative inequality is scale-invariant (i.e., inequality remains invariant when all individuals gain the same proportional change in years of life in retirement). Absolute and relative measures provide complementary perspectives on inequality and may sometimes lead to different results. We use the average interindividual difference (AID) to measure absolute retirement lifespan variation. The AID can be interpreted as the average difference in retirement lifespan between any two random individuals. It is calculated as:

$$\text{AID} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} |x_i - x_j|}{2n^2} \tag{4.1}$$

where x_i and x_j are the retirement lifespans for individuals i and j, and n is the total number of individuals. We use the Gini coefficient (G), a commonly used inequality measure in the literature, for relative inequality. It is calculated as:

$$G = \frac{\text{AID}}{\text{RE}} \tag{4.2}$$

We use the bootstrap method to calculate 95% confidence intervals.

4.4 Results

Not all adults reach retirement. Figure 4.2 shows the percentages of people who die without retiring conditional upon survival to and not being retired at age 50. Men were more likely to die before retirement than women in all periods for all education subgroups. On average, the probability of dying without ever retiring was around 15% for men and below 10% for women. This is partly explained by men's higher mortality and higher employment rates. Indeed, men were more likely to be employed at age 50 than women,[2] and these gender differences in employment rates persist to older ages.

Higher education was associated with a lower percentage of dying before retirement for both men and women, despite higher labor force participation rates among the higher-educated. In 1996–2015, the average difference in the percentage of not surviving to retirement between the lowest and highest education groups was 5.7% for women and 8.1% for men. Educational percentage-point differences in preretirement mortality were stable for men but decreased from 7.6% in 2000–2003 to 3.2% in 2012–2015 for women.

For those who were not retired at age 50 and survived to retirement, Table 4.1 shows their mean initial retirement age, LE, RE, expected years in labor force reentry at the initial retirement age, and the percentage of LE in reemployment.[3] Among the lowest educated, women retired later than men; whereas the gender

[2] In 1996–2015, the average percentage of employed individuals at age 50 was 80.1% for men and 70.8% for women.

[3] See Tables B.1–B.5 in Appendix B.2 for results with 95% bootstrap confidence intervals.

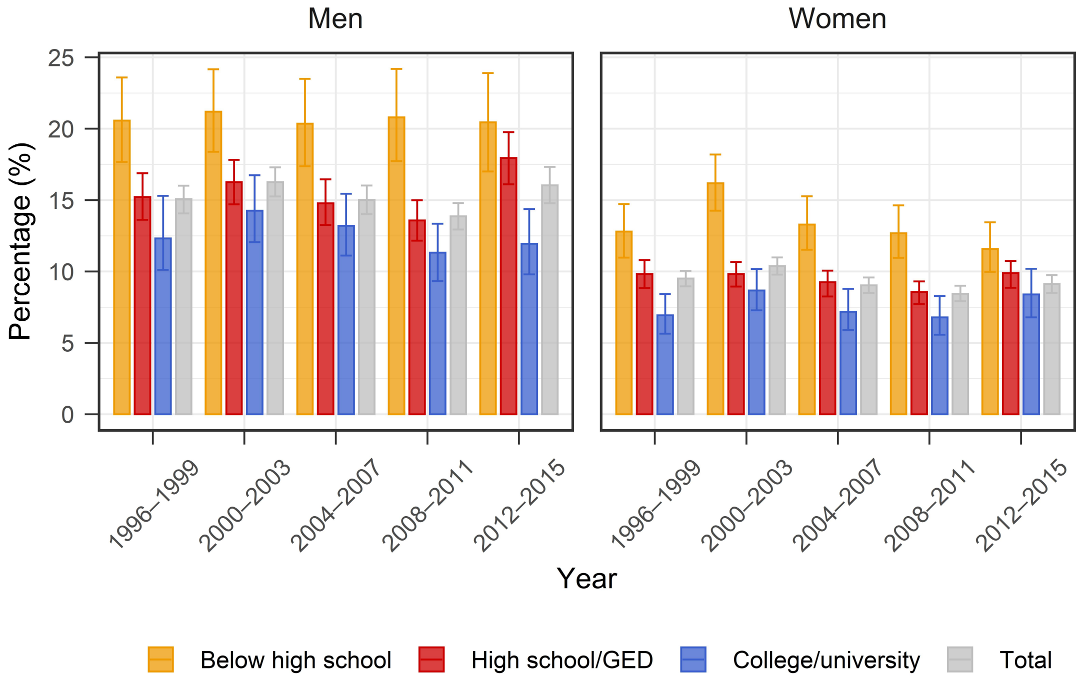

Figure 4.2: Percentage of individuals not surviving to retirement. *Note*: Error bars show 95% bootstrap confidence intervals. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

difference is reversed in the two higher education groups. Overall, for both genders, the initial retirement age was positively associated with education. For women, there were no educational differences in reemployment expressed either as expected years or a proportion of LE at initial retirement; whereas for men, a positive educational gradient was found in both.

While Table 4.1 described only those individuals who survived to retirement, below, we focus on all individuals (i.e., including those who died without retiring). Figure 4.3 shows a clear educational gradient in LE at age 50 for both genders. Higher education is associated with more time both employed and retired. Those with below high school education spent more years not employed and not retired, especially for women.

Table 4.1: Initial retirement age, life expectancy (LE), retirement expectancy (RE), expected years in reemployment at initial retirement, and percentage of LE in reemployment

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Initial Retirement Age										
Total	63.5	64.5	64.5	64.2	65.9	63.8	64.9	64.5	64.4	65.4
Below high school	63.5	63.6	63.7	63.2	64.5	63.9	64.6	64.4	64.3	65.0
High school/GED	62.7	64.0	63.9	63.8	65.4	64.0	64.8	64.4	64.1	65.0
College/university	64.6	65.9	66.2	66.1	67.9	63.3	66.1	65.2	65.4	67.0
LE at Initial Retirement										
Total	16.2	15.9	16.7	17.7	16.2	19.7	18.9	19.7	20.4	19.8
Below high school	14.3	14.4	14.9	15.0	15.2	18.4	16.4	17.9	18.3	19.2
High school/GED	16.3	15.8	16.8	17.7	15.2	19.5	19.4	20.1	20.9	20.0
College/university	17.1	16.4	16.9	18.4	17.7	21.3	18.9	20.8	21.4	19.9
RE at Initial Retirement										
Total	14.4	13.9	14.6	15.6	14.0	17.7	16.8	17.7	18.4	17.7
Below high school	12.7	12.8	13.3	13.5	13.4	16.6	14.6	15.9	16.3	17.2
High school/GED	14.5	13.8	14.8	15.5	12.9	17.4	17.2	17.9	18.8	17.8
College/university	15.0	14.1	14.5	15.8	15.1	19.5	16.7	18.7	19.2	17.6
Expected Years in Re-employment										
Total	1.8	2.0	2.1	2.1	2.2	2.0	2.1	2.0	2.0	2.1
Below high school	1.6	1.6	1.7	1.6	1.8	1.8	1.8	1.9	2.0	2.0
High school/GED	1.8	2.0	2.0	2.2	2.2	2.1	2.2	2.2	2.2	2.2
College/university	2.1	2.3	2.4	2.6	2.6	1.8	2.1	2.1	2.2	2.3

Table 4.1 (continued)

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
LE% in Re-employment										
Total	11.2	12.6	12.3	12.1	13.7	9.9	11.0	10.2	9.9	10.6
Below high school	11.1	11.1	11.1	10.4	11.9	9.7	11.0	10.8	10.7	10.4
High school/GED	10.9	12.7	12.1	12.3	14.8	10.8	11.3	10.8	10.4	11.1
College/university	12.4	14.2	14.2	13.9	14.9	8.4	11.4	10.2	10.2	11.8

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

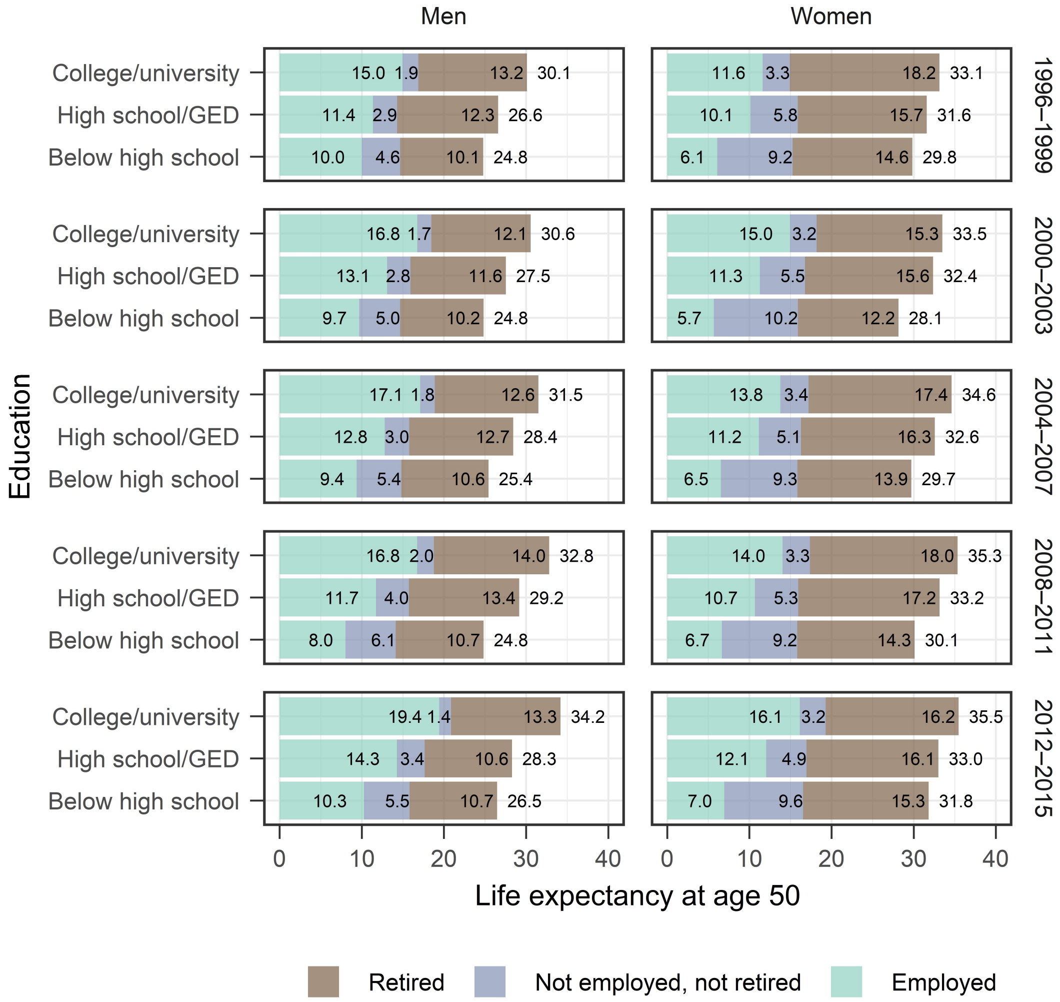

Figure 4.3: Life expectancy (LE) at 50 and the composition by state. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

We also find that women had a higher RE than men. Across education, the absolute difference in RE between women and men was larger among the college/university group; on the other hand, the gender difference in LE was smaller among the college/university group. On average, women with college/university education had a LE that was 2.6 years higher than their male counterparts, whereas they had a 4.0-year higher RE. This demonstrates that our multistate approach captures additional inequalities due to different work-retirement patterns in addition to LE differences. Education is positively associated with both RE and LE. Figure 4.4 shows differences in RE and LE between people with the highest and lowest education.

Differences in RE between educational groups were smaller than differences in LE, particularly for men. This suggests that work dynamics in old ages compensate for the higher mortality of lower-educated people. Among men, although differences in LE (point estimates) increased over time, differences in RE were relatively stable. Again, this indicates that rising inequalities in LE were driven by rising inequalities in time spent working, not in retirement, once their actual work-retirement transitions were considered. For women, the trends of the two measures, as indicated by the confidence intervals, were both unclear.

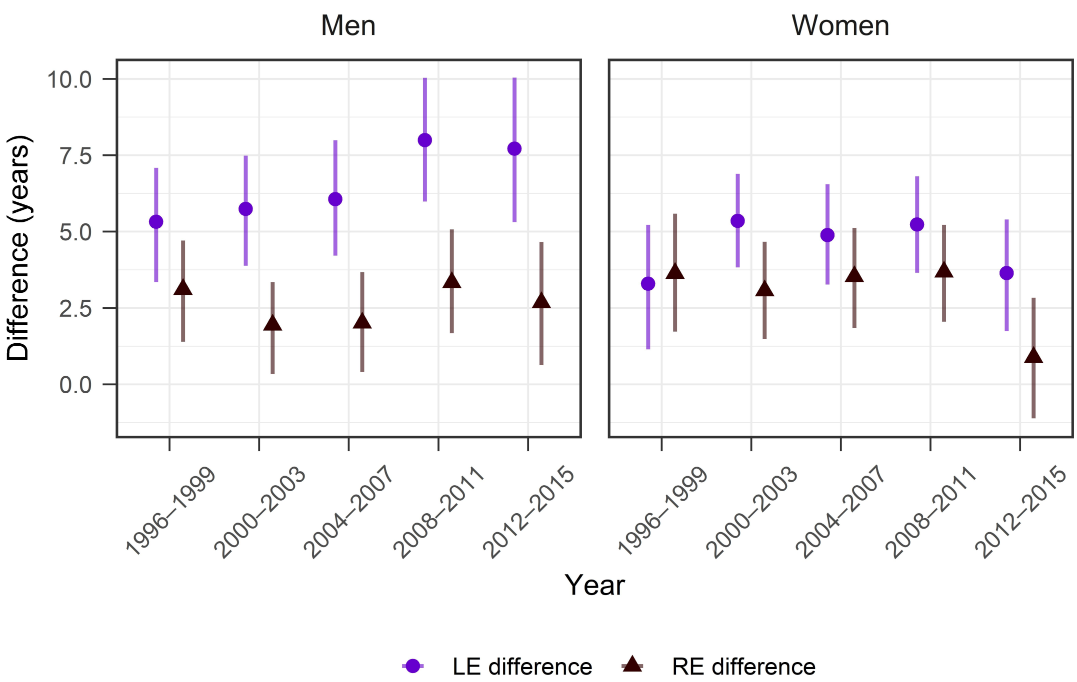

Figure 4.4: Differences in life expectancy (LE) and retirement expectancy (RE) at age 50 between the lowest and highest education groups. *Note*: Error bars show 95% bootstrap confidence intervals. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

Figure 4.5 shows AID and G of retirement lifespan by gender and education. Overall, the overlapping confidence intervals indicate that the variation in retirement lifespan was relatively stable in 1996–2015. The lower-educated had less absolute variation, but given their lower RE, this translates to more relative variation.

Similarly, men had lower AID than women, but men had higher G because of their lower RE.

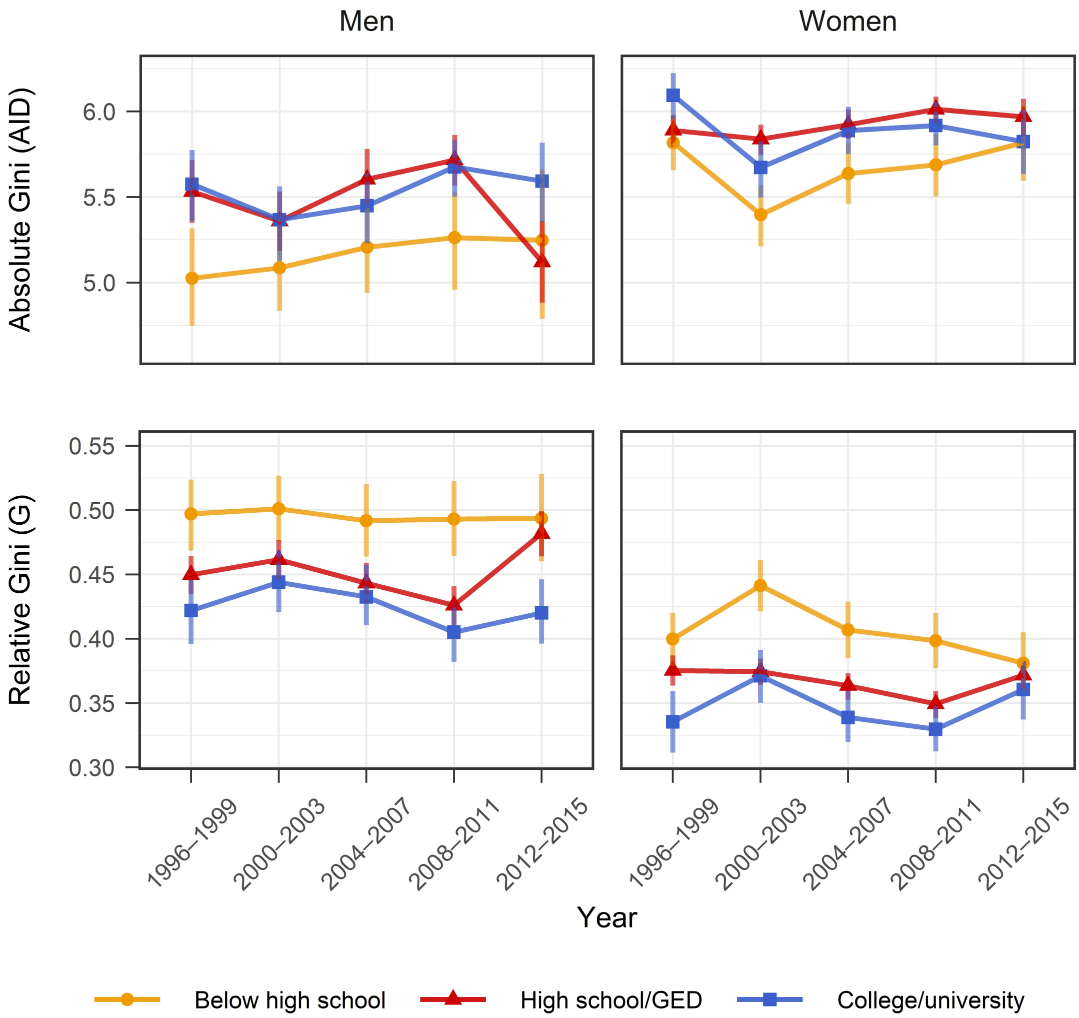

Figure 4.5: Trends of retirement lifespan variation. *Notes*: Calculations are conditional upon surviving to 50, and individuals in all transient states at 50 are included. Error bars show 95% bootstrap confidence intervals. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

4.5 Discussion

This chapter examined gender and educational differences in RE and retirement lifespan variation in the United States from 1996 to 2015. Despite the longevity improvement at the population level over the study period, we find substantial and consistent inequalities in RE by gender and education. Over the study period, women spent 3.8 years longer in retirement than men, on average. Higher-educated men lived 2.6 years longer in retirement than lower-educated men; the gap for women was 3.0 years. Time spent in retirement varies less within the lower-educated group than it does within the other two groups. However, given their lower RE, this translates into higher relative retirement lifespan variation.

4.5.1 Retirement Expectancy

There is growing interest in tracking trends and disparities in lifespans at older ages to better understand the effects of mortality on pension systems as pension reforms are implemented in an aging world (Shi and Kolk, 2022). As a good starting point, researching lifespans at pensionable ages (e.g., age 65)—an approach used by most prior studies—facilitates comparisons between income, education, and countries (Chomik and Whitehouse, 2010; Kalwij et al., 2013; Zarulli et al., 2012). Assuming everyone retires at the full retirement age is a useful approach when studying the pension system as a whole on topics such as intergenerational equity and pension sustainability.

Murtin et al. (2022) showed that in 2011 LE at age 65 (LE_{65}) was 18.3 years for men and 20.5 years for women. We found that for those who survived to retirement, RE was 15.6 years for men and 18.5 for women in 2008–2011 (Table 4.1). The discrepancies in LE_{65} and our estimates of RE for retirees were around 2 years, roughly equivalent to the time spent in labor force reentry. Furthermore, as men with higher education spent more time in labor force reentry, the gap in RE between retirees with the lowest and highest education for men (2.5 years) was smaller than the gap in LE_{65} (4.2 years). For women, as time spent in reentry was rather similar across education groups, the gap in RE between retirees with the lowest and highest education (3.4 years) was similar to the gap in LE_{65} (2.8 years). Hence, the conventional approach of using LE_{65} to approximate RE overestimates the actual time in retirement, and may also overestimate the educational gap in RE as individuals with higher education tend to spend more time in reentry.

Additionally, the conventional approach of using LE at age 65 underestimates inequalities in retirement time by ignoring individuals who died without retiring. This makes our study conceptually different from the other studies. Significant numbers of people die before retiring, which partly explains why estimates of LE at "pensionable ages" are higher than our estimates of retirement expectancy at age 50. Men with higher education levels live longer than men with lower educational attainment. The SES-related differences are not as large among women. These key dynamics that are captured in our multistate approach, but not in conventional studies, show a more accurate picture of inequalities in retirement lifespan.

A few studies have examined RE considering dynamic transitions. For example, Leinonen et al. (2018) used the Sullivan method to compare RE across occupational classes in Finland, and Ghilarducci and Webb (2018) used the nonparametric approach of hot-deck imputation with HRS data to study RE across gender, education, race, etc. They both find that longer RE is associated with higher SES, consistent with our findings. Our patterns of gender and educational differences in the probability of dying without retiring are similar to those found by Ghilarducci and Webb (2018), though we used a period and parametric approach while they used a cohort and nonparametric approach. Our findings are also consistent with the literature on postretirement employment, which highlights the importance of labor force reentry (Cahill et al., 2015). Although men are more likely to reenter the labor force than women (Cahill et al., n.d.), interestingly, there are no gender differences in the duration of reemployment (Table 4.1).

Gender differences in RE were up to 5 years within education groups. This could mainly be explained by women's lower mortality. One caveat is that we used self-reported information on retirement. Prior research suggests that women's earlier exits from the labor force due to family caretaking responsibilities make them less likely to identify themselves as retirees (Allmendinger et al., 1992). Gender inequalities in RE would be even larger if providing care for others after leaving the labor force were to be considered retirement. Yet, retiring to do care work is not the same thing as retiring to control the pace and content of one's time. If caregivers were not perceived as retirees, gender differences in retirement expectations would be smaller. Lower education is associated with a higher chance of death prior to retirement and lower RE. However, the magnitude of the educational difference is volatile across time, suggesting the important role of external social and economic circumstances, consistent with previous literature on the business cycle and late working life (e.g., Dudel and Myrskylä, 2017). At age 50, more educated individuals not only have a longer working LE but also a longer RE for both men and women. This implies that it might be a high-SES privilege to work longer due to better health.

4.5.2 Retirement Lifespan Variation

An important contribution of our study is that we introduce the concept of (within-group) retirement lifespan variation. The AID in retirement lifespan, interpreted as the average difference in retirement lifespan between any two random individuals, is 4.8–6.1 years depending on the gender and education group whose retirement expectations ranged between 10.0 and 18.8 years. This suggests substantial within-group heterogeneity in these retirement lifespans.

Moreover, to put the gender and educational differences in retirement lifespan variation into perspective, the AID and Gini coefficient of remaining lifespan at age 65 range between 4.5 and 5.0 and between 0.23 and 0.35, respectively, for men in 2015 across all countries in the Human Mortality Database (own calculations; HMD, 2022). Thus, we found that educational differences, as well as gender gaps, in retirement lifespan variation in the United States were broadly similar to the male cross-country gap in the overall variation in lifespans after age 65, across countries as diverse as Russia, Japan, and the United States. Although the distributions of retirement lifespans in this chapter and lifespans after age 65 (the comparison of HMD countries) will differ somewhat, this simple comparison shows that education and gender are stratifying the variation in retirement lifespans in the United States to an extent comparable to these large differences in lifespan variation across countries.

Gaps in retirement lifespan variation between educational groups did not widen over the period, which is in contrast to what has been found for U.S. trends in lifespan variation over a broader age range (Sasson, 2016). This might be in part because of the different age ranges examined. A study of long-term trends in lifespan variation in Finland showed that the divergence in lifespan variation between socioeconomic groups resulted entirely from differential mortality trends at ages below a moving young-old threshold (close to the LE; van Raalte et al., 2014).The AID and Gini coefficient show different ranks of gender and educational groups. By definition, the Gini coefficient is calculated as AID divided by the mean (in our case, RE), so declines in the Gini coefficient may be driven by increases in the mean (Permanyer and Scholl, 2019). For example, if AID increases from 5 to 6 and RE increases from 10 to 15, correspondingly, the Gini coefficient decreases from 0.5 to 0.4. Hence, the AID and Gini coefficients may show different results. We do not prefer either measure, as they both give complementary perspectives.

4.5.3 Methodological Considerations

The assumptions on which the models are based need to be considered in interpretation. First, the Markovian assumption, that a transition probability at age x only depends on the state at x (besides age, period, and education), not prior transition histories, can over-simplify the reality. Among retirees at older ages, people who have unstable employment histories are more likely to die due to possible precarious economic conditions. Taking transition history into account when estimating transition probabilities is unfeasible, as we would need a sufficiently long window of observation and a large sample size, yet such data are rarely available. Second, the multistate life table technique is based on hypothetical cohorts who are assumed to experience stationary transition probabilities. Period changes such as the Covid-19 pandemic that have an impact on the labor market or mortality will affect the experience of the actual retirement life of people. However, these potential challenges do not limit our analysis. For example, the Markov assumption might seem strong, but the most recently occupied state is a very good predictor of transitions, and to some extent, captures the past, as do the socioeconomic variables we use.

To test the robustness of the findings, we used an alternative threshold age of 70 (Figures B.2–B.4) above which respondents who were in NENR were reclassified as "retired." The general patterns remain, but the less educated are more affected by the choice of a higher threshold. Consequently, choosing a higher threshold yields larger educational differences, but the changes in magnitude are small.

One important extension of our work would be to include race/ethnicity in the analysis. If we further break down our analysis of the HRS data by race/ethnicity, some groups will have very small sample sizes. Nevertheless, racial/ethnic disparities in mortality and labor participation are important to understand inequalities in the United States, and future work should explore these aspects.

4.5.4 Policy Implications

Understanding the distribution of retirement lifespan is important for welfare policies. Providing resources to protect individuals against contingencies, including old age and inability to work is on the global policy agenda. Individuals with poorer health are more likely to quit jobs earlier and less likely to return to work, and they also depend more heavily on welfare programs. Thus, shortfalls in health and economic resources are reflected in retirement, particularly for less-educated individuals and women. Policymakers who aim at equity in social provision for older adults can be better informed by monitoring how these provisions vary across and within gender and education groups. In the United States, social insurance programs such as Social Security and Medicare are based on lifetime work history. The Supplemental Security Income and Medicaid make up some of the differences between individuals with different earnings trajectories. But still, economic security varies substantially among retirees. Higher-earning individuals will have higher retirement benefits (in addition to their private savings), which will widen the well-being gaps between social groups beyond the gaps in LE and RE. A policy-relevant analysis of disparities in expected retirement income over the retirement period would complement our study of RE.

As the population ages, policymakers are concerned about sustainable health care and social security policies. Many countries are encouraging individuals to postpone their retirement (Organisation for Economic Co-operation and Development (OECD), 2021b). It is true that policy discussions to delay the full retirement age for Social Security keep the option of early retirement, such that individuals who enter early retirement due to health and occupational factors can have access to retirement benefits. However, their retirement income streams are reduced due to actuarial adjustments. Thus, raising the full retirement age will inevitably increase the risk of old-age poverty. Future research should incorporate economic security in the analysis of retirement inequalities.

Inequalities in LE have gained increasing attention among researchers who study the fairness and sustainability of health care and pension systems (Auerbach et al., 2017; Goldman and Orszag, 2014). We argue that RE are equally, if not more important, to monitor in this regard. How health, economic, and social factors related to changing inequalities in retirement lifespan are critical open questions. These factors need to be better understood by actuaries when adjusting forecasts, and by policymakers in changing social insurance or tax policy.

5

How Does Mortality Contribute to Lifetime Pension Inequality?

5.1 Introduction

A large body of literature has considered the substantial and persistent socioeconomic gradient in mortality risks and longevity. One implication of such gradients is their effects on redistribution through state-regulated programs, such as health care and pension systems. Demographers interested in mortality gradients have examined population aging differences by socioeconomic status (SES) (Kitagawa and Hauser, 1973; Majer et al., 2011; Pamuk, 1985), but the effects of differential mortality on pension benefits have not received as much attention. Thus, whether individuals with lower SES benefit less from pension programs because of their higher mortality risks remains an open question.

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Three factors determine an individual's accumulated pension over the life course. First, given the mortality gradient, individuals with higher SES live more years and accumulate higher pensions. Second, preretirement earnings determine contributions to the pension system, which is further translated into flows of pension benefits. Third, because of the explicit progressivity of many pension programs (i.e., redistributing toward lower earners), proportional benefits become lower at increasingly higher levels of preretirement earning. Whereas the first two factors predict greater benefits to those with higher SES, the third does the same for those with lower SES. The relative importance of these three factors is far from self-evident.

Researchers have often studied pension progressivity by comparing measures such as the replacement rate across earnings groups (e.g., Dudel and Schmied, 2019; Whitehouse, 2006). The replacement rate is the proportion of labor earnings translated into retirement pension income. Higher replacement rates mean more benefits with respect to prior earnings-based contributions. In contrast, a cohort-based life course analysis using measures such as the lifetime benefits/tax ratio (e.g., Smith et al., 2003) may modify the association between SES and annual benefits because it introduces the additional factor of mortality, which counteracts progressivity defined annually. Recent research has highlighted the detrimental effects of SES mortality differences using various methods. This research has concluded that SES mortality differences increase lifetime pension inequalities and impede the progressivity that is usually conceptualized annually without considering SES-specific mortality patterns (Sánchez-Romero and Prskawetz, 2020).

Understanding lifetime pension inequality is relevant from a policy-making perspective: the progressivity of pension systems is often a policy goal. Yet, progressive replacement rates do not afford the same level of progressivity for the entire cohort over the life course if the system considers replacement only among living retirees compared with their previous incomes. Thus, an interesting question is, who benefits (more) from pension systems when longevity varies? The answer depends on both replacement and mortality inequalities between cohort members across such characteristics as gender, income levels, and education.

In this study, we use high-quality Swedish national taxation records on earnings and pension payments from 1970 to 2018 to examine how lifetime pensions are structured across socioeconomic groups. We disentangle inequalities in lifetime pensions between social groups based on gender, education, and preretirement earnings into age-specific components attributable to differences in annual pension income and mortality.

We expand the literature in several ways. Prior research has not used individual-level data over the complete life course, largely because of the unusually long span of data required for this kind of lifetime analysis. We measure values of lifetime pensions of real birth cohorts with high-quality register data that—unlike survey data, which often suffer from missing values and reporting bias—provide an accurate picture of an entire population. Researchers have mainly examined the role of mortality on lifetime pension inequality by using counterfactual analysis—that is, by recalculating lifetime pensions based on hypothetical mortality rates (e.g., Organisation for Economic Co-operation and Development (OECD) 2017; Sánchez-Romero et al., 2020)—rather than decomposition techniques that yield additive terms summing to total lifetime pension inequality. Our life table–based decomposition is a novel approach that presents not only age-specific mortality effects but also additive effects of preretirement earnings and the redistributive role of the pension system. We also explore the potential impacts of policy changes, such as raising pensionable ages.

Substantively, our results can inform policymakers attempting to balance the goals of social equity and (demographic) actuarial fairness. We also shed new light on the literature on later-life income stratification. Given that the share of older adults in the population is rising almost worldwide and that pension income is the main source of income for most older people, reducing old-age poverty is becoming ever more important. The share of state budgets allocated to pensions is rising throughout the aging world; meanwhile, inequalities in pension payments are becoming an increasingly important aspect of economic inequality over the life course.

5.2 Background

5.2.1 What Is the Function of Pension Systems?

Pension systems in contemporary high-income countries serve many goals, including (1) helping individuals redistribute resources from working to old ages; (2) protecting individuals from poverty in old age; (3) providing insurance and reducing variance in monthly old-age income, regardless of longevity; and (4) transferring money from higher income individuals to lower income individuals as an integrated part of larger tax-funded and mandatory government welfare systems, thus helping achieve the first three goals. In traditional typologies of pension systems in OECD countries, systems described as “Bismarckian” are oriented toward income replacement (meeting the first and third goals), whereas “Beveridgean” systems focus on poverty protection (the second goal) with less emphasis on relating pensions to previous earnings (Ebbinghaus, 2021).

All but the first goal of life course transfers involve varying degrees of redistribution between individuals. For instance, the third goal, also known as risk pooling (Ayuso et al., 2017), may counteract the other goals of a pension system if individuals with unusually long lifespans are concentrated among high-income individuals.

In theory, everyone at working ages could buy private pension insurance that, in retirement, would be translated into annuities from their savings through an open market, thereby fulfilling the first and third goals. Yet, this practice has never occurred at the societal level. Instead, lower income countries have relied mostly on family care, gradually replacing it with public pension systems as they become richer. For privately funded pension systems, creating actuarially fairly funded pension insurances is challenging because of mortality differences by gender and socioeconomic group, difficulties in forecasting future mortality, the great efforts required to maintain a pension scheme over decades, and the risks involved in providing such insurances. Thus, all OECD countries (with the partial exception of Chile) fund public pension systems through taxes on working-age individuals that are transferred to pensioners (the so-called pay-as-you-go system), through mandated (and often tax-favored) pension savings for individuals (Whitehouse, 2006), or both.

Reducing inequality at older ages is intrinsic in most pension systems. Indeed, the initial motivation for all pension systems (particularly those of the Beveridgean tradition) was to eliminate poverty among older adults and ensure an adequate standard of living for them. Pension systems thus protect against socially unacceptable social deprivation among the very old who can no longer work. With individuals living longer beyond retirement ages, however, saving adequate resources during working years to fund retirement has become less realistic for some. This point is particularly relevant for low earners, who are more heavily reliant on public pension schemes than high earners (U.S. Government Accountability Office, 2019). Because public pension systems are equalizers, old-age inequality in total income from all sources is smaller in countries where public pension benefits represent a larger share of pensioners' total income (Brown and Prus, 2004).

5.2.2 Types of Redistribution and Inequalities

Different types of redistributions are involved in achieving each of the aforementioned goals of pension systems. Accordingly, redistribution and inequality can be assessed for different comparison groups. In systems where working-age individuals fund the currently retired population, total contributions and total benefits within any given generation tend not to be equal. Thus, intergenerational redistribution is inevitable, further stimulating discussions about pension fairness across generations. Many studies have focused on this aspect, particularly on whether the overall system is sustainable with an aging population following declining fertility and mortality (Howse, 2007; Lee and Mason, 2011). Other research has focused on pension reforms and differences between funded and nonfunded systems (Sinn, 2000). We do not elaborate on either of these aspects in this study. We focus instead on the redistribution between individuals of the same cohort: within-generation, interpersonal redistribution and inequality. The sources of such inequality are prior labor income, the extent to which labor income is translated into pension income, and lifespan. Lifespan is crucial because it determines the length of pension accumulation. Although our focus is on interpersonal redistribution and inequality, understanding intrapersonal redistribution (i.e., individuals redistributing their income from working age to old age) is also integral to our lifetime analysis.

Here, we summarize the three determinants of within-generation inequality. First, preretirement labor earnings are closely linked to annual pension income. Men tend to have higher labor earnings than women and thus tend to have higher annual pension incomes. Second, the extent to which the system intends to redistribute incomes from the rich to the poor is often reflected in differential replacement rates. Such redistributive effects of public pension programs, like other government programs, tend to be measured yearly (Nelissen, 1998), which ignore between-individual differences in mortality risks and thus in the number of years they can receive a pension. Third, the longer individuals live, the more years they can benefit from the pension system. This feature reflects that pension systems pool risks, protecting individuals against uncertainty regarding how long they will live. Individuals therefore do not risk using up their money long before they die or having unintentional property left upon their death (Ayuso et al., 2017). Consequently, a pension system redistributes money from the shorter-lived to the longer-lived.

Studies have found that people with higher SES tend to live longer than those with lower SES even in today's low-mortality regimes (e.g., Brønnum-Hansen and Baadsgaard, 2012; Mackenbach et al., 2018). The exact magnitude of this SES gradient varies between countries. In the United States in 2001–2014, men in the top 1% of the income distribution lived an average of 14.6 years longer than those in the bottom 1% (Chetty et al., 2016). In many OECD countries, the SES gap in longevity has been growing (Kravdal, 2017; Meara et al., 2008; Östergren, 2015; Permanyer et al., 2018).

5.2.3 Research on How Mortality Affects Pension Inequality

Research beginning with Aaron (1977) has demonstrated mortality's regressive effects on the overall redistribution of pension systems in many contexts. Many studies have focused on the role of mortality inequalities by (lifetime) earnings (e.g., Bishnu et al., 2019; Garrett, 1995), probably because public pension income is solely based on prior earnings-related contributions. Other researchers have examined differences across social factors such as class, education, gender, and race/ethnicity (Brown, 2007; Brown, 2003; Jijiie et al., 2022; Tan and Koedel, 2019; Vidal-Meliá et al., 2019).

Most studies have focused on the U.S. context. One such study simulated individual life histories for two cohorts (1930 and 1960), finding that the gap in lifetime Social Security benefits between men in the top and bottom income quintiles increased from US$103,000 to US$173,000 across the two cohorts (National Academies of Science, Engineering, and Medicine (NASEM) 2015). This increase was attributed to growing inequality in life expectancy: projected life expectancy at age 50 increased for the top quintile (from 31.7 to 38.8 years) but decreased for the bottom quintile (from 26.6 to 26.1 years) across the two cohorts (NASEM 2015). Focusing on cohorts born in 1962–1980, Tan and Koedel (2019) found that the U.S. retirement system is still modestly progressive and that mortality inequalities reduce its progressivity.

Studies in other countries with distinct pension systems have confirmed mortality's regressive role. Research found that pension systems in Germany and Italy, unlike in the United States, are regressive, transferring money from low to high earners (Caselli et al., 2003; Haan et al., 2020; Mazzaferro et al., 2012). The OECD

(2017) examined lifetime pensions across its member countries, assuming a three-year difference in life expectancy between low and high earners and an arbitrary ratio of earnings between them (50% and 200% of average earnings, respectively). The study found that the differences in lifetime pensions between low and high earners vary between 10.6% and 16.6% across OECD countries. The true magnitude of life expectancy differences between these income groups may not be three years. Nevertheless, fixing the differences at three years is useful to show that the impact of life expectancy gaps is widespread and suggests that the magnitude of lifetime pension inequality depends on the context.

Research has also examined the potential impact of pension reforms, given that many countries have moved from defined benefits to (notional) defined-contribution pension systems. Using simulation, Lee and Sánchez-Romero (2019) found that a notional defined-contribution (NDC) system using cohort- and income-specific life tables leads to the lowest level of lifetime pension inequality in the U.S. context; a defined-benefit (DB) system with progressive replacement or an NDC system with cohort-specific but not income-specific life tables shows slightly higher lifetime pension inequality levels; and a DB system with a flat replacement rate shows the highest inequality. Thus, the authors concluded that an NDC system should use income-specific life tables to reduce lifetime pension inequality, and a DB system should move toward more progressive replacement rates. A theoretical analysis based on life cycle hypotheses incorporating individual behavioral responses (e.g., timing of retirement) yielded similar conclusions (Sánchez-Romero et al., 2020).

Some studies have used mathematical models to understand the variations of lifetime pension inequality under different pension systems (Pestieau and Ponthiere, 2016; Sánchez-Romero et al., 2020). Others have analytically calculated SES-specific lifetime pensions based on SES-specific life tables and pension formulae (e.g., OECD 2017; Olivera, 2019). Inputs are often not from data linked at the individual level but instead are aggregated from different sources or arbitrary SES-specific inputs. This approach is useful for international comparisons in which harmonized microdata are unavailable. Another approach is to use microsimulation to construct hypothetical cohorts, often with data from different sources and mortality forecasts (Goldman and Orszag, 2014; Hurd and Shoven, 1985; NASEM, 2015; Nelissen, 1998). The simulation approach is useful to parse the effects of different pension systems (Lee and Sánchez-Romero, 2019) and changes in individual-level inputs (e.g., earnings trajectory, retirement age, lifespan) on population-level lifetime pension inequality. Another advantage of simulation is that it can help address right-censoring, particularly in analyses of future trends in pension inequality. Only a few studies (e.g., Haan et al., 2020) have been able to directly calculate lifetime pension inequality from individual-level microdata with rich information. We impute pensions and mortality at very old ages, but the imputed person-years represent only a trivial share of the total person-years.

5.2.4 Research Gaps and Our Contributions

No study has analyzed lifetime pension inequality based on birth cohorts' experiences because of data limitations. The long series of individual-level linked administrative data are not subject to the problems typically affecting surveys, such as missing values and reporting bias, especially for income variables. Hence, one contribution of this study is to provide precise, empirical evidence of the regressive role of the mortality gradient.

Methodologically, our combination of the life table approach with the decomposition technique is a novel addition to research on lifetime pension inequality. This analytical framework can answer research questions that have not been thoroughly answered. First, we can answer questions about the size of the contributions of mortality and preretirement earnings to lifetime pension inequality. In most government pension systems, whether based on mandatory savings or a DB or NDC system, pension income is highly correlated with preretirement labor income;

therefore, a large proportion of lifetime pension inequality results from inequality in preretirement labor income. Our decomposition method disentangles total lifetime pension inequality into additive components due to mortality differences, preretirement earnings differences, and the intended redistributive effects of the system. We also examine how (hypothetical) changes to the entire pension system—such as overall generosity, pension timing, and life expectancy changes—impact SES differences between groups. Second, we can address questions of how mortality differences at a given age affect lifetime pension inequality. Research has shown that mortality inequality between SES groups becomes smaller with age (Hoffmann, 2011; Rehnberg, 2020), suggesting that mortality inequality at older ages may contribute less to total lifetime pension inequality than mortality inequality at younger ages. Whether this is true also depends on the age-specific pension variable. Empirical evidence of the age pattern of mortality's contribution is lacking: research has shown only the total mortality contribution, partly because of methodological constraints.

Given that most of the relevant research refers to the U.S. context, less is known about countries with contrasting pension systems, such as Sweden. Our study also differs conceptually from previous research in that we capture all sources of pensions (income-related government pensions, guaranteed pensions, collective-agreement pensions, disability pensions, and widowhood benefits) and provide a holistic view of the entire Swedish pension system, rather than evaluating individual components of a (government) pension system (e.g., U.S. Social Security old-age insurance). The drawback of this feature is that our study is not useful for evaluating subcomponents of a given pension system; the advantage is that we can assess the pension system's overall societal redistribution.

5.2.5 The Swedish Context and Pension System

For most of the twentieth century, life expectancy in Sweden ranked among the world's highest, although data in recent decades indicate that this is no longer the case (Drefahl et al., 2014). Male mortality remains low from an international perspective, whereas female mortality is at average OECD levels (Drefahl et al., 2014). Inequality in life expectancy by income levels at age 35 increased over 1970–2007 for Swedish men and women (Hederos et al., 2018). In particular, poor and low-educated men were the most vulnerable to premature deaths (Hartman and Sjögren, 2018). An increasing gap in life expectancy at age 65 was also observed over 2006–2015 (Fors et al., 2021).

Sweden is often described as a universalistic welfare state and as an exemplar of the social democratic regime in Esping-Andersen's (1990) typology of welfare states. At the time of our study, Sweden offered a generous public pension system (first pillar), but occupational pension systems (second pillar) linked to collective agreements covering the majority of the population were also important (Palme, 2005). Thus, the Swedish pension system could broadly be described as Bismarckian. An overview of the Swedish pension systems for our cohorts is provided in Appendix C.1.

The statutory retirement age was 65 for our cohorts, although individuals could (and commonly did) access many of their retirement benefits beginning at age 60 (Hagen, 2013). Our pension variable covers a wide selection of first- and second-pillar pensions (Whitehouse, 2006), including other pensions targeted at individuals with special needs (e.g., survivor's pension). However, the variable does not cover sickness and disability pension schemes targeted at ages before the statutory retirement age. For the cohorts analyzed, individuals could save in private annuities (i.e., "pension insurance") with different tax rates, depending on the saver's circumstances. Private pensions (paid out as a normal pension) are included in our pension variable, but they are rare.

5.3 Data and Methods

5.3.1 Data

Our analyses draw on two data sets—tax and death registers—linked with a unique personal ID number. The initial sample includes 209,491 individuals born in 1920 (55.6%) or 1925 (44.4%). The use of two cohorts helps test the robustness of the results. No important institutional change occurred between the two cohorts, so differences in results would reflect cohort differences in mortality schedules and earnings inequality, with the latter partly explained by cohort differences in labor force participation, particularly for women. (See Tables C.1 and C.2, Appendix C.3.) We exclude 1,628 individuals who had international migration records after age 50; 17,050 individuals who died before age 60; and 5,027 individuals with missing values for key variables (mainly education). Hence, the analytic sample contains 103,712 individuals born in 1920 and 82,074 individuals born in 1925.

Individuals' yearly labor earnings and pension income are derived from taxation registers. The main outcome variable lifetime pension income includes state pensions, employer-financed pensions, and private pensions (private pensions being a very small share; see Apendix C.1). We focus on pension income at ages 60 and older; lifetime pensions are conditional on surviving to age 60.[1]

We examine two socioeconomic factors: education and preretirement labor earnings. The education variable is obtained from education registers and has three levels: primary, secondary, and tertiary (or more). We group individuals into earnings quintiles based on (pretax) labor earnings over ages 50–59, separately by gender.[2] Ideally, we would include earnings at younger ages for grouping, but earlier

[1]After conditioning on surviving to age 50, we find that 5.8% (11,418) did not reach age 60. Men, the less educated, and those with less income were more likely to die before age 60 than women, the more educated, and those with more income, respectively (see Table C.3, Appendix C.3).

[2]Appendix C.3 shows the proportion of individuals with years of zero earnings over ages 50–59 (Tables C.1 and C.2) and the mean and standard deviation of the earnings variable (Table C.4).

data are not available. Grouping based on lifetime earnings (i.e., earnings over the entire work history) may lead to different results. However, the most important part of the Swedish pension system for our cohorts, the Allmän Tillägspension, is based on income during the highest-earning 15 years (in practice, often around ages 50–59), not lifetime earnings. The average annual earnings over these 10 years include years with zero earnings, but excluding years with zero earnings when calculating average annual earnings produces very similar results. A large share of women were (mostly) outside the labor force because female labor force participation was far from universal in Sweden at the time. Therefore, the lowest quintile mostly includes women outside the labor market. Women in the second quintile had some labor force attachment. For the third and higher quintiles, the variable reflects different income levels among working women (see Table C.2). Earnings and pension income are shown in 1,000 Swedish krona (SEK). The exchange rate of SEK to U.S. dollars varied over the period, with an average of approximately SEK 8 to US$1.

Death records are available until 2019. In total, 1,658 (1.6%) individuals from the 1920 cohort survived to 2020 (age 99), and 8,387 (10.2%) individuals from the 1925 cohort survived to 2020 (age 94). For individuals who survived to 2020, we assume that their pension income is constant with the last three years' average over subsequent years and that their mortality follows Statistics Sweden's (2020) forecasts.[3]

[3]This assumption is reasonable because inflation-adjusted pension income is relatively invariable over time (see Figures C.1 and C.2). We use Statistics Sweden's (2020) mortality forecasts for ages that were not observable (ages 100+ for the 1920 cohort and 95+ for the 1925 cohort). Within gender, we calculate mortality rates for SES groups by assuming relative mortality differences (i.e., mortality ratios) between SES groups in future years to be the same as those observed in 2015–2019 while matching total gender-specific mortality rates to those forecasted by Statistics Sweden. The potential bias in our assumption should be minor for our estimates of lifetime pensions at age 60, given that only a small proportion of individuals from the two cohorts survived to 2020.

5.3.2 Lifetime Pension Income

Our analyses are based on cohort life tables. For each subgroup, we construct a life table from age 60 to age 105+. Then, we add a column of age-specific pension income, pen_x, to the life table. Lifetime pensions conditional on surviving to age 60, LP_{60}, are a function of inputs: the total number of individuals surviving to age 60 (l_{60}), person-years lived in the age interval $[x, x+1)$, L_x, and pen_x:

$$LP_{60} = f(l_{60}, L_x, pen_x) = \frac{1}{l_{60}} \sum_{x=60}^{\omega} L_x \times pen_x, \tag{5.1}$$

where ω is the terminal age 105+, and the radix l_{60} is 1. This equation is analogous to Sullivan's (1971) method of healthy life expectancy, a widely used technique in population health research. The difference is that we replace the proportion of individuals without morbidity with penx. Applying life table equations that Chiang (1960, 1972) suggested, we can write L_x in the form of age-specific mortality rates (m_x) and average person-years lived in the age interval $[x, x+1)$ for persons dying in this interval (a_x):

$$L_x = L_{x-1} \times \frac{1 - m_{x-1}a_{x-1}}{1 + m_x - m_x a_x}, \tag{5.2}$$

We assume ax to be 0.5. This assumption works well and is widely used for calculating life tables. Hence, LP_{60} is a function of mx and penx:

$$LP_{60} = f(m_x, pen_x). \tag{5.3}$$

For earnings and pension income, we adjust for inflation, with 2018 as the base year.

Some studies used a discount rate when calculating lifetime pensions because they focused on the actuarial sustainability of pension systems (e.g., NASEM 2015; Dudel and Schmied, 2008; Whitehouse, 2006). This calculation adds less weight to pensions at older ages. We do not include a discount rate in our main analyses, given that our primary interest is in the received money flows in the pension system. Also, accumulating nondiscounted values is standard in research on social stratification.

For comparability with other studies focusing on pension sustainability, we present results derived from using a discount rate of 2% in Appendix C.2. This discount rate approximates the GDP per capita growth and wage growth over the period, and overall income growth determines the long-term financial sustainability of a pay-as-you-go system (Samuelson, 1958).

Using the life table approach, we aggregate individuals by their lifespan and then calculate the average lifetime pension. This approach essentially yields the same result as directly averaging individuals' lifetime accumulated pension (i.e., without aggregating by lifespan first). Variation across individuals of the entire population calculated from a life table approach (e.g., Olivera, 2019) differs from direct individual calculations because aggregating individuals to the midpoint of one-year age-groups reduces the variation to some extent.

5.3.3 Decomposition

Decomposition techniques are widely applied to explain the difference in an aggregate measure between two (sub)populations by differences in its input covariates. As described earlier, lifetime pensions are a function of covariates m_x and pen_x, and our aim is to explain the difference in lifetime pension between SES groups by differences in m_x and pen_x. We apply the Horiuchi et al. (2008) decomposition method. Specifically, LP_{60} can be seen as a differentiable function of the covariates m_x and pen_x. We assume continuous changes between the two groups of interest (e.g., low and high SES). Lifetime pensions of low- and high-SES groups are denoted as LP^1_{60} and LP^2_{60}, respectively, and the difference between them can be written as follows:

$$LP^2_{60} - LP^1_{60} = \sum_{x=60}^{\omega} \left(\int_{m^1_x}^{m^2_x} \frac{\partial f(m_x, pen_x)}{\partial m_x} dm_x + \int_{pen^1_x}^{pen^2_x} \frac{\partial f(m_x, pen_x)}{\partial pen_x} dpen_x \right). \quad (5.4)$$

This way, the total difference between LP^1_{60} and LP^2_{60} is split into components attributable to differences in m_x and pen_x. Numeric integration is used for the estimation (Horiuchi et al., 2008). This decomposition method has been widely used to decompose health expectancies (van Raalte and Nepomuceno, 2020).

We apply a second decomposition by further splitting the pen_x into two components: *earn* and $diff_x$. Here, *earn* is the average yearly labor earnings between ages 50 and 59, and $diff_x$ is the difference between pension income at each age and the average earnings at ages 50–59 (i.e., $pen_x = earn + diff_x$).[4] The covariates are m_x4, $diff_x$, and earn. This reformulation is motivated by the large proportion of inequalities in yearly pension income attributable to inequalities in preretirement labor earnings. Generally, $diff_x$ takes negative values because individuals' pension income tends to be lower than their previous labor earnings. A $diff_x$ closer to zero means pension income more closely matches labor earnings. Therefore, comparing $diff_x$ across SES indicates the redistribution effect (measured yearly). If $diff_x$ is smaller in absolute value among low-SES groups than among high-SES groups, the system is progressive. The total contributions of earn and $diff_x$ sum to the total contributions of pen_x in the first decomposition. The decomposition method is implemented using the R package *DemoDecomp* (Riffe, 2018).

We also analyze the impacts of several scenarios of policy and mortality changes. Changes in retirement ages are examined by shifting pen_x along age x.[5] Changes

[4]Alternatively, the relationship between prior earnings and yearly pension income can be specified as a ratio. Our pension variable is the sum of pension incomes from various programs, and many of them are not earnings-related. Thus, theoretically, the relationship between yearly pension income and prior earnings is neither additive nor relative. Empirically, the relationship between earnings and yearly pension income depends on the location of the earnings distribution. Particularly at the lower end of the earnings distribution, yearly pension income is unlikely to be related to earnings on a ratio basis. For instance, for women with zero earnings (more than 40% of the lowest income quintile for the 1920 cohort), the ratio would be positive infinity. A small increase in earnings does not lead to a big increase in pension income because of the guarantee pension. The ratio between average yearly pension and average earnings for the lowest female quintile in 1920 is 15.14, whereas the usual replacement rate of occupational pension is smaller than 1. Thus, the specification of using ratios is empirically less meaningful than the specification of using absolute differences.

[5]When examining the impact of raising the retirement age by one year, we replace pen_x with pen_x1 for ages 61–105 and set pen_{60} to 0. When examining the impact of lowering retirement age by one year, we replace pen_x with $pen_x + 1$ for ages 60–104 and leave pen105 unchanged. This approach might not perfectly reflect reality because individuals' retirement patterns may change as a result of changes in statutory retirement age, but it is a good starting point for the analysis of such policies.

in the pension system generosity are assessed by recalculating pen_x. Mortality scenarios are evaluated by modifying the m_x.[6]

5.4 Results

Table 5.1 shows that life expectancy at age 60 increases by education and earnings quintile for both men and women (see also the survival curves in Figures C.3 and C.4). For the 1920 cohort, men aged 60 in the highest earnings quintile were expected to live 4.5 more years than their peers in the lowest quintile (22.0 vs. 17.5 years). Similarly, for the 1920 cohort, life expectancy was 2.6 years lower for men with primary education than for men with tertiary education; the corresponding gap for men in the 1925 cohort was 3.4 years. We found similar patterns for women, albeit to a lesser extent. Overall, mortality differences by earnings were smaller for women than for men. Interestingly, unlike men, women in the lowest earnings quintile did not have the lowest life expectancy. Table 5.1 also shows that men and women who were more educated and who earned higher incomes had higher pension incomes at age 70, reflecting an income-based pension system. Overall, pensions increased rapidly up to age 66 and remained stable for all groups thereafter (see age-specific pension income in Figures C.3 and C.4).

[6] We examine simple scenarios in which mortality rates across all ages experience the same proportional reduction.

Table 5.1: Descriptive statistics for remaining life expectancy at age 60, average pension at age 70, and lifetime pension: Means, with percentages shown in parentheses

	Number		LE_{60} (years)		Mean Pension at 70 (in SEK 1,000)[a]		Lifetime Pension (in SEK 1,000)[a]	
	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort
Men Total	51,088 (100)	40,368 (100)	20.0	21.0	192.2	197.6	3,173.5	3,589.2
Men by Education								
Primary	34,757 (68)	25,486 (63)	19.5	20.2	168.5	169.3	2,705.7	2,992.8
Secondary	13,086 (26)	11,328 (28)	20.8	21.7	222.3	221.0	3,795.6	4,128.6
Tertiary	3,245 (6)	3,554 (9)	22.1	23.6	311.4	311.9	5,650.4	6,138.8
Men by Earnings								
Lowest	10,218 (20)	8,074 (20)	17.5	18.6	105.8	113.6	1,606.6	1,913.6
Second	10,217 (20)	8,073 (20)	19.3	20.2	158.4	161.4	2,465.2	2,802.0
Third	10,218 (20)	8,074 (20)	20.2	21.0	178.0	178.6	2,932.9	3,273.3
Fourth	10,217 (20)	8,073 (20)	20.9	21.8	204.6	209.8	3,507.8	3,930.9
Highest	10,218 (20)	8,074 (20)	22.0	23.2	298.3	309.6	5,334.9	6,014.1
Women Total	52,624 (100)	41,706 (100)	24.5	25.1	109.4	118.8	2,405.8	2,725.6

Table 5.1 (continued)

	Number		LE_{60} (years)		Mean Pension at 70 (in SEK 1,000)[a]		Lifetime Pension (in SEK 1,000)[a]	
	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort
Women by Education								
Primary	41,128	31,049	24.2	24.7	99.8	107.3	2,178.0	2,443.5
	(78)	(74)						
Secondary	9,363	8,300	25.3	26.0	131.6	136.6	2,925.3	3,169.1
	(18)	(20)						
Tertiary	2,133	2,357	27.1	27.3	192.8	203.3	4,503.0	4,888.5
	(4)	(6)						
Women by Earnings								
Lowest	10,525	8,341	24.6	24.9	65.6	63.5	1,481.0	1,621.4
	(20)	(20)						
Second	10,525	8,341	23.2	23.8	72.2	79.6	1,618.6	1,871.8
	(20)	(20)						
Third	10,524	8,341	24.7	25.6	93.2	109.0	2,117.8	2,526.0
	(20)	(20)						
Fourth	10,525	8,341	24.7	25.2	127.9	141.0	2,761.8	3,134.1
	(20)	(20)						
Highest	10,525	8,342	25.4	26.1	185.9	198.0	4,044.4	4,475.2
	(20)	(20)						

Note: See summary statistics for the earnings variable in Table C.4.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] We adjusted inflation to the 2018 level when computing the average pension at age 70 and lifetime pensions. SEK 1,000 ≈ US$125.

We find substantial gaps in lifetime pensions between education and earnings groups.[7] Lifetime pension income of men with tertiary education was more than twice that of men with primary education. The absolute difference was about SEK 3 million (approximately US$375,000) for both cohorts. Differences for women with primary versus tertiary education were SEK 2.3–2.4 million for both cohorts. Additionally, lifetime pensions increased by earnings quintile for men and women, with the largest difference observed between the fourth and highest quintiles for both genders and both cohorts.

We also find large differences by gender: men had shorter life expectancies but higher lifetime pensions than women. For any given quintile from the second onward, women had lifetime pensions that were approximately similar to those of men of the preceding quintile. Additional analysis (Figure C.9) shows that women had an advantage because of their lower mortality, but a disadvantage in yearly pension income more than offset the mortality component and led to an overall male advantage in lifetime pensions.

Education and earnings differences in life expectancy are larger among men than among women. The literature has long documented gendered differences in the association between SES and mortality (Pappas et al., 1993). On the other hand, differences in yearly pension income were smaller (in absolute terms) between women's SES groups than between men's SES groups because of a more homogeneous income distribution among working-age women than working-age men. Both mortality and yearly pension levels resulted in larger gaps in lifetime pension income between men's SES groups.

[7] See Figures C.5 and C.6 for box plots of observed (i.e., truncated) accumulated pensions income until the end of 2018. Lifetime pensions are defined here as the expected value of accumulated pension from age 60 to death, but they can also be calculated from age 60 to a specific age, analogous to temporary life expectancy (i.e., expected years of life within the specified age interval). These results are presented in Figures C.7 and C.8.

Decomposition results for the comparison between primary and tertiary education groups by gender and cohort are shown in Figure 5.1, where the sum of all red and black bars in each panel equals the total difference in lifetime pension. Mortality differences accounted for an important part of the total differences in lifetime pension. For men born in 1920, differences in mortality rates of all ages above 60 resulted in a difference of SEK 636,000 in lifetime pension income, constituting 22% of the total difference (SEK 2,945,000); corresponding figures for men in the 1925 cohort were SEK 852,000 and 27%, respectively. However, lifetime pension differences due to yearly pension income showed almost no change across the cohorts for men. As shown in Table 5.1, women had lower annual and lifetime pensions than men. Overall, the SES gradient in annual pension levels was similar for men and women. In absolute terms but not relative terms, we find a larger difference in lifetime pensions across SES groups for men than for women. Women had a less marked SES gradient for mortality, particularly for earnings groups.

Among men, the importance of mortality differences between the two cohorts increased slightly, in line with the increasing gap in remaining life expectancy (from 2.6 to 3.4 years). Contributions of mortality were smaller for women's educational groups than men's (in absolute and relative terms), which is reasonable given that mortality differences between women's education groups were also smaller. The magnitude of contributions of mortality differences decreased only at advanced ages (around age 85); before this point, age-specific mortality contributions were relatively stable. This finding could be explained by the decline in SES differences in mortality with increasing age and the steeper slope above age 85 (Figure C.10). Indeed, the age patterns of mortality in Figure 5.1 resemble the age patterns of mortality when life expectancy differences are decomposed (Figure C.11). The contributions of age-specific pension and mortality were much lower at older ages because many fewer people survived to these ages.

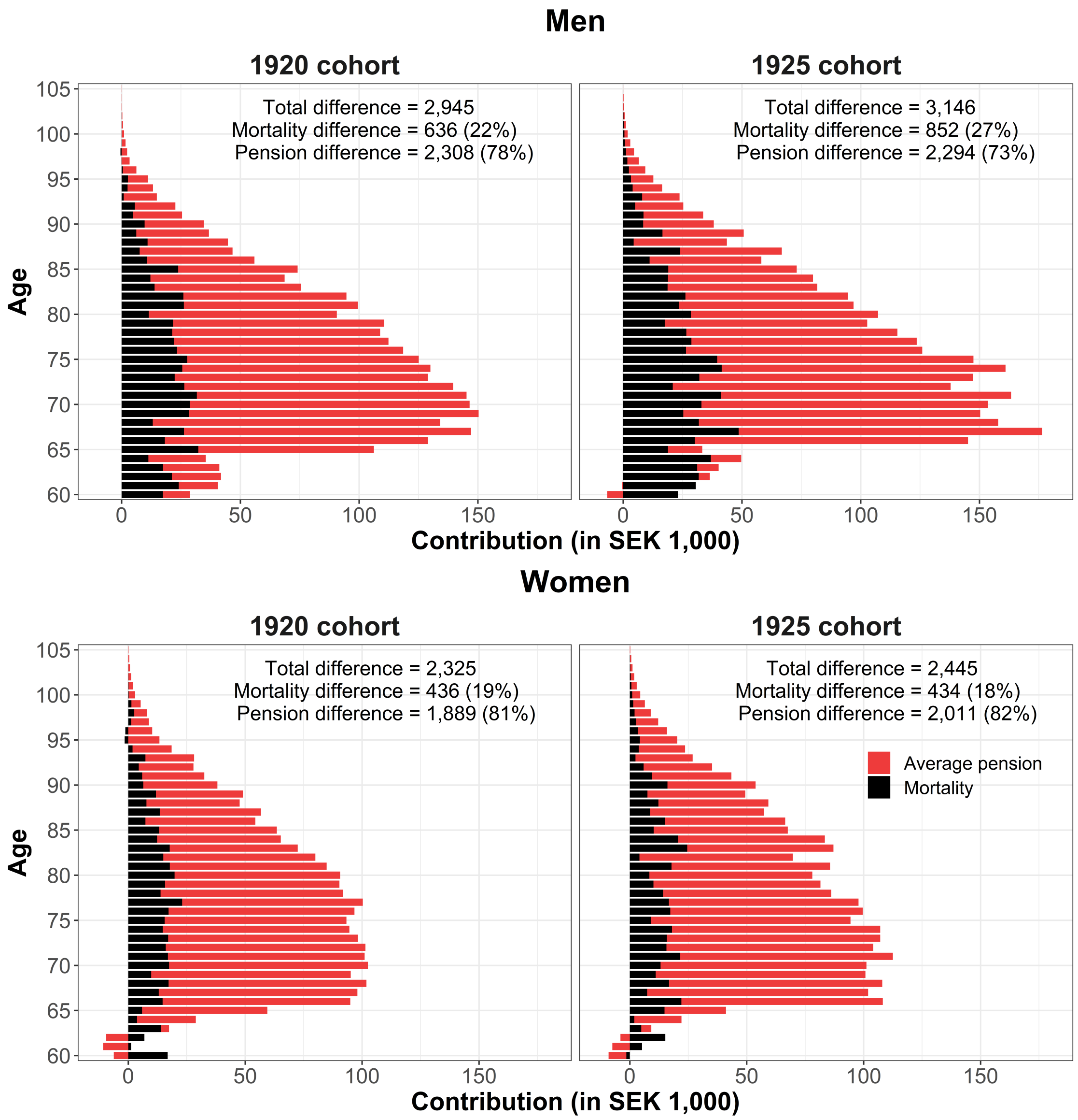

Figure 5.1: Decomposition of total lifetime pension differences between primary and tertiary education groups into differences explained by mortality and yearly pension. *Note:* SEK 1,000 ≈ US$125. *Source*: Authors' calculation based on linked register data from Statistics Sweden.

Meanwhile, age-specific differences in pension income contributed significantly only beginning at the typical retirement age of 65 for men and women in both cohorts. Before age 65, contributions to yearly pension income were minor and even reversed among women because lower educated women retired earlier much more frequently and had higher average pension income at these ages. Men's and women's contributions of yearly pension differences were consistently high beginning at age 66 and started decreasing rapidly at approximately age 80.

Figure 5.2 shows the decomposition results for comparisons of the lowest and highest earnings quintiles. For men, we largely find the same patterns as for education. The differences in lifetime pension were larger in the 1925 cohort. For women, the earnings results differ from the education findings: the contributions of mortality differences were much smaller, accounting for only 4% and 6% of lifetime pension differences between the lowest and highest quintiles for the 1920 and 1925 cohorts, respectively. As noted earlier, women's life expectancy at age 60 was not the lowest among the lowest earnings quintile, and mortality was only slightly higher among women in the lowest quintile than among those in the highest quintile. Figures 5.1 and 5.2 show that most lifetime pension inequalities were explained by differences in yearly pension income, which was largely determined by preretirement labor earnings. On the other hand, most pension systems are progressive and aim to provide higher replacements for low-SES groups. Thus, the differences in lifetime pensions between SES groups explained by average yearly pensions (red bars) observed in Figures 5.1 and 5.2 are a function of both labor earnings and the pension system's redistribution effect. We further explored this aspect by splitting age-specific pension income into two components: preretirement labor earnings and the difference between pension income and labor earnings. Hence, we estimated the extent to which preretirement labor earnings and the pension system's redistribution function (perceived yearly) contributed. Before showing these results, we show how pension income is attached to labor earnings by education and earnings group. We calculated the difference and ratio between individuals' average yearly pension income at ages 66–75 and average yearly earnings at ages 50–59. This calculation, though, does not reflect any formula for how earnings were translated into pensions in the pension system, which was not possible because our pension variable included divergent pension programs.

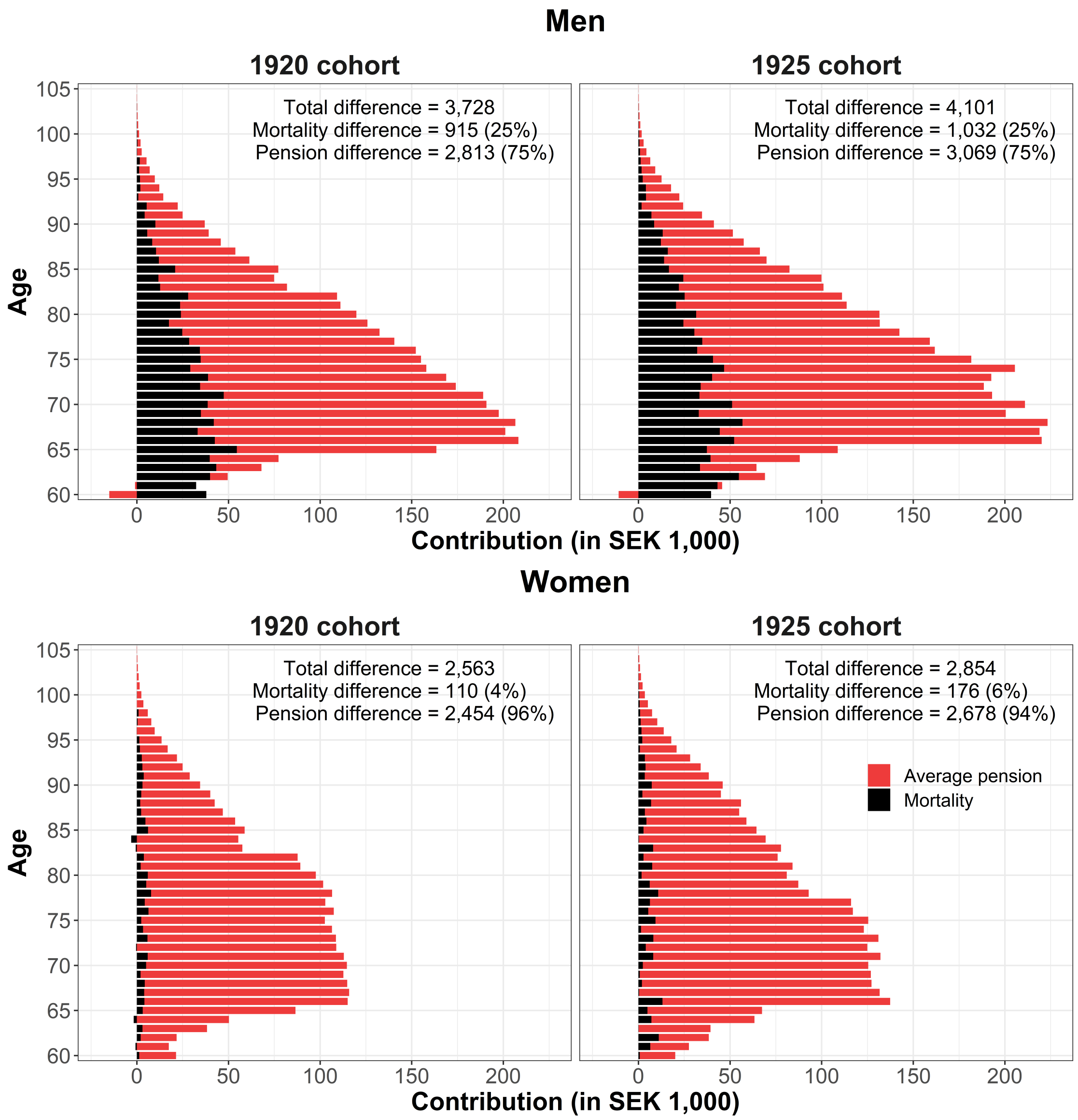

Figure 5.2: Decomposition of total lifetime pension differences between the bottom and the top earnings quintile groups into differences explained by mortality and yearly pension. *Note:* SEK 1,000 ≈ US$125. *Source*: Authors' calculation based on linked register data from Statistics Sweden.

Table 5.2 shows that the difference and the ratio declined with education and earnings quintile, indicating progressivity in the pension system. Whereas women in the highest earnings quintile born in 1920 received approximately three fourths of their labor earnings, their peers in the lowest quintile received pensions more than 15 times their labor earnings. The large ratio for women in the lowest quintile reflects a guarantee pension, which benefits individuals with very low earnings, such as homemakers. However, from the second to the fourth quintiles, the ratio and the difference decreased little for men and moderately for women. In the 1925 cohort, the ratio decreased from 0.78 to 0.74 for men and from 0.94 to 0.77 for women. Thus, the pension system translated earnings into pensions at nearly constant rates for individuals who had medium earnings, with only modest progressivity. The relatively weak link between women's earnings and pension partly reflects that women received a comparatively large share of their income as widowhood pensions (which was independent of their own earnings) because many of them married older husbands (Kolk, 2015) and outlived their husbands.

Table 5.3 shows the results of an extended three-way decomposition. For simplicity, we refer to the three components attributable to mortality, differences between pension income and preretirement labor earnings, and labor earnings as mortality effect, redistribution effect, and earnings effect, respectively. The results show that most of the total lifetime pension difference was due to the earnings effect. Differences in lifetime pensions would have been considerably larger without a progressive pension system. If there had been no redistribution between groups, SES differences would have been approximately twice as large. It is noteworthy that the decompositions were based on comparisons between the lowest and highest SES groups. We expect to see a much smaller redistribution when comparing groups in the middle of the SES distribution, as suggested by the results in Table 5.2. The overall patterns in Table 3 are similar across different comparisons, except for the comparison between women's lowest and highest earnings quintiles. Compared with women in the lowest quintile, women in the highest quintile had much higher earnings, but they (as shown in Table 5.2) received only 72% of their labor earnings as their pension (at age 70) versus more than 1,500% for women in the lowest quintile. Such substantial differences resulted in huge earnings and redistribution effects, driving lifetime pension inequality in opposite directions. The differences explained by mortality are of lower magnitude than SES differences in earnings and the progressive redistribution of the pension system.

Table 5.2: Absolute and relative differences between average yearly pension income (at ages 66–75) and average yearly labor earnings (at ages 50–59) across educational groups and earnings quintiles

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Difference (in SEK 1,000)[a]	Ratio	Difference (in SEK 1,000)[a]	Ratio	Difference (in SEK 1,000)[a]	Ratio	Difference (in SEK 1,000)[a]	Ratio
Total	−74.08	0.72	−66.89	0.75	−0.40	1.00	−17.21	0.88
By Education								
Primary	−55.54	0.75	−51.56	0.77	5.30	1.06	−12.78	0.90
Secondary	−95.97	0.70	−80.92	0.74	−13.66	0.91	−25.38	0.85
Tertiary	−200.63	0.60	−148.09	0.68	−58.44	0.77	−52.00	0.80
By Earnings								
Lowest	−12.10	0.90	−12.17	0.90	60.05	15.14	45.62	3.32
Second	−46.28	0.77	−46.45	0.78	28.29	1.65	−4.76	0.94
Third	−63.31	0.74	−62.06	0.75	−3.24	0.97	−21.89	0.84
Fourth	−82.04	0.71	−76.46	0.74	−25.98	0.83	−42.11	0.77
Highest	−183.41	0.62	−154.00	0.67	−63.75	0.74	−65.98	0.75

Source: Authors’ calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table 5.3: Three-way decompositions of differences in lifetime pensions between education and earnings groups

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%
Primary vs. Tertiary Education								
Mortality effect	636.2	21.6	852.1	27.1	436.1	18.8	433.5	17.7
Redistribution effect	−3,597.8	−122.2	−2,963.6	−94.2	−2,086.4	−89.7	−1,569.4	−64.2
Earnings effect	5,906.2	200.6	5,257.5	167.1	3,975.2	171.0	3,580.9	146.5
Total	2,944.7	100.0	3,146.0	100.0	2,325.0	100.0	2,444.9	100.0
Lowest vs. Highest Earnings Quintiles								
Mortality effect	915.0	24.5	1,032.0	25.2	109.6	4.3	175.8	6.2
Redistribution effect	−4,269.7	−114.5	−4,026.9	−98.2	−3,632.8	−141.7	−3,655.3	−128.1
Earnings effect	7,083.0	190.0	7,095.5	173.0	6,086.5	237.4	6,333.4	221.9
Total	3,728.3	100.0	4,100.6	100.0	2,563.3	100.0	2,853.8	100.0

Note: Mortality effect, redistribution effect, and earnings effect refer to the parts of total lifetime pension differences attributable to differences in mortality, differences in the differences between pension income and labor earnings, and differences in labor earnings, respectively.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

In comparisons of less-divergent SES groups (e.g., primary vs. secondary education, lowest vs. third earnings quintiles), the absolute differences in lifetime pension are unsurprisingly smaller, yet the share explained by mortality differences is more or less constant across comparisons (see Tables C.5 and C.6 and C.12–C.16). Our main findings are robust in these comparisons. Among them, the largest differences in lifetime pension are those between secondary and tertiary education groups and the third and highest earnings quintiles, suggesting that the differences between SES groups were particularly large between the most advantaged groups and others. To make our results comparable to previous studies focusing on actuarial aspects and financing of pension systems, we replicated our calculations using a discount rate of 2%, giving more weight to present incomes rather than future pension incomes (see Table C.7 and Figures C.17 and C.18). In these calculations, money received at younger ages is valued more. Hence, we observe that mortality was less explanatory of differences in lifetime pension between SES groups, given that low-SES groups obtained a relatively higher share of their pensions earlier; the longevity advantage of high-SES groups at older ages becomes less important when a discount rate is used.

In Table 5.4, we show ratios of yearly earnings, yearly pension, lifetime pension income, and life expectancy between low- and high-SES groups. Yearly pension income is the most equal among the three monetary outcomes, and yearly earnings are the most unequal. The inequality level of lifetime pension income falls between the two. One exception is that for women in the lowest versus highest earnings quintiles, yearly pension is more unequal than lifetime pension income. This finding is likely due to the ages used to compare yearly pension income (ages 66–75): yearly pension income for the highest versus lowest female earnings quintiles is more equal at older ages owing to increases in the minimum pension over time (see Figure C.2). We also find that differences in life expectancy between SES groups (and between men and women) are much smaller than differences in lifetime pensions.

Table 5.4: Ratios of yearly earnings, yearly pension, lifetime pension, and life expectancy at age 60 between education and earnings groups

	Men		Women	
	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort
Primary vs. Tertiary Education				
Yearly earnings				
(average over ages 50–59)	2.28	2.08	2.66	2.13
Yearly pension				
(average over ages 66–75)	1.84	1.84	1.93	1.90
Lifetime pension income (at ages 60+)	2.09	2.05	2.07	2.00
Life expectancy at age 60	1.13	1.17	1.12	1.11
Lowest vs. Highest Earnings Quintiles				
Yearly earnings				
(average over ages 50–59)	4.10	3.69	58.33	13.63
Yearly pension				
(average over ages 66–75)	2.82	2.74	2.86	3.10
Lifetime pension income (at ages 60+)	3.32	3.14	2.73	2.76
Life expectancy at age 60	1.25	1.25	1.03	1.05

Source: Authors' calculation based on linked register data from Statistics Sweden.

Lastly, in addition to decompositions based on the 1920 and 1925 cohorts' experiences, we examined how counterfactual scenarios of policy changes and mortality reduction affect lifetime pension differences to understand which factors are important for lifetime pension and how they affect SES differences in lifetime pensions. Table 5.5 shows the results for the comparisons between primary and tertiary education for the 1920 cohort. Results for other comparison groups are highly consistent (Tables C.8–C.10). We examined how changes in retirement timing and pension system generosity will affect SES gradients. A uniform increase in retirement age would have led to a smaller gap in lifetime pensions in absolute terms because more highly educated individuals had higher yearly pension income and thus would have lost more pension benefits in absolute terms. Yet, uniform increases in retirement age would have enlarged lifetime pension inequality in relative terms because lower earners would have lost a higher proportion of lifetime pension.

The magnitude of these changes is small, particularly for relative inequalities. If the change in retirement timing had differed by education such that the less educated were to retire earlier than they did or the more educated were to increase their retirement age, lifetime pension inequality would have been reduced in both absolute and relative terms. In the extreme case in which only individuals with tertiary education were to postpone their retirement age by three years, the absolute differences in lifetime pension would have decreased by 30.2% and 25% for men and women, respectively. However, the absolute differences in lifetime pension would have remained high, at more than SEK 2 million for men and SEK 1.7 million for women.

Increasing yearly pension by the same fixed amount for all individuals would have increased lifetime pension inequality in absolute terms because the more educated would have benefited more given their longer life expectancy; however, it would have reduced relative inequality. Increasing the minimum pension, which would have affected mainly those with the least pension, would have reduced both absolute and relative inequality.

Finally, we considered changing mortality rates. If mortality had decreased by 10% across all ages for all groups, absolute inequality in lifetime pension would have been larger, but relative inequality would have been smaller. If mortality rates had been reduced by 10% for the less educated but remained stable for the more educated, lifetime pension inequality would have decreased in both absolute and relative terms. Stagnation of mortality among the less educated and a 10% reduction in mortality among the more educated would have exacerbated lifetime pension inequality. The magnitude of the effects of these scenarios is even more limited than in the retirement age scenarios. Overall, even though these scenarios reflect quite large changes in the pension system or behavior, the impact on overall SES differences in lifetime pension is quite small compared with empirically observed differences (see Table 5.1). This finding underscores the importance of prior earnings inequality in generating old-age inequalities.

Table 5.5: Lifetime pension inequality between primary and tertiary education under policy and mortality scenarios, 1920 cohort

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Observed	2,944.7	—	2.09	—	2,325.0	—	2.07	—
Uniform Increase in Retirement Age								
One-year increase	2,803.4	−4.8	2.10	0.6	2,231.4	−4.0	2.07	0.4
Three-year increase	2,525.5	−14.2	2.13	2.0	2,046.5	−12.0	2.09	1.2
Differential Retirement Ages								
Primary edu. one year earlier	2,815.4	−4.4	1.99	−4.1	2,253.0	−3.1	2.00	−3.2
Primary edu. three years earlier	2,580.7	−12.4	1.84	−11.9	2,129.8	−8.4	1.90	−8.2
Tertiary edu. one year later	2,643.0	−10.2	1.98	−5.3	2,129.2	−8.4	1.98	−4.3
Tertiary edu. three years later	2,055.8	−30.2	1.76	−15.7	1,743.5	−25.0	1.80	−12.9
Pension System More Generous								
Yearly pension SEK 10,000 more	2,970.7	0.9	2.02	−3.1	2,353.5	1.2	1.97	−4.6
Yearly pension SEK 20,000 more	2,996.7	1.8	1.97	−5.8	2,382.1	2.5	1.89	−8.3
Pension System Less Generous								
Yearly pension SEK 10,000 less	2,918.7	−0.9	2.16	3.5	2,296.4	−1.2	2.19	5.7
Yearly pension SEK 20,000 less	2,892.7	−1.8	2.25	7.7	2,267.9	−2.5	2.34	−13.1
Raising Minimum Pension								
Minimum pension to SEK 80,000	2,934.3	−0.4	2.07	−0.6	2,223.5	−4.4	1.96	−5.4
Minimum pension to SEK 100,000	2,911.4	−1.1	2.05	−1.6	2,081.5	−10.5	1.82	−11.7
Mortality Reduction Scenarios								

Table 5.5 (continued)

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
10% less for all	3,073.6	4.4	2.08	−0.6	2,394.0	3.0	2.06	−0.5
Primary 10% less, tertiary 0% less	2,792.4	−5.2	1.98	−5.3	2,236.2	−3.8	1.99	−3.9
Primary 0% less, tertiary 10% less	3,225.9	9.5	2.19	5.0	2,482.8	6.8	2.14	3.5

Notes: The observed average lifetime pensions are SEK 2,705,700 for men with primary education, SEK 5,650,400 for men with tertiary education, SEK 2,178,000 for women with primary education, and SEK 4,503,000 for women with tertiary education. For the scenarios of changing retirement age, we shift the observed yearly pension income to younger or older ages by one or three years. In the case of earlier retirement by one year, the last year (i.e., age 105) of pension income is assumed to be the same as the pension income in the last observed year (i.e., age 104). In the case of later retirement by one year, the first year (i.e., age 60) of pension income is set to 0. For the mortality scenarios, we reduce mortality rates across all ages by 10%.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

5.5 Discussion

This study documents large differences in lifetime pensions across SES groups in Sweden. Three factors determine total lifetime pension inequality. First, higher annual earnings before retirement translate to a higher annual pension income. Second, higher life expectancy among high-SES groups results in more lifetime pensions. These two factors contribute to higher inequalities in lifetime pensions. Third, a higher replacement rate among low-SES groups decreases lifetime pension inequalities through a redistributive pension system. We show that a longevity advantage explains up to one quarter of the higher lifetime pensions among high-SES groups, particularly among men. Thus, over a lifetime, mortality differences between SES groups dampen pension system progressivity. However, the results also indicate that mortality is less important than the underlying earnings inequality in working years that carries over into retirement.

Our findings are generally in line with previous research on the topic, which has used different methodological approaches. Many studies have examined the extent of redistribution and how it is affected by mortality differences. Studies have found that mortality cancels out more than 25% of the redistribution in the French pension system, almost fully offsets the redistribution in the U.S. old-age Social Security system, and makes the German and Italian systems regressive (Bommier et al., 2005; Haan et al., 2020; Mazzaferro et al., 2012; Sánchez-Romero et al., 2020). Taken together, these studies highlight that the role of mortality in a pension system varies across countries. Pension designs, individual work histories, and SES mortality patterns may explain cross-country differences. Comparative studies might elucidate the relative importance of these factors in future work. Such analyses of redistribution involve lifetime contributions. Because of data limitations, we focus only on inequalities in lifetime benefits and do not directly examine redistribution.

Socioeconomic inequalities in health and mortality inequalities in Sweden have been among the lowest in Europe since the 1980s (Mackenbach et al., 2018). In

2011, the gap in life expectancy at age 65 between Swedish men with low versus high education was 2.8 years, lower than the average of 3.6 years among 18 OECD countries; for women, the gap was 2.9 years, higher than the OECD average of 2.6 years (Murtin et al., 2022). Research suggests an increasing SES gap in longevity globally (Brønnum-Hansen and Baadsgaard, 2012; Kravdal, 2017; Meara et al., 2008; Östergren, 2015; Permanyer et al., 2018). An open topic is whether the COVID-19 pandemic will affect the socioeconomic mortality gradient (Clouston et al., 2021; Drefahl et al., 2020) and how the pandemic will affect lifetime pension inequality. Mortality inequality might contribute more to lifetime pension inequality in the future. In this study, we found only small cohort differences, but the direction of change suggested a trend toward larger differences.

The pension system design may help interpret our results. Mortality's contribution to SES differences in lifetime pensions is arguably larger without occupational pensions, which provide more generous replacement rates above the state income pension. In the extreme case in which pension income is unrelated to preretirement earnings, SES differences in lifetime pensions would be solely determined by mortality. Because of generous replacement rates in occupational pensions for higher earners, the overall net replacement rate in the mandatory pension schemes (i.e., public and occupational pensions) appears to be U-shaped across earnings, which is unique among OECD countries (OECD, 2021a). Given that Sweden has one of the least progressive first- and second-pillar pension systems among OECD countries (OECD, 2021a), preretirement earnings will be less important and mortality will be more important in other countries. Across cohorts, the share of public pensions has decreased, whereas the share of occupational and private pensions has increased in Sweden (Hagen, 2017); thus, preretirement earnings will be more important in generating SES inequalities in lifetime pensions in the future.[8]

[8]Additionally, the reliance on first- and second-pillar pensions differs considerably across

Lifetime pensions are more unequally distributed across male SES groups than female SES groups. There are three potential explanations for this finding. First, the SES mortality gradient is usually stronger for men than for women, as found in this study and consistent with prior research (Mackenbach et al., 2018). Among women, the association between low income and high mortality is even reversed in the lowest two quintiles—perhaps because for our cohorts, women in the lowest quintile are often outside the labor market and rely on their husbands with higher incomes, whereas women in the second and third quintiles are more often in the labor market (see Table C.2) and live alone (see Table C.11) or in households with low income.[9] Second, the redistributive effect is stronger for women. Women in the lowest earnings quintile are protected by the minimum pension and, to some extent, by widowhood pensions (given the much higher ratio between pension income and earnings for women in the lowest quintile vs. higher quintiles). Third, women display smaller inequalities in preretirement earnings than men. Because the majority of lifetime pension inequality is explained by preretirement earnings, gender differences in the magnitude of lifetime pension inequality by SES could also be explained by the more homogeneous earnings distribution across women's SES groups.

The difference between yearly pension income and preretirement labor earnings is similar from the second to the fourth earnings quintiles, suggesting that the redistributive role of the Swedish pension system is limited for most of the population in the earnings distribution's middle range. In contrast, the pension system plays a

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subgroups of the labor market, which may help clarify the role of mortality. For instance, the second and fourth quintiles together arguably relied more on the first pillar than the third and highest quintiles combined. Accordingly, we find that for both genders, mortality explained a notably larger share of the gap in lifetime pensions between the second and fourth quintiles than between the third and highest quintiles (see Figures C.15 and C.16).

[9] Prior research has also shown that the type of income measure (individual vs. household) has large impacts on the results regarding mortality inequalities between income groups. Women's longevity monotonically increases with household income, which is not always found for women's individual income (Shi et al., 2021). Table C.11 shows that the share of married women was the largest in the lowest female quintile and that the pattern for men was reversed.

relatively more significant role in redistributing money from the very rich to the very poor, as illustrated by the comparisons between the highest earnings group (who had a large share of earnings that did not translate to lifetime pensions) and the lowest earnings group (who received a guarantee pension, even in the absence of contributions), particularly for women.

Recent policy discussions on pension reforms often do not consider SES differences in longevity. Because of increasing overall longevity, many low-mortality countries (e.g., Denmark, Greece, Italy, the Netherlands, Portugal) link the statutory retirement age to life expectancy, and Sweden has plans to do so (OECD, 2021a). Implications of such policies on redistribution will be particularly relevant for Bismarckian pension systems, which explicitly aim to redistribute earnings into pensions in an actuarially fair way. Hence, using SES-specific life tables would increase pension fairness in defined-contribution and notional defined-contribution pension systems. Individuals with higher SES and earnings live longer. Differences in longevity by SES would then be reflected in assumptions on lifespan. Thus, individuals with higher SES and earnings should have lower payout rates, which entails practical challenges, such as how to measure SES and which ages to consider for measuring SES. Further concerns of raising pensionable ages are about who can survive to retirement and inequalities in lifespan after retirement (Alvarez et al., 2021; Shi et al., 2022a).

Our definition of "lifetime" is from age 60 onward, so premature mortality before age 60 is not included. SES differences in lifetime pensions measured at age 50 would have been larger than our estimates because the SES–mortality gradient tends to be higher at ages 40–60 (Rehnberg et al., 2019). Future research may wish to examine lifetime pensions beginning at a younger age to capture such effects.

Our study offers several notable contributions. First, we used an exceptionally long series of high-quality data on observed earnings, mortality, and all pension sources. Prior mathematical models illustrated the importance of differential mortality to lifetime pension progressivity (Auerbach et al., 2017; Sánchez-Romero et al., 2020), and previous empirical studies have modeled mortality rates for cohorts whose complete mortality schedules were still unknown (Haan et al., 2020; Olivera, 2019). Unlike previous studies, ours used observed income, mortality, and pension data for cohorts whose life course has been almost entirely observed. Thus, our approach is more data-driven and has the advantage of introducing many fewer assumptions. Second, our decomposition approach is novel in revealing how much money lower SES individuals lose because of their mortality disadvantages at each age. Third, we disentangle three effects: mortality, earnings, and the pension system's redistributive effects. Finally, our hypothetical analysis is a useful way to show the impacts of potential policy changes.

A limitation of our hypothetical scenarios is that they assume that these scenarios would not affect individual behaviors, such as retirement timing (for scenarios of pension generosity and mortality), and do not reflect that later retirement would imply higher contributions. However, the counterfactuals are primarily useful to contrast the effects of different dimensions of a pension system, such as retirement age, mortality, and pension levels.

Another limitation is that our earnings grouping is based on earnings accrued over ages 50–59, ignoring earlier earnings trajectories. Our comparison of average yearly earnings over these 10 years and average yearly pension payments (at ages 66–75) are only illustrative, not strict actuarial calculations of the rate of return on actual pension payments. Our entirely empirical approach is both an advantage and a disadvantage compared with previous research. Thus, our study differs conceptually from previous research: our pension variable is the sum of pensions of all pillars. Because the distribution of pension types differs substantially across SES, our study provides a broad picture of how a national pension system works in practice and the consequences for social stratification (not calculations of the extent of redistribution of specific pension programs). In addition to representing a contribution to the literature, this feature makes comparisons of our results with those of many previous studies somewhat difficult. Future research may wish to disentangle how different pension programs (e.g., guarantee pensions, widowhood pensions, collective agreement pensions, private pensions) explain overall lifetime pension differences between SES groups—a set of distinctions our data did not permit.

A further implication of our approach is that the cohorts for whom we could observe nearly their entire lives were born in the early twentieth century, and we therefore studied the pension system in the 1990s and 2000s. It would be interesting to examine whether pension reforms in Sweden in 1999 have changed the broad patterns we observed. The reform in 1999 introduced a notional defined-contribution system to the public pension with balances for intergenerational redistribution and flexible retirement ages that are actuarially fair. It later became a model for many other OECD countries (Palme, 2005). The first cohorts that experienced this new system were born in the mid-1950s.

6
Conclusion

The goal of this thesis was twofold: to depict a more comprehensive picture of patterns of lifespan inequality by using innovating methodologically, and to gain a deeper understanding of the implications of mortality inequality for retirees. Each study focuses on a different aspect of this goal. The first two studies proposed novel methods to take into consideration of differences in lifespan distributions when quantifying lifespan inequality. These new methods shift the attention from the average performance of longevity to overall distinctions of lifespan distributions. The second two studies focused on old-age mortality and examined how differential mortality contributes to social inequality in length of life in retirement and lifetime accumulated pensions.

In Chapter 2, I used a distance metric, the non-overlap index, to capture the sociological concept of stratification, which emphasizes the emergence of unique, hierarchically layered social strata. Prior research on mortality differences between groups has traditionally focused on metrics that describe average levels of mortality, for example life expectancy and standardized mortality rates. Additional insights can be gained by using statistical distance metrics to examine differences in lifespan distributions between groups. The utility of this newly proposed metric was demonstrated by an application using Finnish registration data that cover the entire population over the period from 1996 to 2017. The results indicate that lifespan stratification and life-expectancy differences between income groups both increased substantially from 1996 to 2008; subsequently, life-expectancy differences declined, whereas stratification stagnated for men and increased for women. The non-overlap index uncovers a unique domain of inequalities in mortality and helps to capture important between-group differences that conventional approaches miss.

In Chapter 3, I introduced a variance decomposition approach built upon the conventional variance decomposition technique to understand how distributional differences between population subgroups contribute to overall population-level lifespan inequality. Previously, conventional decomposition techniques have been used to disentangle population-level lifespan inequality into between- and within-group components. The between-group component is typically owing to between-group differences in the mean (i.e., life expectancy), and the within-group component is assumed to be the part of the total variation that cannot be explained by the grouping variable. This framework does not capture between-group differences in the overall distribution—apart from mean differences—that also contribute to population-level lifespan inequality. Incorporating such differences in distributional shapes into the conventional variance decomposition framework can give new insights into the study of lifespan inequality. The proposed decomposition method further disentangles the within-group component into components that can and cannot be explained by the grouping variable. An application using U.S. data showed that racial/ethnic differences in lifespan distributions explained about 20% of the total variance in lifespan variance at the national level for both sexes, whereas the contribution of life-expectancy differences is rather limited.

Chapters 2 and 3 both demonstrate that innovative methods can complement widely used approaches to help gain a more thorough understanding of mortality inequality. New dimensions of inequality can be revealed by using alternative measures and methods such as those introduced in this thesis, which can be easily applied to other data. Admittedly, no single metric is a panacea. Demography can benefit greatly from further methodological development. Especially, distributional approaches are leading to a new exciting area of mortality research.

Chapter 4 assessed gender and educational differences in the average retirement life span and the variation in retirement life span, taking into account individual labor force exit and reentry dynamics. This study used longitudinal data from the Health and Retirement Study from 1996 to 2016, focusing on respondents aged 50 and older. Multistate life tables were estimated using discrete-time event history models, which were used to calculate the average retirement lifespan, as well as absolute and relative variation in retirement lifespan. The results showed a persistent educational gradient for women in average retirement lifespan over the whole period studied; among men, the relationship between education and retirement expectancy differed across periods. Women and the lower-educated had higher absolute variation in retirement life span than men and the higher-educated—yet these relationships were reversed when examined by relative variation. The multistate approach provided an accurate and comprehensive picture of the retirement lifespan of older Americans over the past two decades.

Chapter 5 focused on the role of mortality inequality in pension fairness. As with many social transfer schemes, pension systems around the world are often progressive: individuals with lower incomes receive a higher percentage of their income as a subsequent pension. On the other hand, those with lower earnings have higher mortality and thus accumulate fewer years of pension income. Both of these opposing factors influence the progressiveness of pension systems. Empirical efforts to disentangle the effects of mortality inequality on lifetime pension inequality have been scarce. Using Swedish taxation data linked with death registers for 1970–2018, this chapter showed how education and preretirement earnings related to lifetime pensions from age 60 onward and how mortality inequalities contribute to overall inequalities in lifetime pensions. The results showed that a progressive replacement structure and mortality differences contributed to the overall distribution of pension payments over the life course. Up to one quarter of lifetime pension inequality was attributable to the greater longevity of socially advantaged groups—particularly among men. Hence, mortality inequalities are an important determinant of the overall degree of between-group income transfers in a pension system, but they are not as important as inequalities in prior earnings.

Much of the prior literature on mortality and pension systems has primarily focused on the role of mortality in the sustainability of pension systems and intergenerational fairness. In contrast, within-cohort mortality inequality between social groups is less examined. Findings from Chapters 4 and 5 should be considered in high-level discussions on old-age pension policies, as potential reforms such as raising the eligibility age or cutting benefits may have unexpected implications for different social groups due to their differential effects on retirement lifespan and pension accumulation.

Even in today's low-mortality, high-income welfare states, much of the mortality inequality may be reduced by implementing better health policies. Documenting mortality inequality comprehensively and accurately should be the very first step. As populations age, inequality in old-age mortality and its impact on other kinds of inequality later in life is becoming an increasingly important part of contemporary social and health inequalities. This thesis emphasizes the need of monitoring and explaining mortality inequality using distributional methods, as well as highlights the important consequences of mortality inequality for retirees and pension policies. These methods should be applied to examine mortality inequality in other countries, especially low- and middle-income countries. Furthermore, the impacts of mortality inequality on other welfare instruments, such as healthcare systems, should be studied in future work. Of particular interest is how such impacts vary across countries with distinct policy contexts and mortality regimes.

Appendices

A
Appendix to Chapter 2

A.1 A Brief Description of the Dataset Used in the Empirical Example in Chapter 2

The dataset is constructed by linking the death registry with income data from the Finnish Tax Administration and the National Social Insurance Institution at the individual level. The sample is restricted to individuals aged 25 and above. We use yearly household disposable income per capita as our income measure and classify individuals into groups based on their age-specific income percentiles (Martikainen et al., 2009). We account for the household composition by dividing the total household disposable income by the sum of the consumption units in the household using the OECD modified equivalence scale, in which the first adult is assigned a value of one, each additional adult member is assigned a value of 0.5, and each child is assigned a value of 0.3 (Organisation for Economic Co-operation and Development (OECD), n.d.).

In the next step, we construct period life tables for each year, sex, age, and income quintile (obtained from the previous year) using death counts and exposures for the corresponding group. The original datasets cover the years between 1996 and 2017, and age is formatted as single-year groups (25–26, 26–27, . . . , 94–95, 95

+). We extend the last age group to 110+ using a penalized composite link model, which incorporates P-splines to smooth the death counts with exposures as offsets across age (Rizzi et al., 2015) because it is common for deaths and exposures to have very small counts for certain age groups (e.g. deaths at very young or old ages and exposures at very old ages). The age extension and smoothing method is implemented with the R package ‘ungroup’ (Pascariu et al., 2018).

A.2 Figures

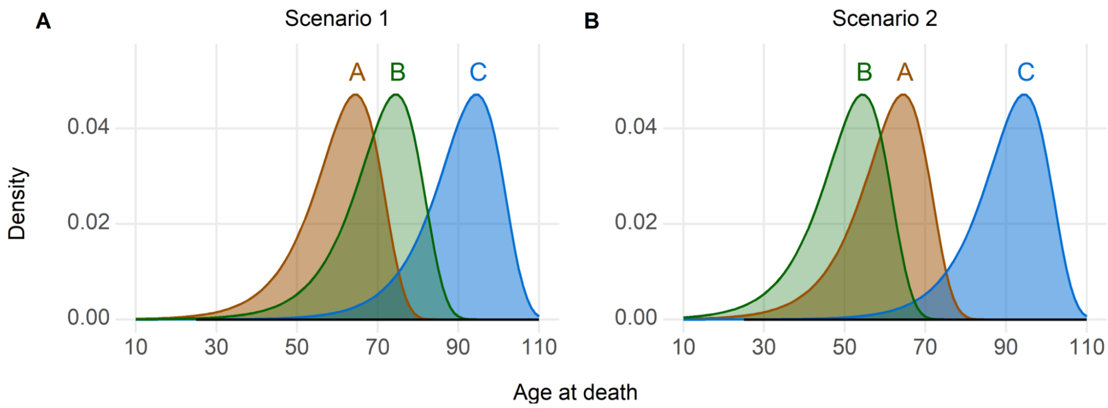

Figure A.1: An example for the intransitivity of stratification. *Notes*: The distributions for A and C are the same in both scenarios 1 and 2. The only difference in the two scenarios is the location of distribution B. S_{AB} in scenario 1 equals S_{AB} in scenario 2; and S_{AC} in scenario 1 equals S_{AC} in scenario 2. However, S_{BC} in scenario 1 is different from S_{BC} in scenario 2. *Source*: Authors' own.

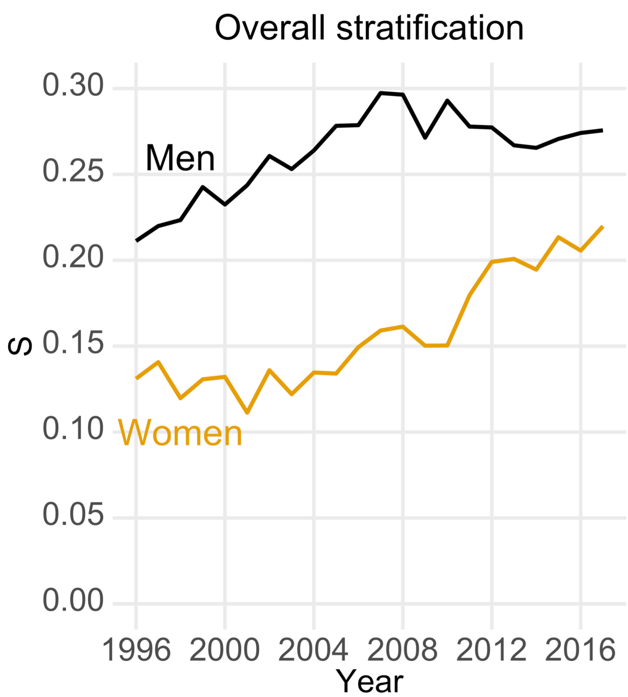

Figure A.2: Trends in mortality stratification over five income quintiles, 1996–2017. *Source*: Authors' own calculation based on Finnish registry data.

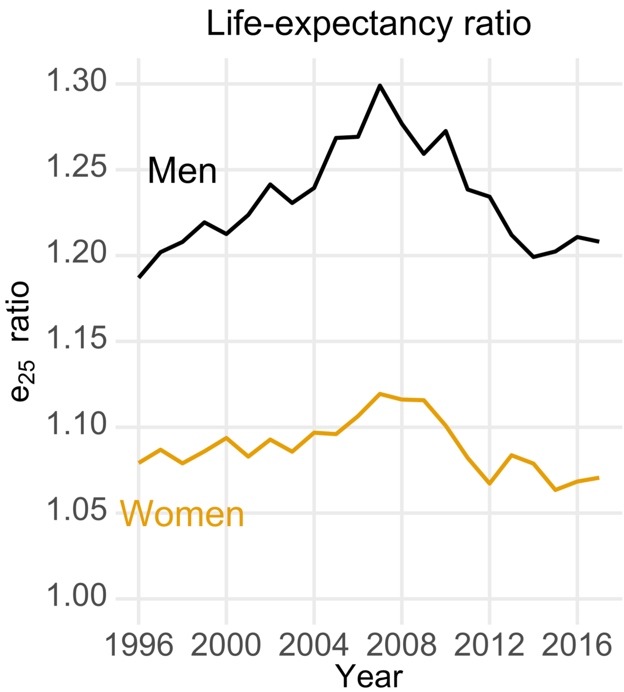

Figure A.3: Trends in the life-expectancy ratio between the lowest and the highest income quintiles, 1996–2017. *Source*: Authors' own calculation based on Finnish registry data.

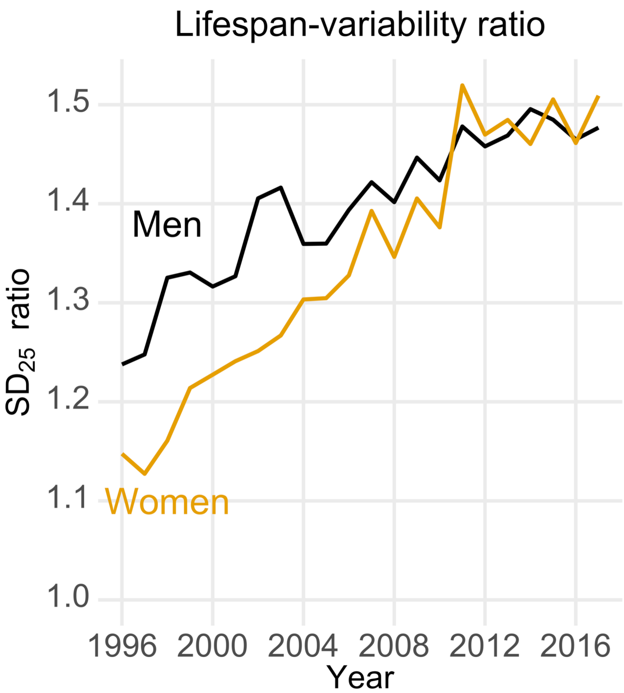

Figure A.4: Trends in the life-variability ratio between the lowest and the highest income quintiles, 1996–2017. *Source*: Authors' own calculation based on Finnish registry data.

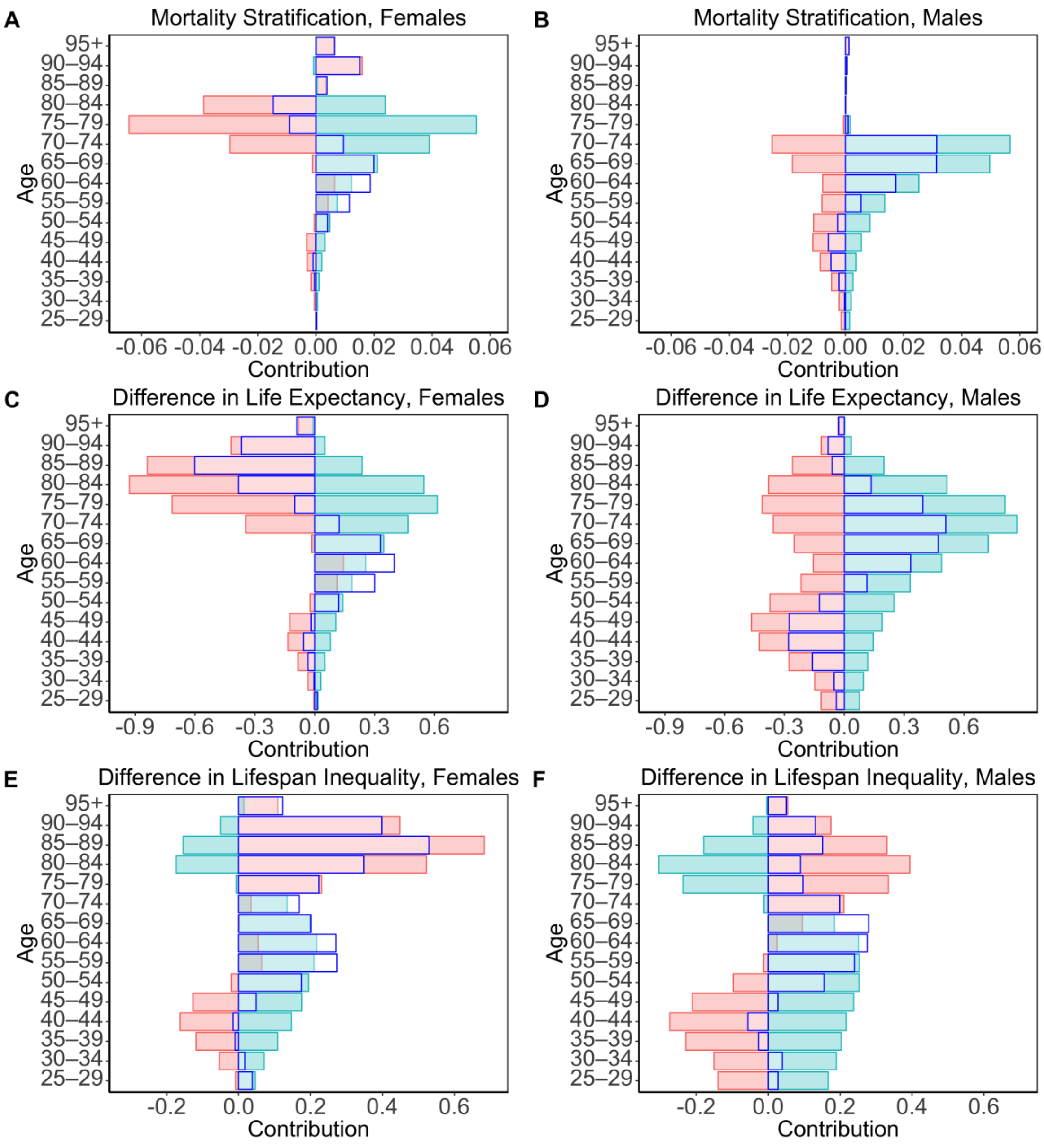

Figure A.5: Age-specific contributions to changes in the three indices between 1996–2000 and 2013–2017, by sex. *Notes*: Red bars refer to age-specific contributions due to changes in the lowest income quintile group; green bars refer to age-specific contributions due to changes in the highest income quintile group; blue bars refer to the sum of the red and blue bars; i.e. total age-specific contributions. The decomposition is an application of the method proposed by Horiuchi et al. (2008). *Source*: Authors' own calculation based on Finnish registry data.

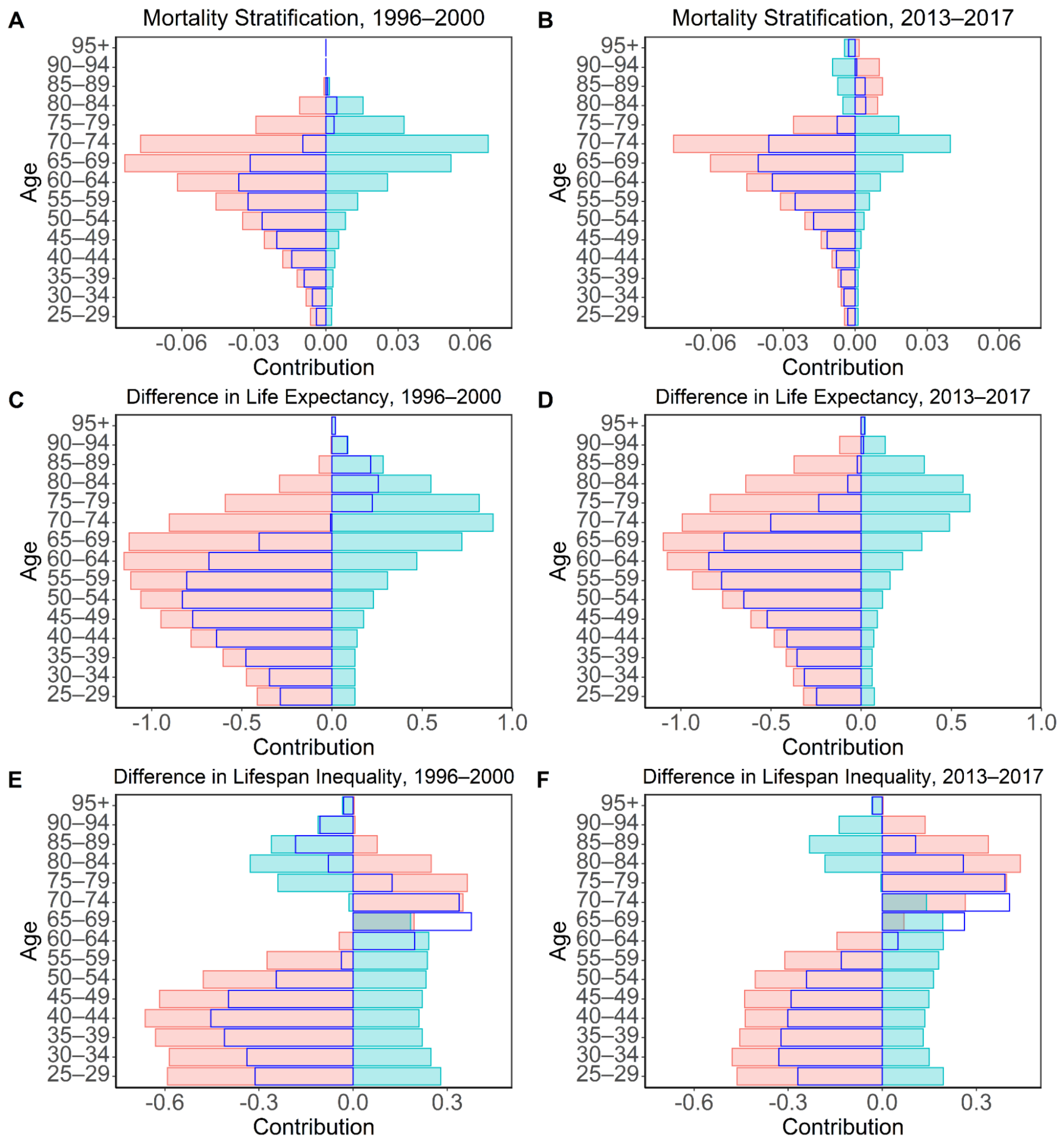

Figure A.6: Age-specific contributions to differences in the three indices between males and females, by period. *Notes*: Red bars refer to age-specific contributions due to changes in the lowest income quintile group; green bars refer to age-specific contributions due to changes in the highest income quintile group; blue bars refer to the sum of the red and blue bars; i.e. total age-specific contributions. The decomposition is an application of the method proposed by Horiuchi et al. (2008). *Source*: Authors' own calculation based on Finnish registry data.

B

Appendix to Chapter 4

B.1 Figures

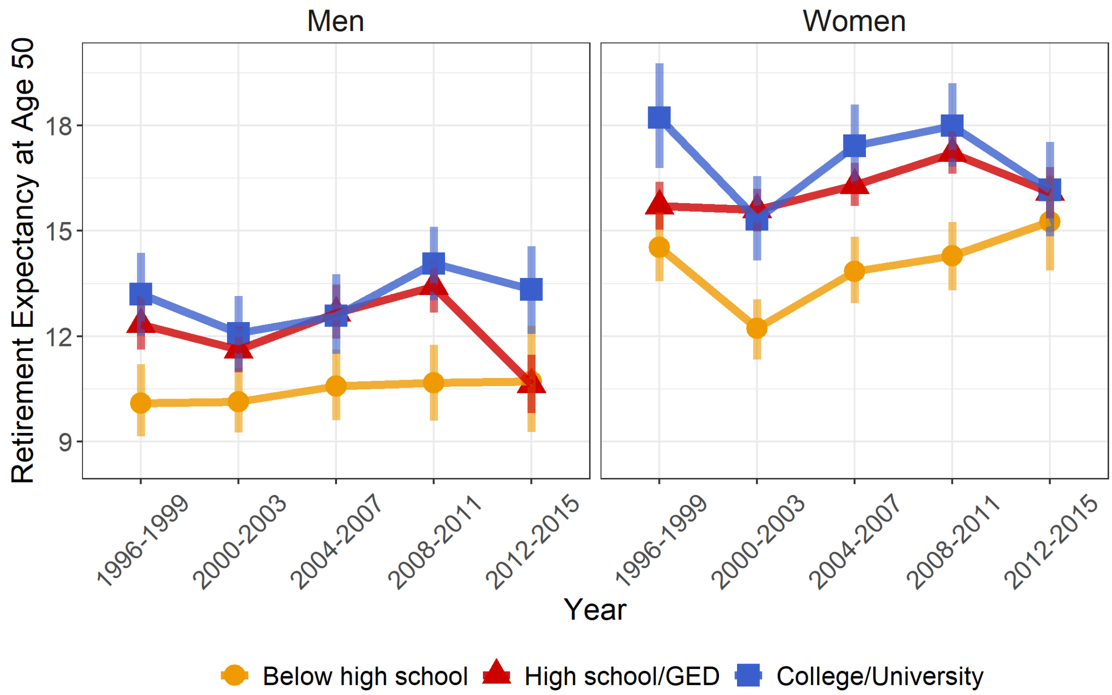

Figure B.1: Trends of retirement expectancy in the United States, with 95% bootstrap confidence intervals. *Note*: Calculations are conditional upon surviving to 50, and individuals in all transient states at 50 are included. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

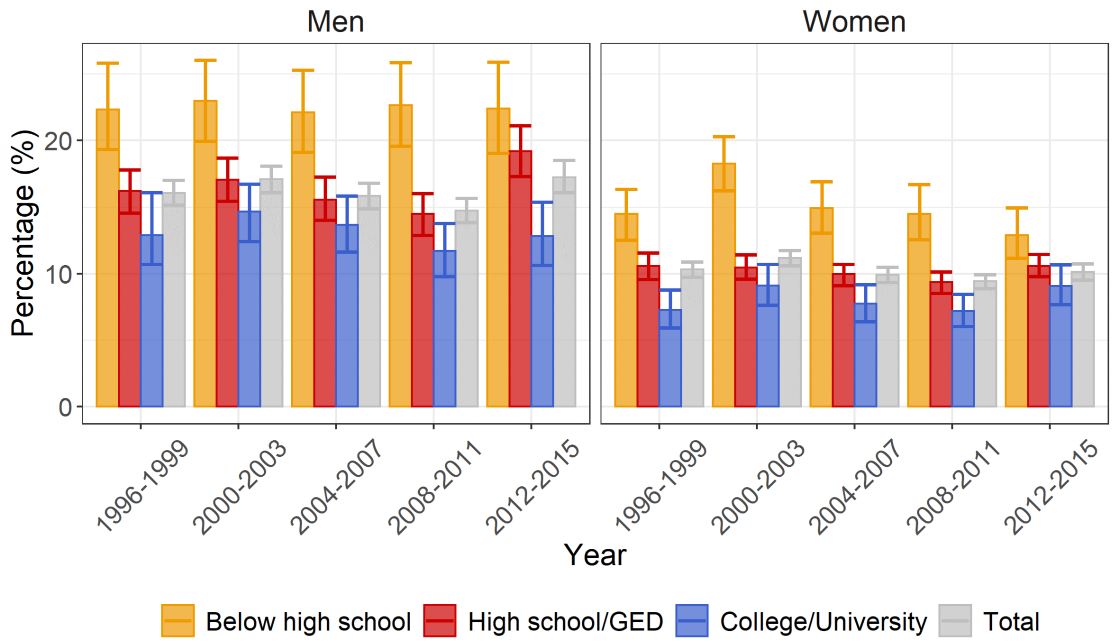

Figure B.2: Percentage of individuals not surviving to retirement in the United States, with retirement threshold age 70. *Note*: Error bars show 95% bootstrap confidence intervals. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

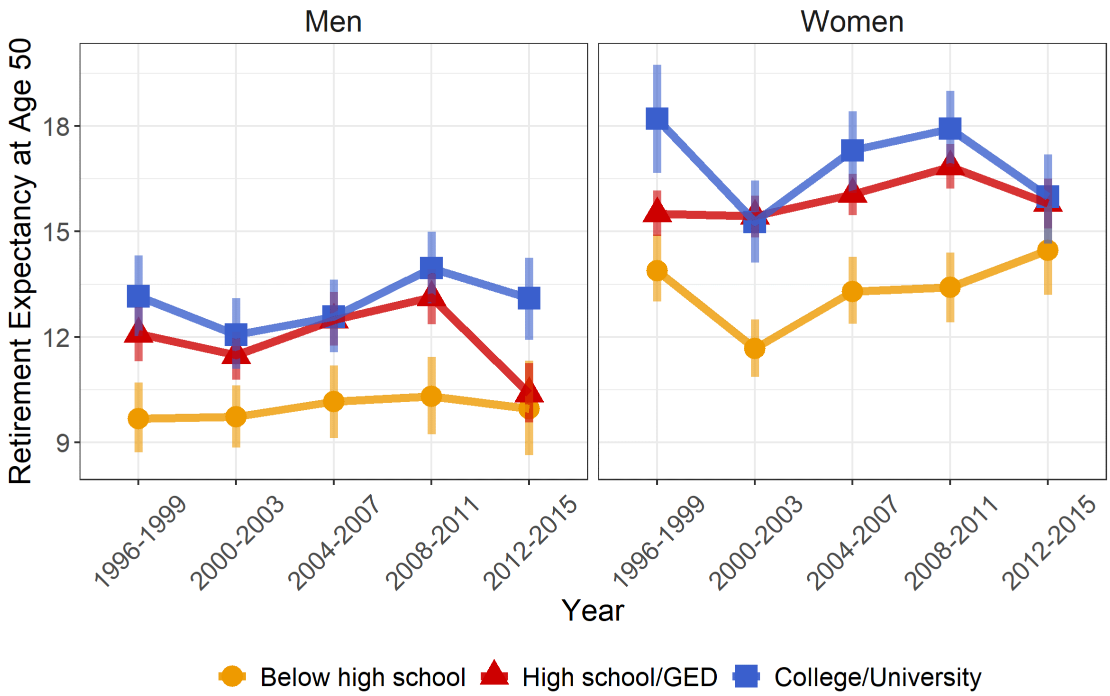

Figure B.3: Trends of retirement expectancy in the United States, with retirement threshold age 70. *Note*: Calculations are conditional upon surviving to 50, and individuals in all transient states at 50 are included. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

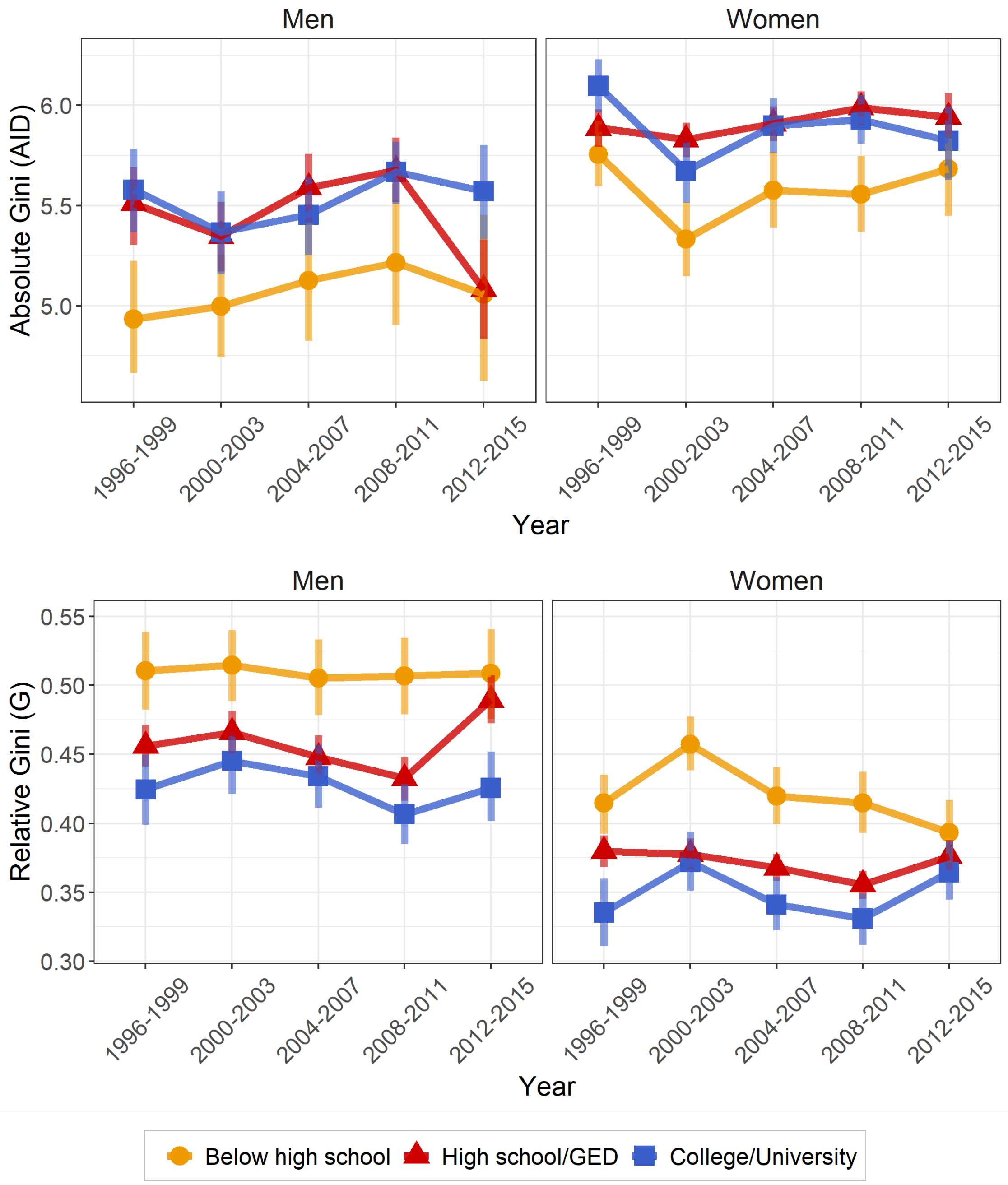

Figure B.4: Trends of retirement lifespan variation in the United States, with retirement threshold age 70. *Note*: Calculations are conditional upon surviving to 50, and individuals in all transient states at 50 are included. *Source*: Authors' calculation based on the Health and Retirement Study, 1996–2016.

B.2 Tables

Table B.1: Initial retirement age, by education and gender, with 95% bootstrap confidence intervals

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Total	63.5	64.5	64.5	64.2	65.9	63.8	64.9	64.5	64.4	65.4
95% CI lower bound	63.2	64.1	64.1	63.8	65.4	63.5	64.5	64.2	64.0	64.9
95% CI upper bound	63.9	64.8	64.9	64.6	66.3	64.2	65.2	64.8	64.7	65.8
Below high school	63.5	63.6	63.7	63.2	64.5	63.9	64.6	64.4	64.3	65.0
95% CI lower bound	62.9	62.9	63.0	62.5	63.6	63.4	64.0	63.8	63.8	64.2
95% CI upper bound	64.1	64.2	64.4	64.0	65.5	64.4	65.1	65.0	64.9	65.8
High school/GED	62.7	64.0	63.9	63.8	65.4	64.0	64.8	64.4	64.1	65.0
95% CI lower bound	62.3	63.6	63.4	63.3	64.8	63.6	64.3	64.0	63.6	64.5
95% CI upper bound	63.2	64.5	64.5	64.3	66.0	64.4	65.2	64.8	64.5	65.6
College/university	64.6	65.9	66.2	66.1	67.9	63.3	66.1	65.2	65.4	67.0
95% CI lower bound	64.0	65.3	65.5	65.4	67.0	62.6	65.2	64.5	64.7	66.1
95% CI upper bound	65.4	66.6	67.0	66.8	68.7	64.1	66.9	65.9	66.0	67.9

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

Table B.2: Life expectancy (LE) at initial retirement, by education and gender, with 95% bootstrap confidence intervals

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Total	16.2	15.9	16.7	17.7	16.2	19.7	18.9	19.7	20.4	19.8
95% CI lower bound	15.9	15.5	16.3	17.3	15.7	19.4	18.5	19.4	20.1	19.4
95% CI upper bound	16.5	16.3	17.1	18.1	16.7	20.0	19.2	20.1	20.8	20.2
Below high school	14.3	14.4	14.9	15.0	15.2	18.4	16.4	17.9	18.3	19.2
95% CI lower bound	13.4	13.6	14.0	13.9	13.8	17.5	15.5	16.9	17.4	18.0
95% CI upper bound	15.5	15.4	15.9	16.1	16.8	19.3	17.2	18.8	19.2	20.5
High school/GED	16.3	15.8	16.8	17.7	15.2	19.5	19.4	20.1	20.9	20.0
95% CI lower bound	15.5	15.2	16.1	16.9	14.3	18.8	18.9	19.5	20.3	19.3
95% CI upper bound	17.1	16.4	17.6	18.4	16.0	20.1	20.0	20.7	21.6	20.7
College/university	17.1	16.4	16.9	18.4	17.7	21.3	18.9	20.8	21.4	19.9
95% CI lower bound	16.1	15.4	15.9	17.5	16.6	20.0	17.8	19.7	20.3	18.6
95% CI upper bound	18.2	17.3	17.9	19.3	18.9	22.7	20.0	21.9	22.5	21.2

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

Table B.3: Retirement expectancy at initial retirement, by education and gender, with 95% bootstrap confidence intervals

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Total	14.4	13.9	14.6	15.6	14.0	17.7	16.8	17.7	18.4	17.7
95% CI lower bound	14.1	13.6	14.3	15.2	13.5	17.5	16.5	17.4	18.1	17.3
95% CI upper bound	14.7	14.2	15.0	15.9	14.5	18.0	17.1	18.0	18.7	18.1
Below high school	12.7	12.8	13.3	13.5	13.4	16.6	14.6	15.9	16.3	17.2
95% CI lower bound	11.9	12.1	12.4	12.5	12.0	15.8	13.8	15.1	15.4	16.0
95% CI upper bound	13.6	13.7	14.2	14.4	15.0	17.5	15.3	16.8	17.2	18.5
High school/GED	14.5	13.8	14.8	15.5	12.9	17.4	17.2	17.9	18.8	17.8
95% CI lower bound	13.8	13.2	14.1	14.8	12.1	16.7	16.7	17.3	18.2	17.1
95% CI upper bound	15.2	14.4	15.5	16.2	13.7	18.0	17.8	18.5	19.4	18.5
College/university	15.0	14.1	14.5	15.8	15.1	19.5	16.7	18.7	19.2	17.6
95% CI lower bound	13.9	13.1	13.5	15.0	14.0	18.2	15.6	17.6	18.2	16.3
95% CI upper bound	16.0	15.0	15.5	16.7	16.2	20.9	17.9	19.8	20.4	18.8

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

Table B.4: Expected years in re-employment at initial retirement, by education and gender, with 95% bootstrap confidence intervals

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Total	1.8	2.0	2.1	2.1	2.2	2.0	2.1	2.0	2.0	2.1
95% CI lower bound	1.7	1.9	1.9	2.0	2.1	1.8	1.9	1.9	1.9	1.9
95% CI upper bound	2.0	2.2	2.2	2.3	2.4	2.1	2.2	2.2	2.2	2.3
Below high school	1.6	1.6	1.7	1.6	1.8	1.8	1.8	1.9	2.0	2.0
95% CI lower bound	1.3	1.4	1.4	1.3	1.5	1.6	1.6	1.6	1.7	1.7
95% CI upper bound	2.1	1.8	1.9	1.8	2.1	2.0	2.0	2.2	2.2	2.3
High school/GED	1.8	2.0	2.0	2.2	2.2	2.1	2.2	2.2	2.2	2.2
95% CI lower bound	1.6	1.8	1.8	2.0	2.0	1.9	2.0	2.0	2.0	2.0
95% CI upper bound	2.1	2.2	2.3	2.4	2.5	2.3	2.4	2.4	2.4	2.4
College/university	2.1	2.3	2.4	2.6	2.6	1.8	2.1	2.1	2.2	2.3
95% CI lower bound	1.9	2.1	2.1	2.3	2.4	1.6	1.9	1.9	2.0	2.1
95% CI upper bound	2.4	2.6	2.7	2.8	3.0	2.0	2.4	2.4	2.4	2.6

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

Table B.5: Life expectancy (LE) % in re-employment at initial retirement, by education and gender, with 95% bootstrap confidence intervals

	Men					Women				
	1996–99	2000–03	2004–07	2008–11	2012–15	1996–99	2000–03	2004–07	2008–11	2012–15
Total	11.2	12.6	12.3	12.1	13.7	9.9	11.0	10.2	9.9	10.6
95% CI lower bound	10.3	11.8	11.4	11.2	12.8	9.3	10.4	9.6	9.3	9.9
95% CI upper bound	12.1	13.5	13.3	13.0	14.9	10.6	11.7	11.0	10.6	11.4
Below high school	11.1	11.1	11.1	10.4	11.9	9.7	11.0	10.8	10.7	10.4
95% CI lower bound	9.5	9.7	9.5	8.8	10.1	8.5	9.7	9.4	9.4	9.0
95% CI upper bound	13.7	12.4	12.6	11.9	13.9	11.0	12.3	12.2	12.0	11.8
High school/GED	10.9	12.7	12.1	12.3	14.8	10.8	11.3	10.8	10.4	11.1
95% CI lower bound	9.9	11.6	11.1	11.3	13.5	9.9	10.5	10.0	9.6	10.2
95% CI upper bound	12.3	13.8	13.4	13.5	16.1	11.7	12.1	11.8	11.2	12.0
College/university	12.4	14.2	14.2	13.9	14.9	8.4	11.4	10.2	10.2	11.8
95% CI lower bound	10.9	12.8	12.7	12.6	13.3	7.5	10.1	9.1	9.1	10.4
95% CI upper bound	14.0	15.7	16.0	15.5	16.8	9.5	12.8	11.4	11.3	13.2

Source: Authors' calculation based on the Health and Retirement Study, 1996–2016.

C
Appendix to Chapter 5

C.1 Overview of Pension Systems of the Cohorts Studied

For the cohorts in our study (those born 1920 and 1925), the first pillar of the Swedish pension systems consisted of a universal guarantee pension (folkpension) and an earnings-related part (Allmän Tillägspension or ATP). The ATP was more important than the guarantee pension, and it was targeted to contribute 60% of the average of the best 15 years out of a 30-year working period (30 years is the requirement for full pension). In practice, the pension payments were based entirely on 15 years of prior labor income. Later, a supplemental part was added to the ATP pension for those with very low ATP pensions. For a more detailed description, see Hagen (2013). The ATP-system was introduced in 1960 (Hagen, 2013). The cohorts in this study were entirely covered retroactively. In practice, therefore, full retirement required fewer than 30 years, making the system more generous. Both systems were defined-benefit (DB) systems, funded as PAYGO systems. In the 1980s, political actors saw this pension system as unsustainable, leading to the introduction of a Notional-Defined Contribution (NDC) system which was an early example of pension reforms (Hagen, 2013; Palme, 2005). The NDC system differs in substantial ways from the pension system we describe above but is not of relevance for the cohorts in our study.

Importantly, together with the public pension, over 90% of all workers in Sweden are also covered by the second-pillar, sector-wide collective agreement pensions negotiated between labor unions and employers (Lindquist and Wadensjö, 2009). The characteristics of the collective agreement pensions vary a lot (for our cohorts they were mostly DB plans). The collective agreement pensions could contribute substantially to the pensions of, in particular, high earners and government workers (rising up to 50% of all pension earnings for the highest-earnings decile), as the ATP system had an income ceiling (Hagen, 2013). The different collective agreement pensions (second pillar) were introduced gradually over the 1970s and 1980s covering a large share of the labor force (mostly being funded DB schemes that have been gradually replaced with funded defined contribution schemes). They were generally more generous for private sector white-collar workers with higher earnings than blue-collar workers (Olofsson, 1993). A typical target was often that workers would receive 80% of their pre-retirement salary (if they had worked for 30 years) through the combination of all pensions described above, though it could be either higher or lower (Hagen, 2013). These pensions are also included in our variables.

Private savings (e.g. capital investments, savings in bank accounts, or housing) for old age in Sweden are usually different from any formal pension-like savings or annuity. In other words, they are not related to monthly payments as from an annuity or a pension, where the total payment is linked to length of life. We do not consider such private savings in this study, as it is not possible to distinguish them from overall wealth. Unlike pension, wealth will often be bequeathed to children. However, we included private pension incomes, which are often not lifetime annuities but paid out as temporary annuities in a fixed period of 5 or 10 years (Palmer, 2008). It is noteworthy that such private pension incomes account only a limited share of the total pension payments at the population level (Hagen, 2013). In 2018, private pensions constituted less than 2% of all pension payments for cohorts born before 1928 (Pensions Myndigheten, 2020). Private pensions are arguably more important at younger ages, as they are mostly paid out in a short period of 5 or 10 years (Palmer, 2008). Hence, the small amount and the short payout length together suggest that private pensions only have a minor impact on our overall pension variable.

C.2 Figures

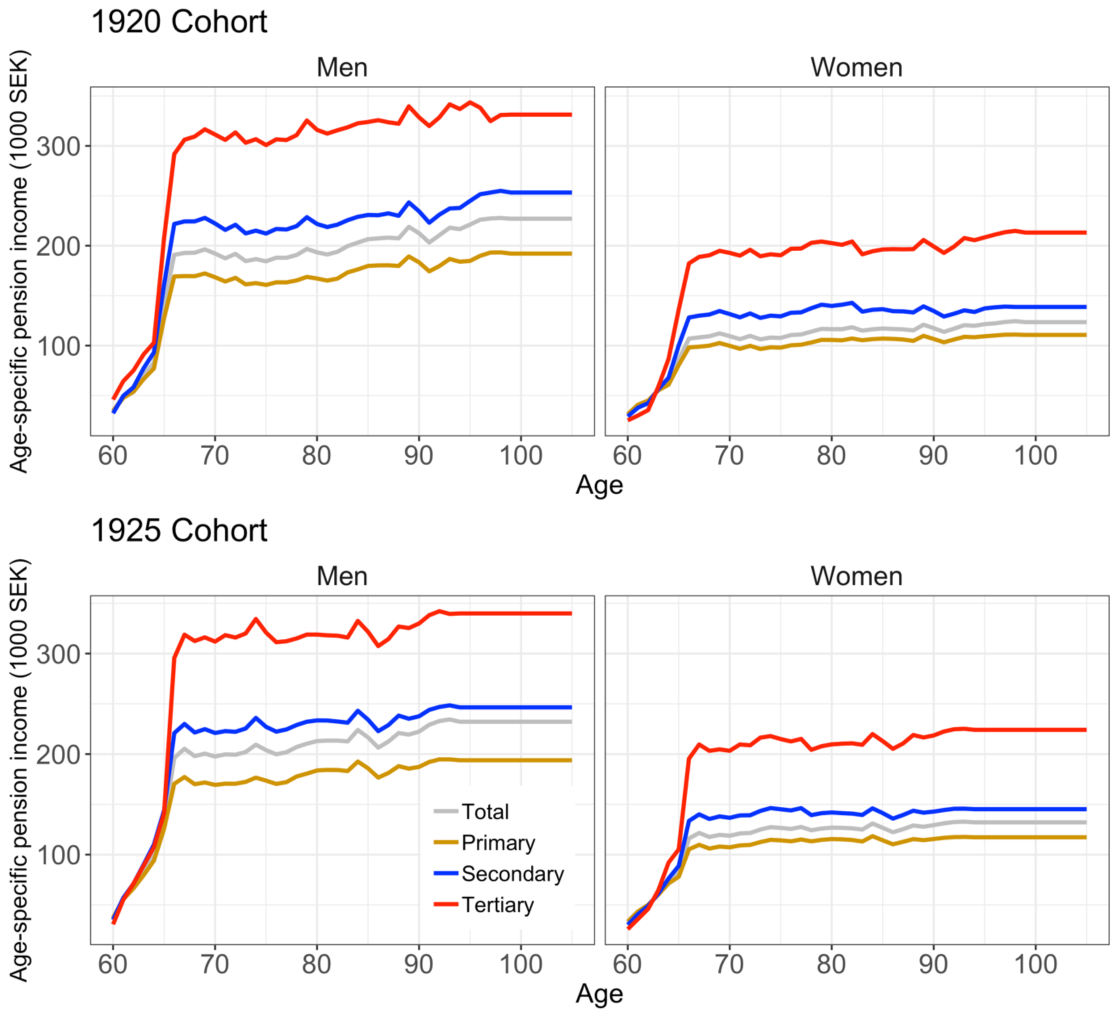

Figure C.1: Age-specific average pension income by education. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

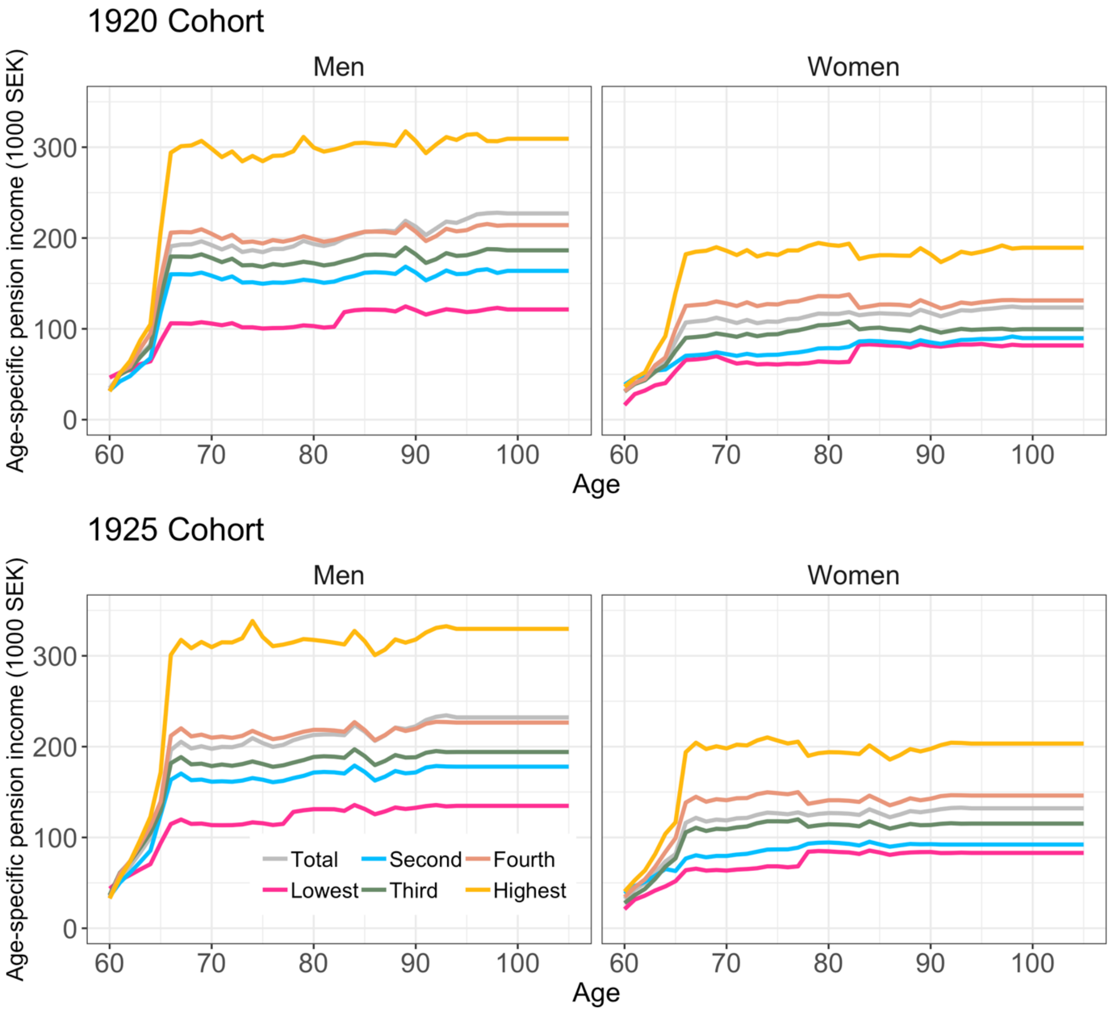

Figure C.2: Age-specific average pension income by earnings quintile. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

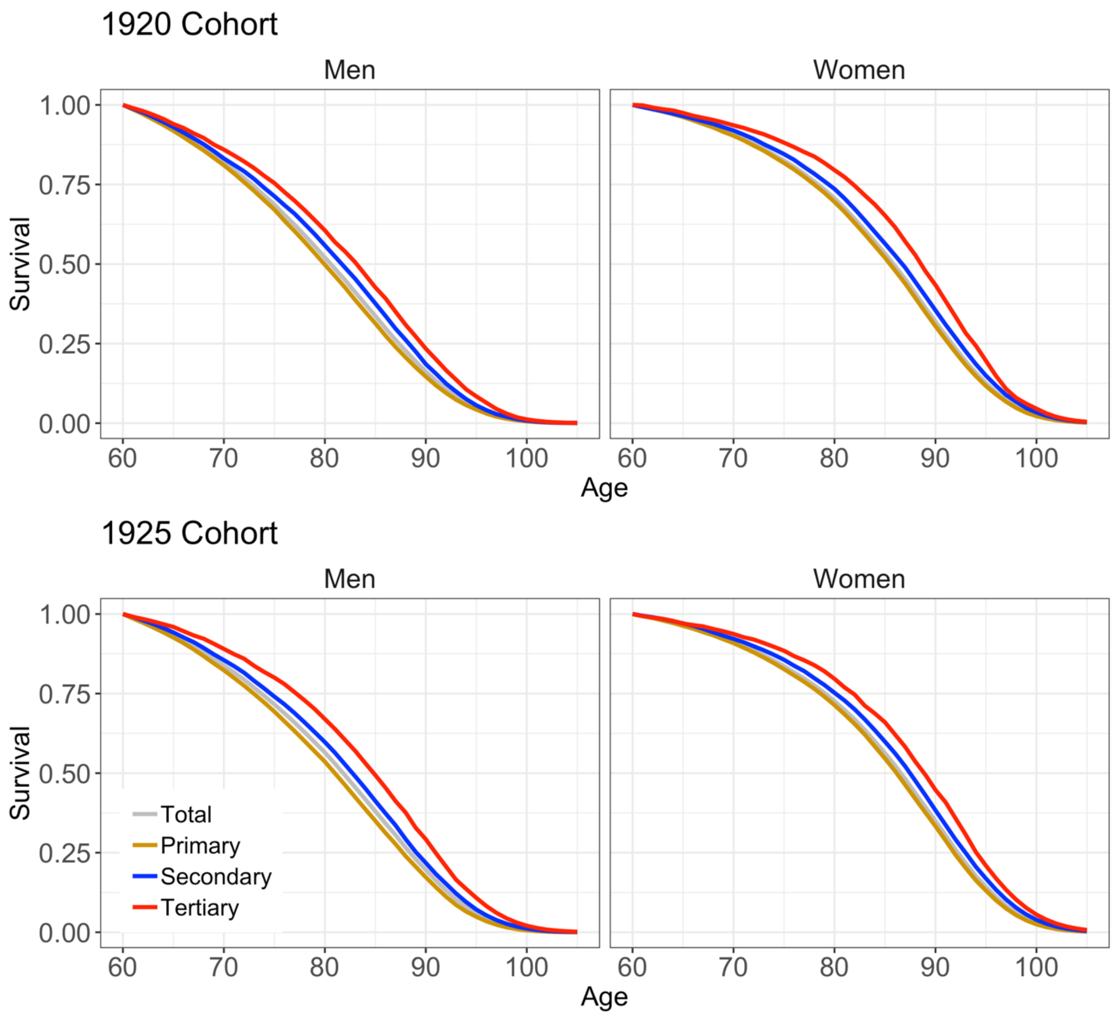

Figure C.3: Survival curves by education. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

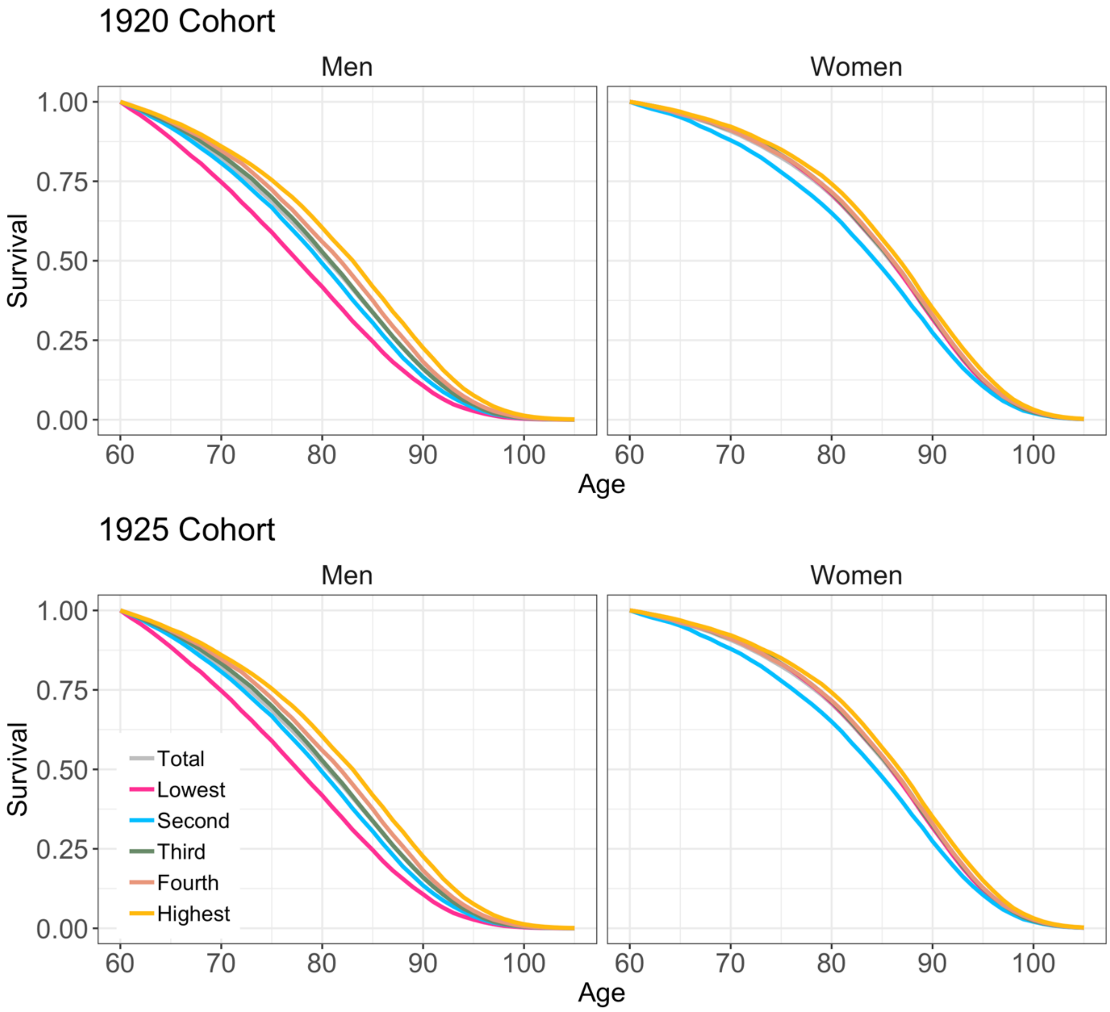

Figure C.4: Survival curves by income quintile. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

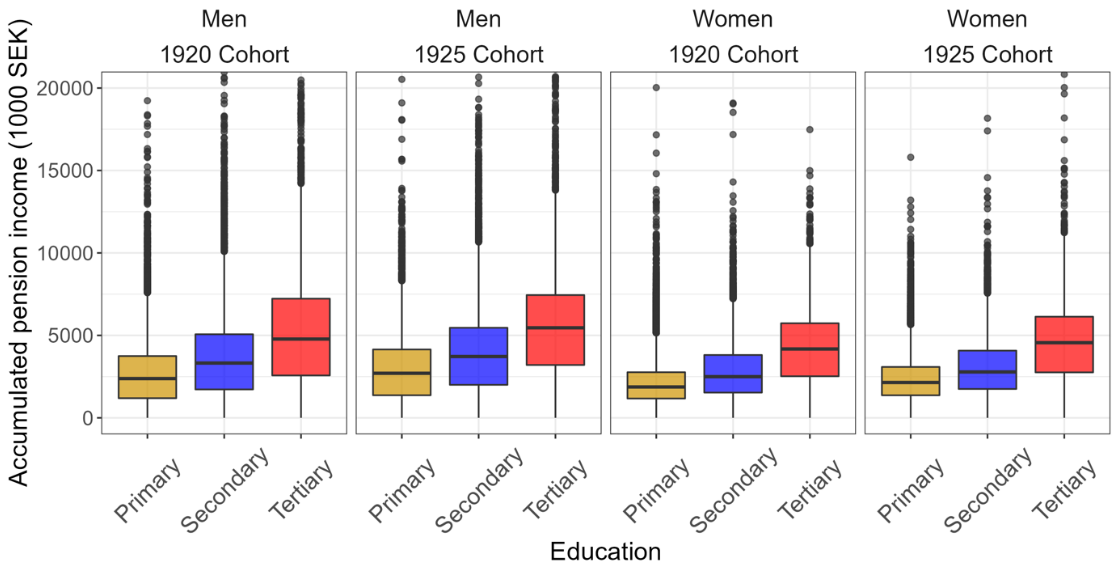

Figure C.5: Box plots of accumulated pension income through 2018, by education. *Notes*: Accumulated pension income is the sum of pension income from age 60 to 98 for the 1920 cohort, and from age 60 to 93 for the 1925 cohort. Outliers (dots) that are defined as above the Q3 + 1.5IQR are displayed. The y axis is truncated. Extreme outliers and the maximum are not shown. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

Figure C.6: Box plots of accumulated pension income through 2018, by earnings. *Notes*: Accumulated pension income is the sum of pension income from age 60 to 98 for the 1920 cohort, and from age 60 to 93 for the 1925 cohort. Outliers (dots) that are defined as above the Q3 + 1.5IQR are displayed. The y axis is truncated. Extreme outliers and the maximum are not shown. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

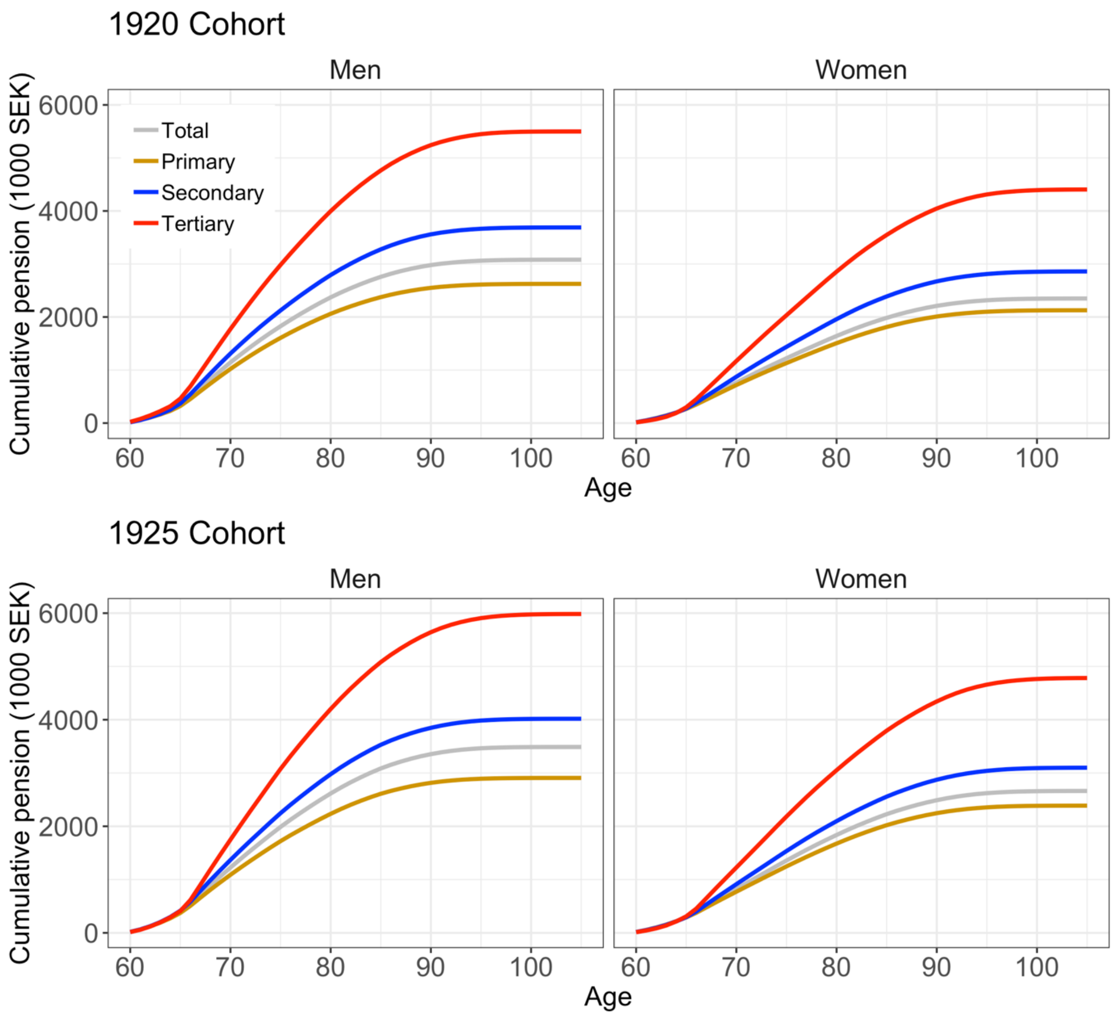

Figure C.7: Age-specific cumulative pension income, by education. *Notes*: Age-specific average accumulated pension income refers to the expected value of pension between age 60 and x along the age axis. The values at the end points of the lines are equivalent to the values of group-specific lifetime pension incomes. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

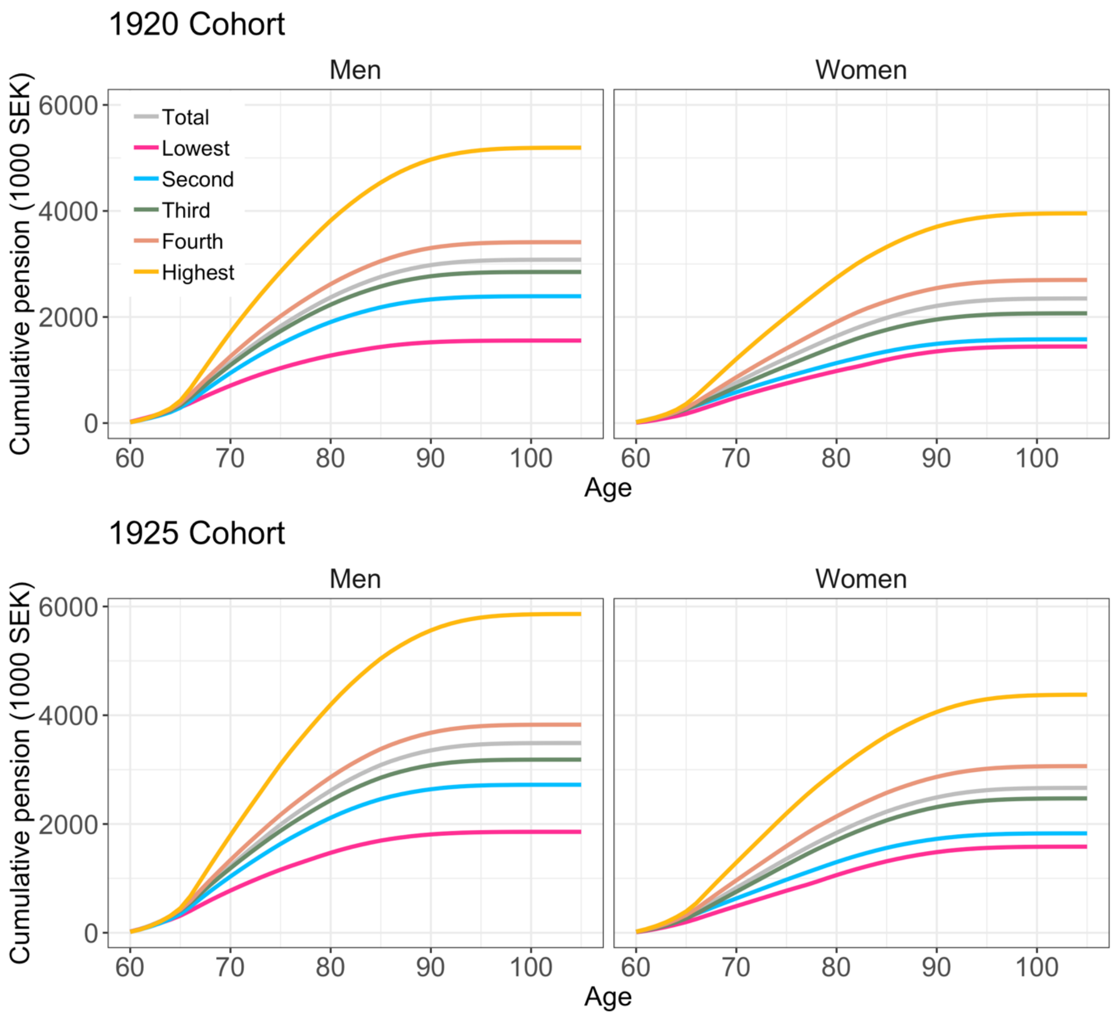

Figure C.8: Age-specific cumulative pension income, by earnings. *Notes*: Age-specific average accumulated pension income refers to the expected value of pension between age 60 and x along the age axis. The values at the end points of the lines are equivalent to the values of group-specific lifetime pension incomes. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

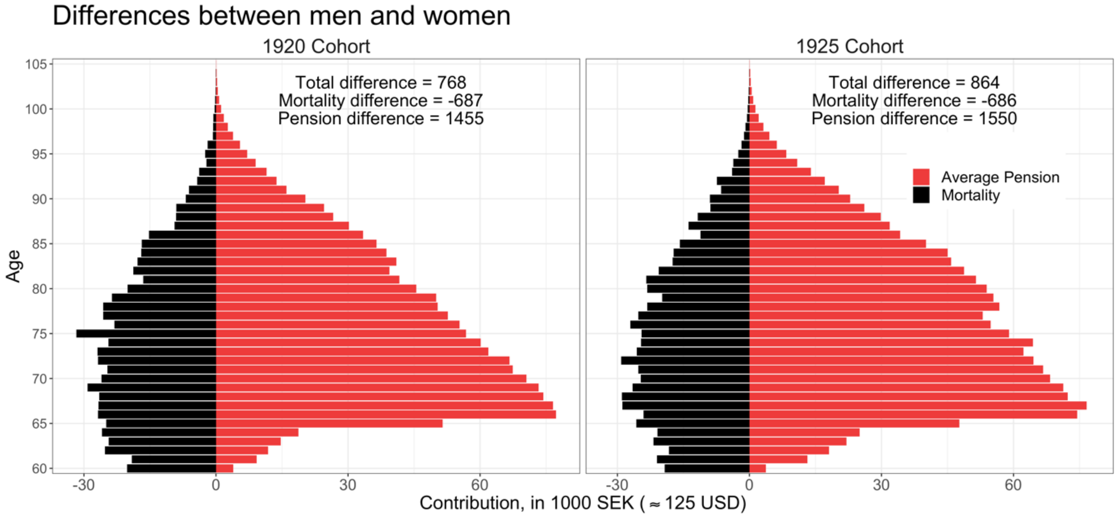

Figure C.9: Decompositions of total lifetime pension differences between men and women into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

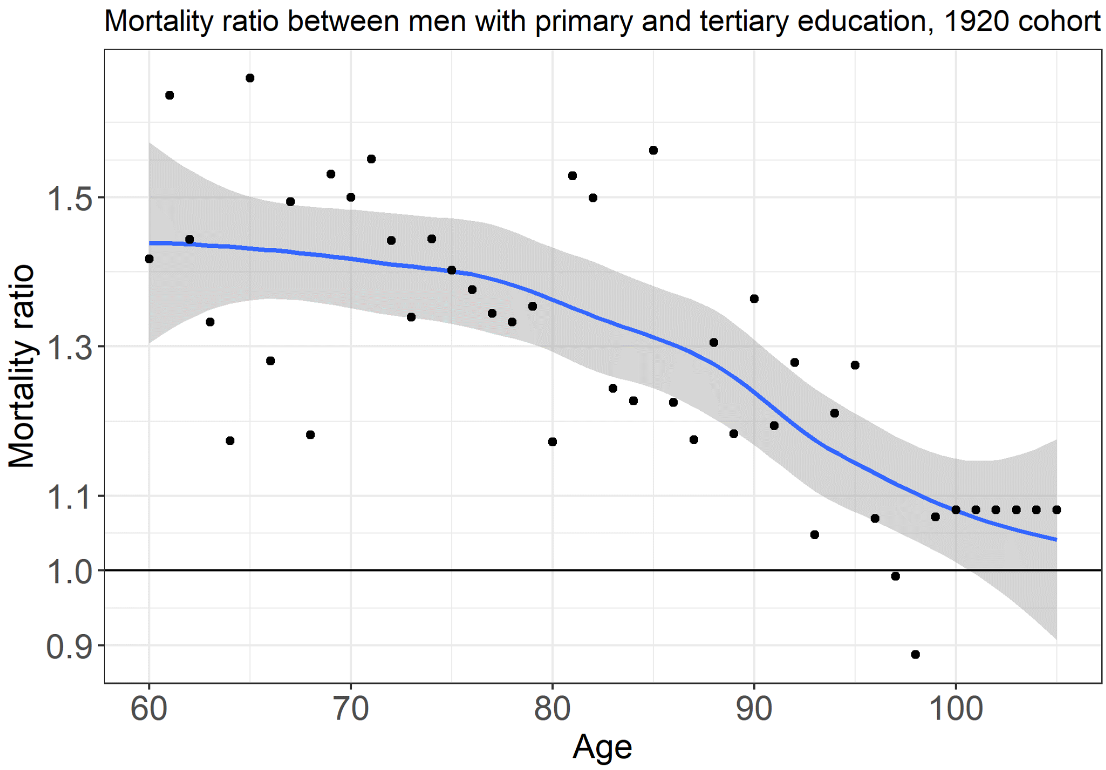

Figure C.10: Mortality ratio between men with primary and tertiary education, 1920 cohort. *Notes*: Mortality ratios above age 100 are assumed to be constant as the average over the last three years (i.e., ages 97–99). The smoothed line is estimated using loess regression. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

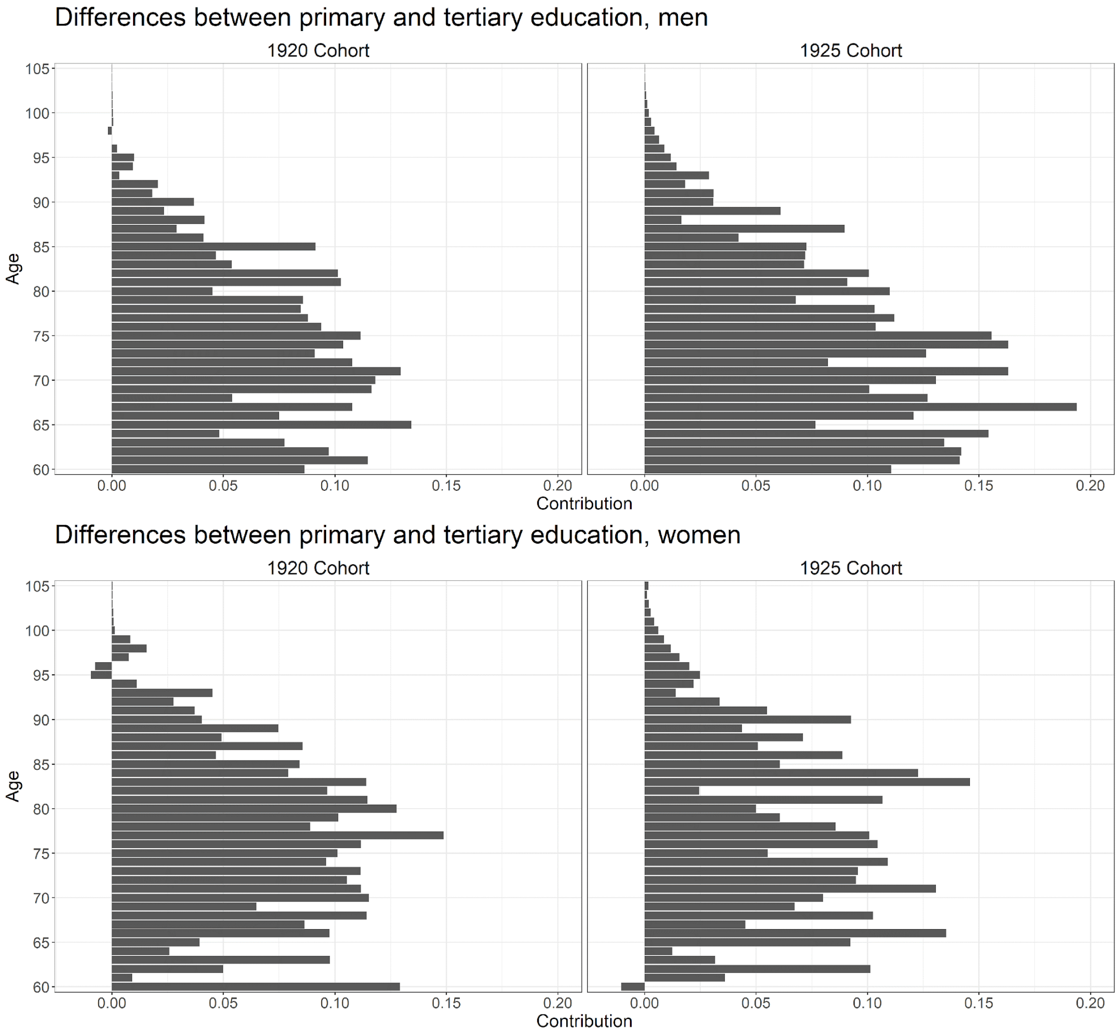

Figure C.11: Decompositions of life expectancy (e_{60}) differences between primary and tertiary education groups into differences explained by differences in age-specific mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

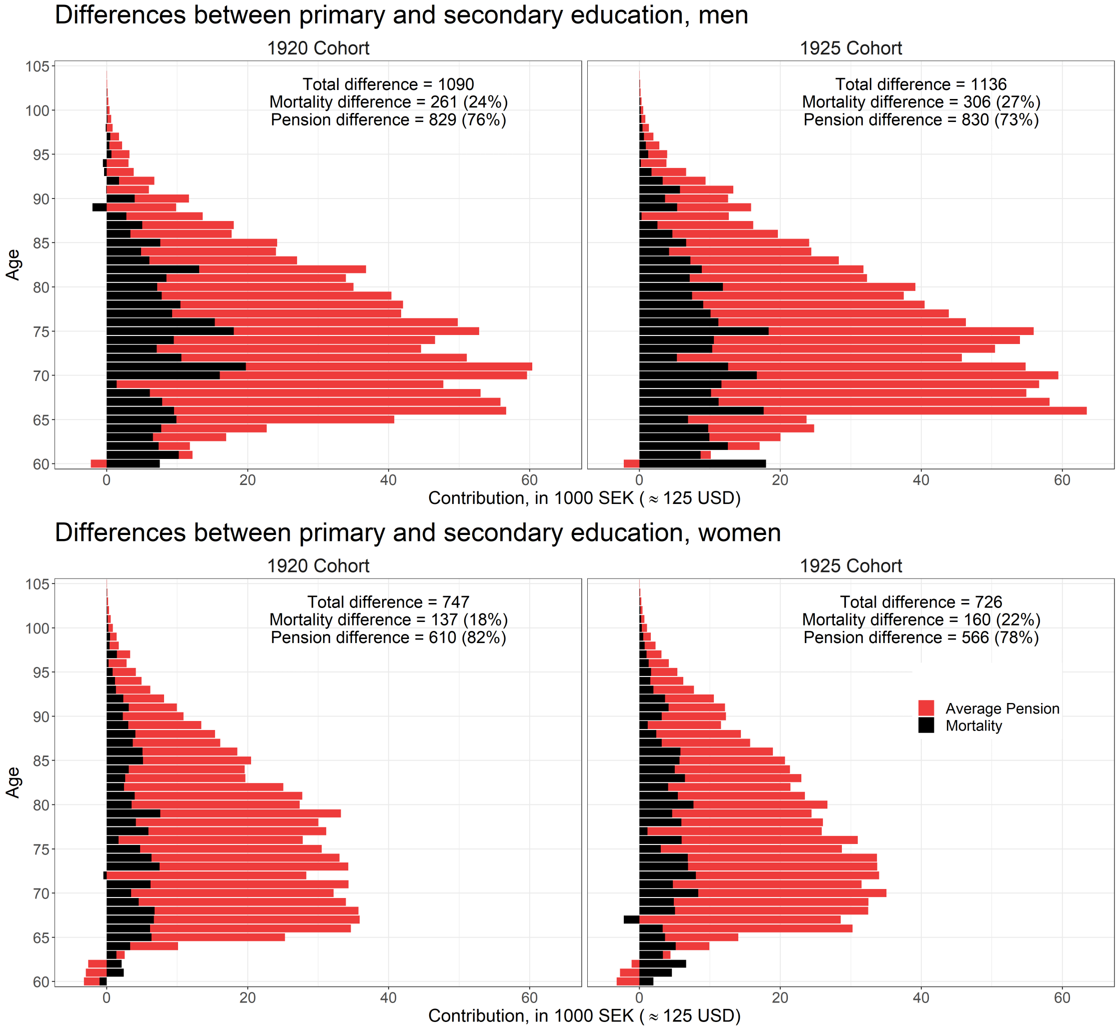

Figure C.12: Decompositions of total lifetime pension differences between primary and secondary education groups into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

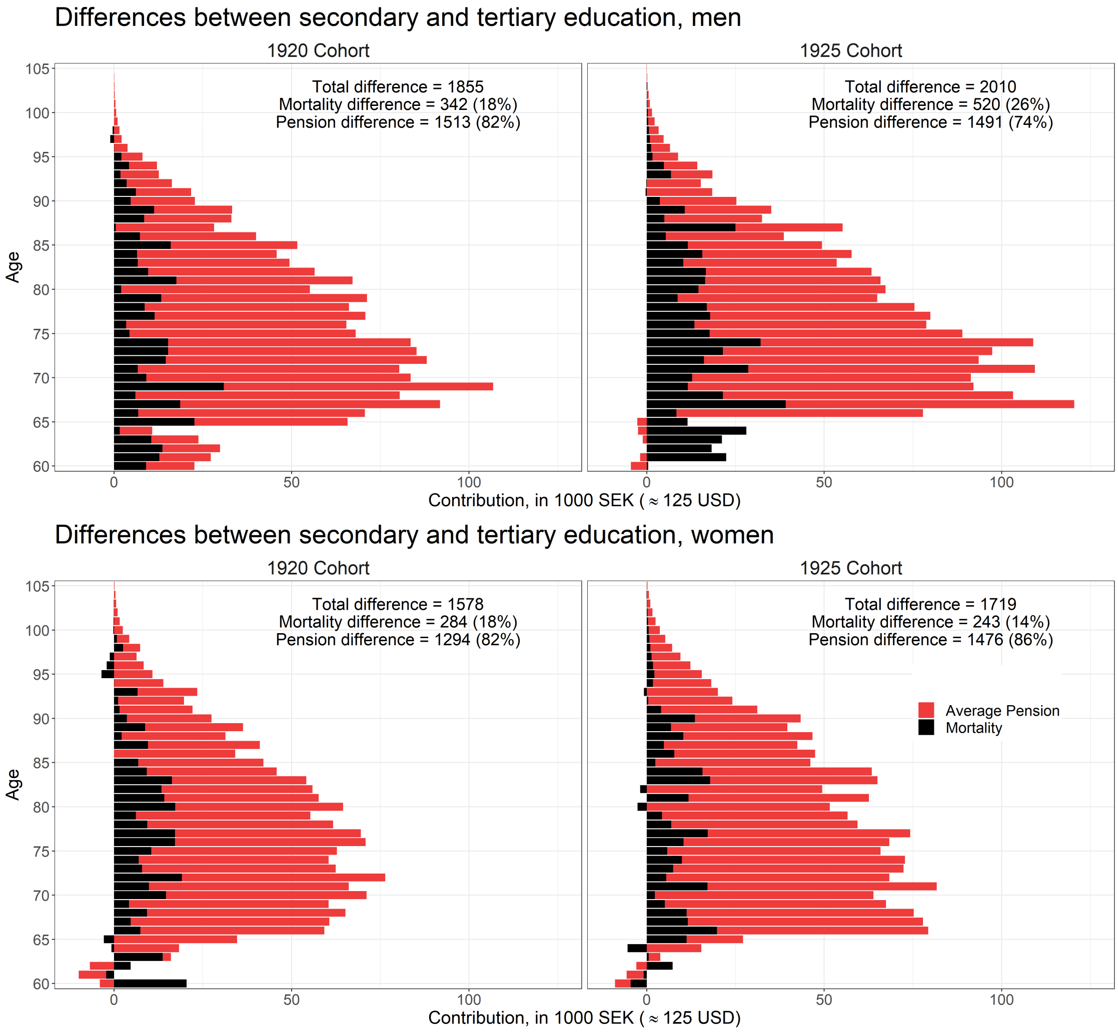

Figure C.13: Decompositions of total lifetime pension differences between secondary and tertiary education groups into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

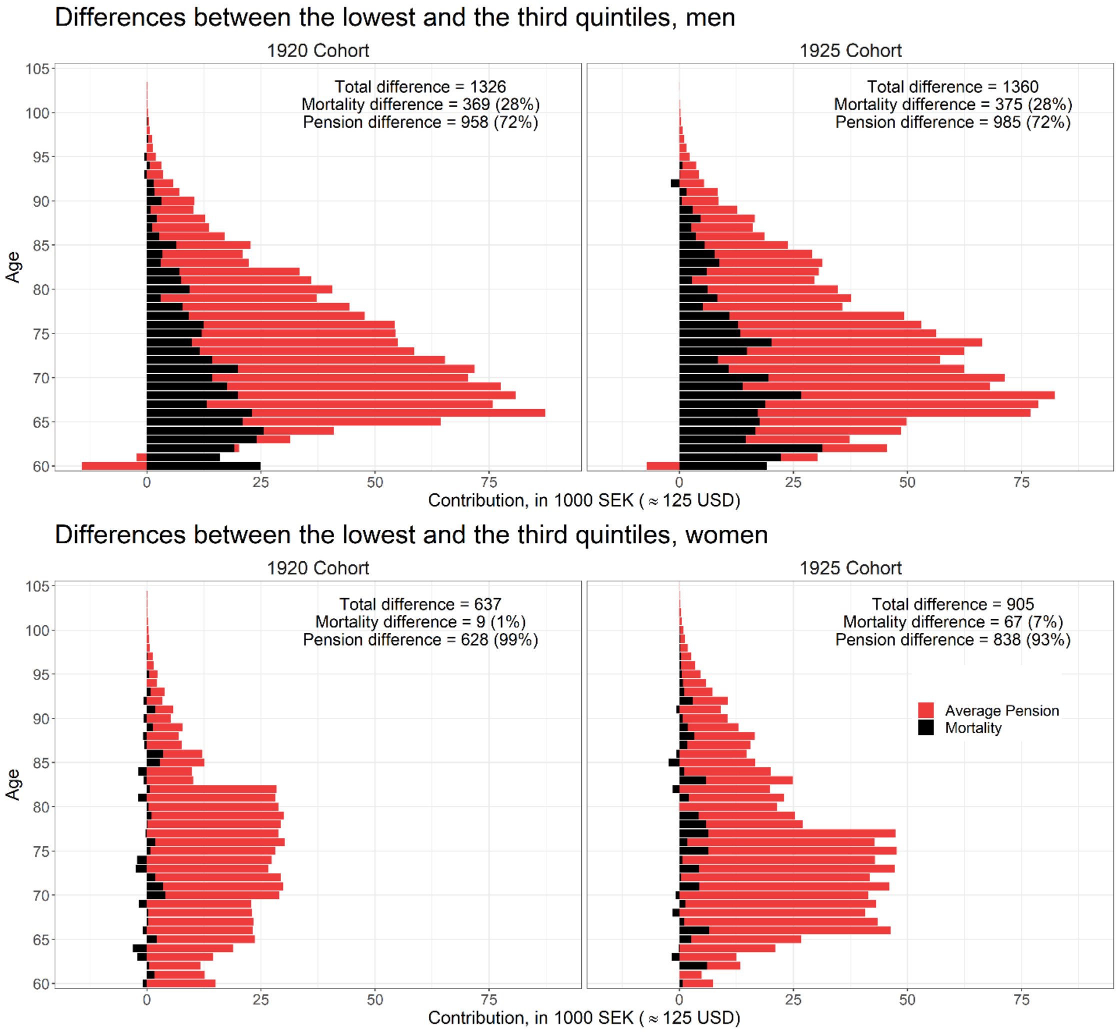

Figure C.14: Decompositions of total lifetime pension differences between the lowest and the third earnings quintile groups into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

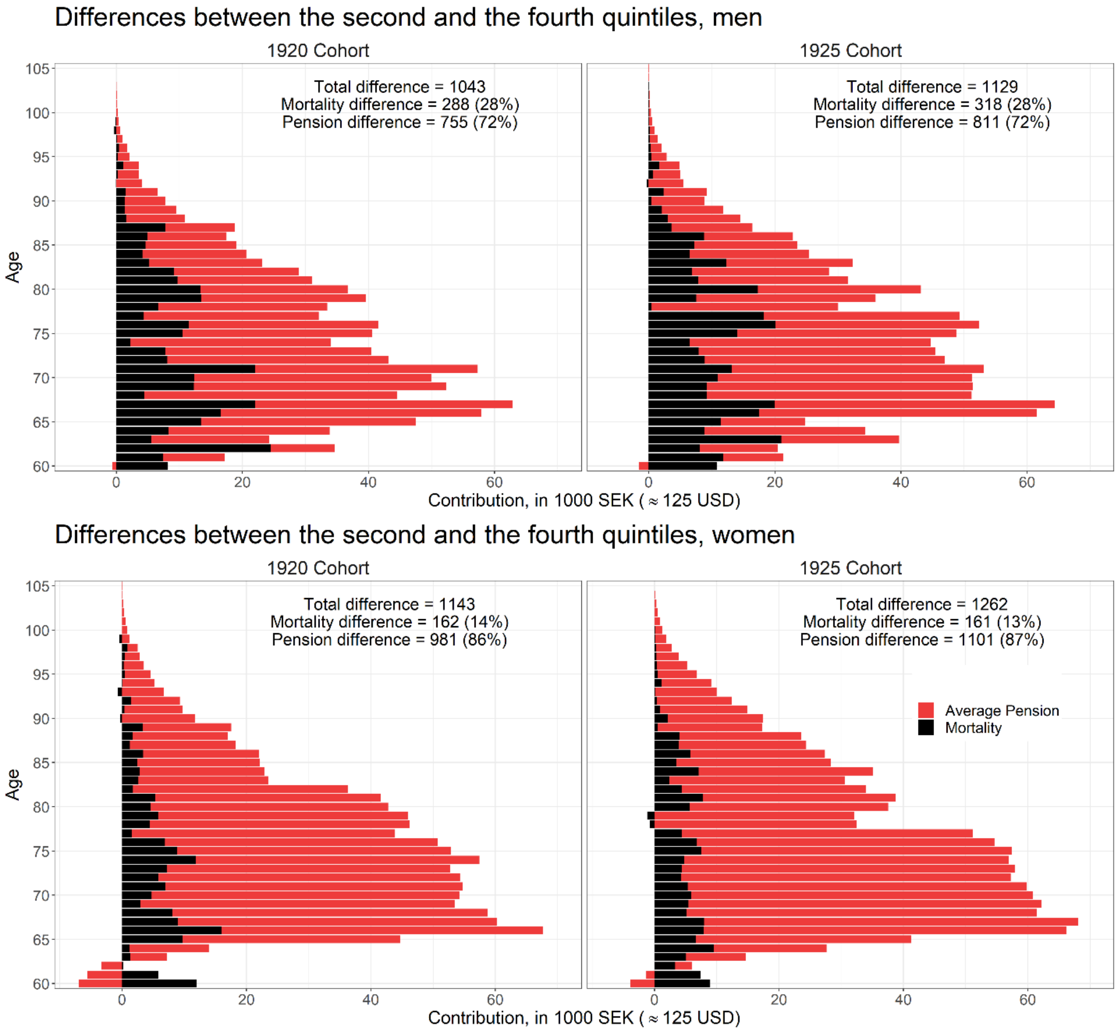

Figure C.15: Decompositions of total lifetime pension differences between the second and the fourth earnings quintile groups into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

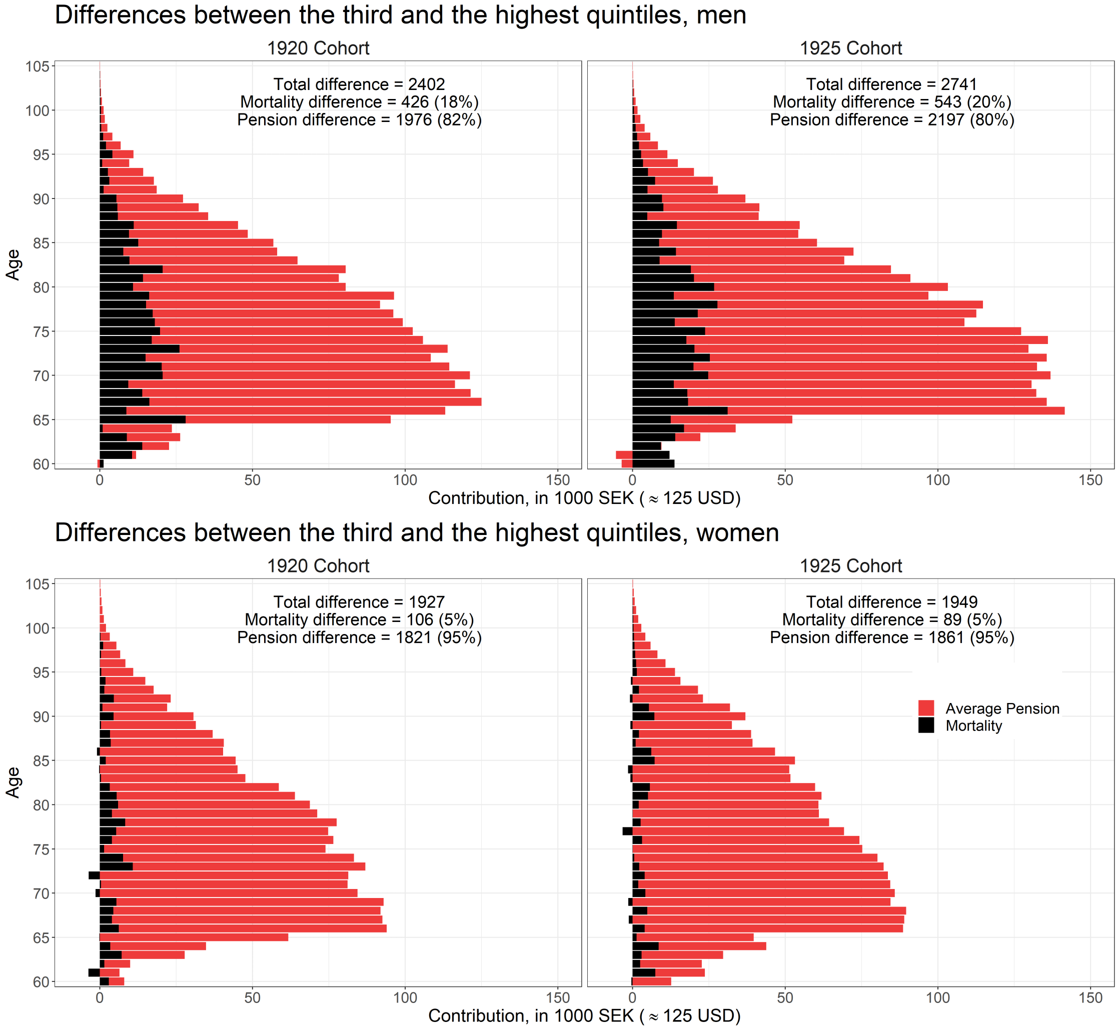

Figure C.16: Decompositions of total lifetime pension differences between the third and the highest earnings quintile groups into differences explained by age and mortality. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

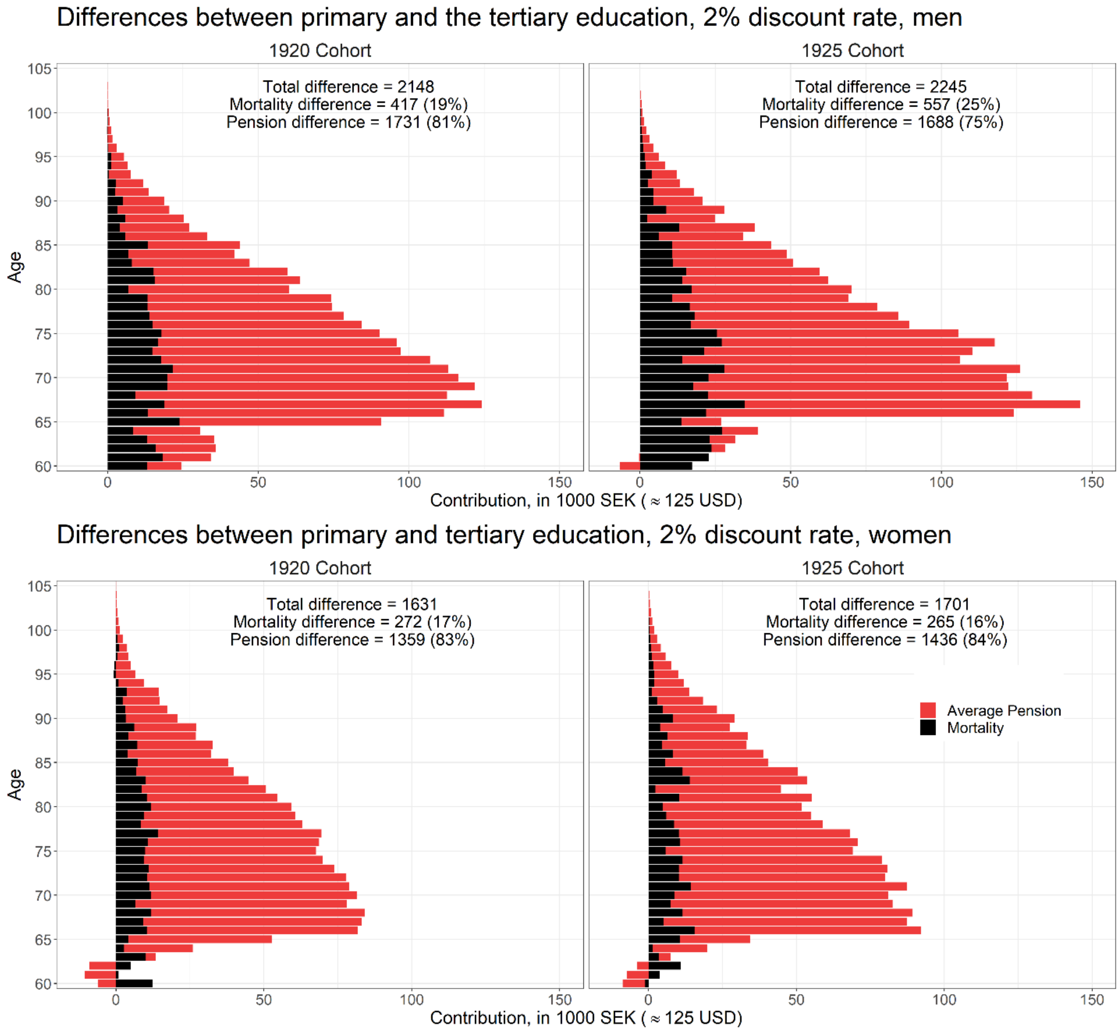

Figure C.17: Decompositions of total lifetime pension differences between primary and tertiary education groups into differences explained by age and mortality, with 2% discount rate. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

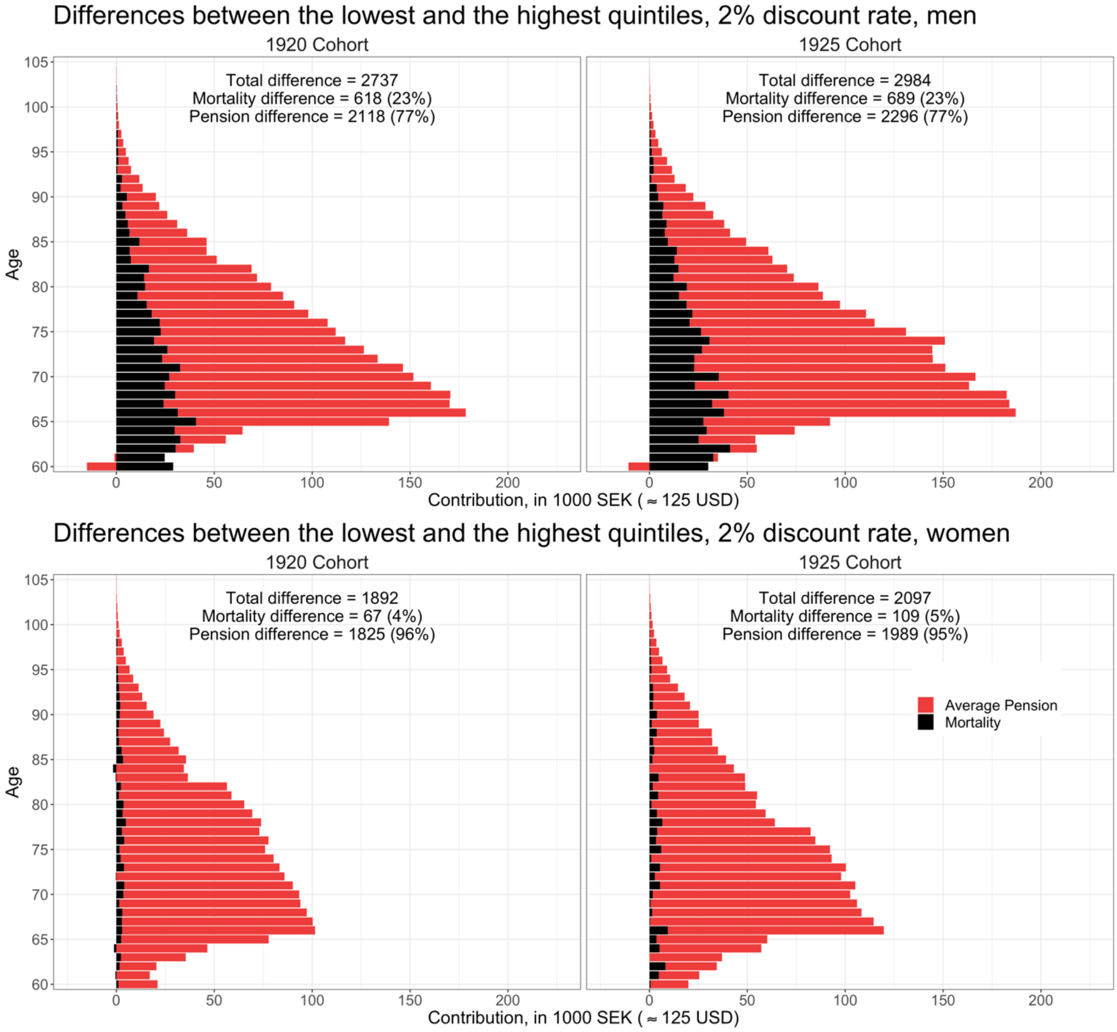

Figure C.18: Decompositions of total lifetime pension differences between the bottom and the top earnings quintile groups into differences explained, with 2% discount rate. *Source*: Authors' calculation based on linked administrative data from Statistics Sweden.

C.3 Tables

Table C.1: Percentages of men with years of zero earnings at ages 50–59, by cohort, education, and earnings

	Number of Years of Zero Earnings											
	0	1	2	3	4	5	6	7	8	9	10	*N*
1920 Cohort												
Total	86.6	9.3	1.7	0.8	0.4	0.4	0.3	0.4	0.1	0.0	0.1	51,088
By Education												
Primary	85.7	9.4	1.9	0.9	0.5	0.5	0.4	0.5	0.1	0.0	0.1	34,757
Secondary	87.9	9.5	1.3	0.7	0.2	0.1	0.1	0.1	0.1	0.0	0.0	13,086
Tertiary	91.1	7.2	0.8	0.2	0.3	0.1	0.0	0.1	0.0	0.0	0.0	3,245
By Earnings												
Lowest	61.6	19.1	7.4	3.9	2.1	1.8	1.4	1.8	0.5	0.1	0.3	10,218
Second	90.1	9.4	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,217
Third	93.2	6.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,218
Fourth	94.2	5.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,217
Highest	93.7	5.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,218
1925 Cohort												
Total	97.1	1.5	0.8	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	40,368
By Education												
Primary	96.6	1.6	1.1	0.3	0.1	0.1	0.0	0.1	0.0	0.0	0.1	25,486
Secondary	97.9	1.2	0.4	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	11,328
Tertiary	98.3	1.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3,554
By Earnings												
Lowest	87.9	5.4	3.9	1.1	0.5	0.4	0.1	0.2	0.1	0.1	0.2	8,074
Second	99.2	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,073
Third	99.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,074
Fourth	99.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,073
Highest	99.2	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,074

Source: Authors' calculation based on linked register data from Statistics Sweden.

Table C.2: Percentages of women with years of zero earnings at ages 50–59, by cohort, education, and earnings

	Number of Years of Zero Earnings											
	0	1	2	3	4	5	6	7	8	9	10	*N*
1920 Cohort												
Total	57.8	10.5	4.2	3.2	3.0	2.9	3.0	2.6	2.2	2.2	8.3	52,624
By Education												
Primary	54.4	10.5	4.4	3.5	3.2	3.2	3.3	3.0	2.5	2.5	9.4	41,128
Secondary	67.2	10.5	3.5	2.5	2.4	2.1	2.1	1.5	1.4	1.5	5.3	9,363
Tertiary	81.3	9.0	2.3	1.4	1.5	0.7	0.6	1.0	0.7	0.6	1.2	2,133
By Earnings												
Lowest	3.4	3.0	2.8	3.2	4.0	5.1	6.7	8.6	10.4	11.2	41.6	10,525
Second	33.0	16.2	10.4	9.4	9.0	8.7	7.9	4.6	0.6	0.0	0.0	10,525
Third	72.0	16.9	5.6	2.9	1.6	0.6	0.3	0.0	0.0	0.0	0.0	10,524
Fourth	86.9	10.5	1.6	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0	10,525
Highest	93.7	5.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10,525
1925 Cohort												
Total	79.2	4.5	3.0	1.9	1.5	1.2	1.1	1.0	1.0	1.2	4.4	41,706
By Education												
Primary	76.2	4.9	3.4	2.1	1.6	1.4	1.3	1.1	1.2	1.4	5.3	31,049
Secondary	86.0	3.9	2.0	1.2	1.1	0.7	0.7	0.7	0.6	0.7	2.4	8,300
Tertiary	94.4	1.9	0.8	0.6	0.3	0.5	0.4	0.1	0.2	0.2	0.6	2,357
By Earnings												
Lowest	23.0	8.2	6.5	6.9	6.1	5.5	5.6	4.7	5.1	6.1	22.2	8,341
Second	78.5	10.2	7.4	2.1	1.1	0.5	0.1	0.0	0.0	0.0	0.0	8,341
Third	95.9	3.1	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8,341
Fourth	99.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,341
Highest	99.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8,342

Source: Authors' calculation based on linked register data from Statistics Sweden.

Table C.3: Percentages of 50-year-old individuals dying before age 60, by cohort, gender, education, and earnings

	Men		Women	
	1920 Cohort	1925 Cohort	1920 Cohort	1925 Cohort
Total	7.4	7.6	4.1	4.0
By Education				
Primary	7.9	8.2	4.2	4.2
Secondary	6.8	7.1	3.7	3.5
Tertiary	4.8	4.9	3.3	3.2
By Earnings				
Lowest	13.8	11.8	5.7	5.2
Second	7.2	7.5	5.3	4.9
Third	5.3	6.5	3.6	3.7
Fourth	5.2	5.9	3.2	2.9
Highest	4.9	6.2	2.5	3.3

Notes: In the main analysis, individuals were selected conational on surviving to age 60. Earnings quintiles were classified based on average yearly income between ages 50 and 59. Here, we used the same earnings cut-points as those used in the main analysis. For individuals who died before age 60, we used average yearly earnings between age 50 and the year prior to death.
Source: Authors' calculation based on linked register data from Statistics Sweden.

Table C.4: Mean and standard deviation of average yearly earnings between ages 50 and 59, by cohort, gender, education, and earnings

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total	264.1	165.1	268.1	148.7	108.8	91.9	138.7	90.1
By Education								
Primary	222.1	109.0	223.8	98.4	93.6	78.0	122.4	78.5
Secondary	315.3	183.1	306.1	149.6	144.0	98.1	165.0	90.5
Tertiary	507.2	279.4	464.5	230.6	249.1	139.7	260.4	114.2
By Earnings								
Lowest	116.6	44.9	127.4	44.8	4.2	5.7	19.7	19.5
Second	202.7	12.7	210.1	10.8	43.3	14.6	86.3	15.0
Third	239.0	9.7	243.6	9.6	95.9	15.0	133.5	13.3
Fourth	284.1	18.3	289.3	18.8	153.0	18.7	185.9	16.4
Highest	478.0	247.6	470.0	207.5	247.8	69.2	268.1	60.4

Notes: Means and standard deviations are shown in SEK 1,000 $\approx$ US\$125. Inflation was adjusted to the 2018 level.
Source: Authors' calculation based on linked register data from Statistics Sweden.

Table C.5: Three-way decompositions of differences in lifetime pensions between primary and secondary education and between secondary and tertiary education

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%
Primary vs. Secondary Education								
Mortality effect	261.1	24.0	305.5	26.9	136.8	18.3	159.7	22.0
Redistribution effect	−1,047.0	−96.1	−895.4	−78.8	−636.6	−85.2	−513.5	−70.8
Earnings effect	1,875.9	172.1	1,725.7	151.9	1,247.1	166.9	1,079.4	148.8
Total	1,090.0	100.0	1,135.8	100.0	747.2	100.0	725.6	100.0
Secondary vs. Tertiary Education								
Mortality effect	341.6	18.4	519.6	25.8	284.0	18.0	243.4	14.2
Redistribution effect	−2,598.8	−140.1	−2,099.3	−104.4	−1,457.9	−92.4	−1,062.3	−61.8
Earnings effect	4,112.0	221.7	3,589.9	178.6	2,751.6	174.4	2,538.3	147.6
Total	1,854.7	100.0	2,010.3	100.0	1,577.8	100.0	1,719.4	100.0

Note: Mortality effect, redistribution effect, and earnings effect refer to the parts of total lifetime pension differences attributable to differences in mortality, differences in the differences between pension income and labor earnings, and differences in labor earnings, respectively.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.6: Three-way decompositions of differences in lifetime pensions between earnings quintiles

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%
Lowest vs. Third Earnings Quintiles								
Mortality effect	368.8	27.8	374.9	27.6	8.7	1.4	66.9	7.4
Redistribution effect	−1,346.5	−101.5	−1,311.0	−96.4	−1,629.4	−255.9	−2,033.6	−224.8
Earnings effect	2,304.1	173.7	2,295.8	168.8	2,257.4	354.5	2,871.2	317.4
Total	1,326.4	100.0	1,359.7	100.0	636.8	100.0	904.5	100.0
Second vs. Third Earnings Quintiles								
Mortality effect	288.1	27.6	317.7	28.1	162.4	14.2	160.9	12.7
Redistribution effect	−881.5	−84.5	−851.0	−75.4	−1,644.1	−143.8	−1,337.0	−105.9
Earnings effect	1,636.0	156.9	1,662.2	147.2	2,625.0	229.6	2,438.5	193.2
Total	1,042.6	100.0	1,128.9	100.0	1,143.3	100.0	1,262.3	100.0
Third vs. Highest Earnings Quintiles								
Mortality effect	425.9	17.7	543.4	19.8	105.7	5.5	88.6	4.5
Redistribution effect	−3,053.5	−127.1	−2,798.9	−102.1	−1,982.5	−102.9	−1,618.1	−83.0
Earnings effect	5,029.6	209.4	4,996.4	182.3	3,803.4	197.4	3,478.8	178.5
Total	2,402.0	100.0	2,740.9	100.0	1,926.5	100.0	1,949.3	100.0

Note: Mortality effect, redistribution effect, and earnings effect refer to the parts of total lifetime pension differences attributable to differences in mortality, differences in the differences between pension income and labor earnings, and differences in labor earnings, respectively.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.7: Three-way decompositions of differences in lifetime pensions between primary and tertiary education and between the lowest and highest earnings quintiles, with 2% discount rate

	Men				Women			
	1920 Cohort		1925 Cohort		1920 Cohort		1925 Cohort	
	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%	Lifetime Pension (in SEK 1,000)[a]	%
Primary vs. Tertiary Education								
Mortality effect	417.1	19.4	556.8	24.8	271.7	16.7	265.1	15.6
Redistribution effect	−2,980.8	−138.8	−2,471.1	−110.1	−1,704.0	−104.5	−1,312.5	−77.1
Earnings effect	4,711.3	219.4	4,159.0	185.3	3,062.9	187.8	2,748.7	161.6
Total	2,147.6	100.0	2,244.7	100.0	1,630.6	100.0	1,701.3	100.0
Lowest vs. Highest Earnings Quintiles								
Mortality effect	618.5	22.6	688.8	23.1	67.2	3.5	108.7	5.2
Redistribution effect	−3,573.7	−130.6	−3,357.9	−112.5	−2,886.9	−152.5	−2,894.3	−138.0
Earnings effect	5,691.8	208.0	5,653.6	189.4	4,712.3	249.0	4,883.0	232.8
Total	2,736.6	100.0	2,984.5	100.0	1,892.5	100.0	2,097.4	100.0

Note: Mortality effect, redistribution effect, and earnings effect refer to the parts of total lifetime pension differences attributable to differences in mortality, differences in the differences between pension income and labor earnings, and differences in labor earnings, respectively.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.8: Lifetime pension inequality between primary and tertiary education under policy and mortality scenarios, 1925 cohort

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Observed	3,146.0	—	2.05	—	2,444.9	—	2.00	—
Uniform Increase in Retirement Age								
One-year increase	3,006.8	−4.4	2.07	0.7	2,345.3	−4.1	2.01	0.3
Three-year increase	2,730.6	−13.2	2.10	2.2	2,148.5	−12.1	2.02	0.8
Differential Retirement Ages								
Primary edu. one year earlier	3,009.9	−4.3	1.96	−4.4	2,366.0	−3.2	1.94	−3.1
Primary edu. three years earlier	2,777.0	−11.7	1.83	−11.0	2,232.4	−8.7	1.84	−8.0
Tertiary edu. one year later	2,836.5	−9.8	1.95	−5.0	2,233.9	−8.6	1.91	−4.3
Tertiary edu. three years later	2,230.8	−29.1	1.75	−14.9	1,817.7	−25.7	1.74	−12.8
Pension System More Generous								
Yearly pension SEK 10,000 more	3,180.0	1.1	2.00	−2.7	2,471.0	1.1	1.92	−4.1
Yearly pension SEK 20,000 more	3,213.9	2.2	1.95	−5.1	2,497.0	2.1	1.85	−7.5
Pension System Less Generous								
Yearly pension SEK 10,000 less	3,112.0	−1.1	2.12	3.1	2,418.9	−1.1	2.10	5.0
Yearly pension SEK 20,000 less	3,078.1	−2.2	2.19	6.7	2,392.9	−2.1	2.23	11.4
Raising Minimum Pension								
Minimum pension to SEK 80,000	3,143.9	−0.1	2.04	−0.3	2,371.0	−3.0	1.93	−3.5
Minimum pension to SEK 100,000	3,130.2	−0.5	2.03	−0.9	2,253.1	−7.8	1.83	−8.4

Table C.8 (continued)

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Mortality Reduction Scenarios								
10% less for all	3,263.5	3.7	2.04	−0.8	2,523.8	3.2	1.99	−0.3
Primary 10% less, tertiary 0% less	2,986.2	−5.1	1.95	−5.1	2,349.2	−3.9	1.93	−3.8
Primary 0% less, tertiary 10% less	3,423.3	8.8	2.14	4.5	2,619.6	7.1	2.07	3.6

Notes: The observed average lifetime pensions are SEK 2,992,800 for men with primary education, SEK 6,138,800 for men with tertiary education, SEK 2,443,500 for women with primary education, and SEK 4,888,500 for women with tertiary education. For the scenarios of changing retirement age, we shift the observed yearly pension income to younger or older ages by one or three years. In the case of earlier retirement by one year, the last year (i.e., age 105) of pension income is assumed to be the same as the pension income in the last observed year (i.e., age 104). In the case of later retirement by one year, the first year (i.e., age 60) of pension income is set to 0. For the mortality scenarios, we reduce mortality rates across all ages by 10%.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.9: Lifetime pension inequality between the lowest and the highest earnings quintiles under policy and mortality scenarios, 1920 cohort

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Observed	3,728.3	—	3.32	—	2,563.3	—	2.73	—
Uniform Increase in Retirement Age								
One-year increase	3,545.4	−4.9	3.36	1.0	2,456.6	−4.2	2.74	0.5
Three-year increase	3,184.7	−14.6	3.43	3.2	2,244.1	−12.5	2.77	1.5
Differential Retirement Ages								
Primary edu. one year earlier	3,671.0	−1.5	3.21	−3.4	2,505.5	−2.3	2.63	−3.8
Primary edu. three years earlier	3,564.3	−4.4	3.01	−9.3	2,415.1	−5.8	2.48	−9.1
Tertiary edu. one year later	3,444.3	−7.6	3.14	−5.3	2,383.8	−7.0	2.61	−4.4
Tertiary edu. three years later	2,890.3	−22.5	2.80	−15.7	2,029.0	−20.8	2.37	−13.2
Pension System More Generous								
Yearly pension SEK 10,000 more	3,772.6	1.2	3.12	−6.1	2,571.7	0.3	2.49	−8.8
Yearly pension SEK 20,000 more	3,817.0	2.4	2.95	−11.2	2,580.2	0.7	2.31	−15.5
Pension System Less Generous								
Yearly pension SEK 10,000 less	3,684.0	−1.2	3.57	7.6	2,554.9	−0.3	3.07	12.4
Yearly pension SEK 20,000 less	3,639.6	−2.4	3.90	17.4	2,546.5	−0.7	3.57	30.9
Raising Minimum Pension								
Minimum pension to SEK 80,000	3,673.5	−1.5	3.20	−3.7	2,233.1	−12.9	2.23	−18.5
Minimum pension to SEK 100,000	3,582.3	−3.9	3.03	−8.9	1,890.7	−26.2	1.87	−31.5

Table C.9 (continued)

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Mortality Reduction Scenarios								
10% less for all	3,892.2	4.4	3.28	−1.2	2,652.6	3.5	2.72	−0.4
Primary 10% less, tertiary 0% less	3,629.6	−2.6	3.13	−5.8	2,501.0	−2.4	2.62	−4.0
Primary 0% less, tertiary 10% less	3,990.9	7.0	3.48	4.9	2,714.9	5.9	2.83	3.7

Notes: The observed average lifetime pensions are SEK 1,606,600 for men in the lowest quintile, SEK 5,334,900 for men in the highest quintile, SEK 1,481,000 for women in the lowest quintile, and SEK 4,888,500 for women in the highest quintile. For the scenarios of changing retirement age, we shift the observed yearly pension income to younger or older ages by one or three years. In the case of earlier retirement by one year, the last year (i.e., age 105) of pension income is assumed to be the same as the pension income in the last observed year (i.e., age 104). In the case of later retirement by one year, the first year (i.e., age 60) of pension income is set to 0. For the mortality scenarios, we reduce mortality rates across all ages by 10%.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.10: Lifetime pension inequality between the lowest and the highest earnings quintiles under policy and mortality scenarios, 1925 cohort

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Observed	4,100.6	—	3.14	—	2,853.8	—	2.76	—
Uniform Increase in Retirement Age								
One-year increase	3,545.4	−4.9	3.36	1.0	2,456.6	−4.2	2.74	0.5
Three-year increase	3,184.7	−14.6	3.43	3.2	2,244.1	−12.5	2.77	1.5
Differential Retirement Ages								
Primary edu. one year earlier	3,671.0	−1.5	3.21	−3.4	2,505.5	−2.3	2.63	−3.8
Primary edu. three years earlier	3,564.3	−4.4	3.01	−9.3	2,415.1	−5.8	2.48	−9.1
Tertiary edu. one year later	3,444.3	−7.6	3.14	−5.3	2,383.8	−7.0	2.61	−4.4
Tertiary edu. three years later	2,890.3	−22.5	2.80	−15.7	2,029.0	−20.8	2.37	−13.2
Pension System More Generous								
Yearly pension SEK 10,000 more	3,772.6	1.2	3.12	−6.1	2,571.7	0.3	2.49	−8.8
Yearly pension SEK 20,000 more	3,817.0	2.4	2.95	−11.2	2,580.2	0.7	2.31	−15.5
Pension System Less Generous								
Yearly pension SEK 10,000 less	3,684.0	−1.2	3.57	7.6	2,554.9	−0.3	3.07	12.4
Yearly pension SEK 20,000 less	3,639.6	−2.4	3.90	17.4	2,546.5	−0.7	3.57	30.9
Raising Minimum Pension								
Minimum pension to SEK 80,000	3,673.5	−1.5	3.20	−3.7	2,233.1	−12.9	2.23	−18.5
Minimum pension to SEK 100,000	3,582.3	−3.9	3.03	−8.9	1,890.7	−26.2	1.87	−31.5

Table C.10 (continued)

	Men				Women			
	Absolute Difference		Relative Difference		Absolute Difference		Relative Difference	
	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change	Difference (in SEK 1,000)[a]	% Change	Ratio	% Change
Mortality Reduction Scenarios								
10% less for all	3,892.2	4.4	3.28	−1.2	2,652.6	3.5	2.72	−0.4
Primary 10% less, tertiary 0% less	3,629.6	−2.6	3.13	−5.8	2,501.0	−2.4	2.62	−4.0
Primary 0% less, tertiary 10% less	3,990.9	7.0	3.48	4.9	2,714.9	5.9	2.83	3.7

Notes: The observed average lifetime pensions are SEK 1,606,600 for men in the lowest quintile, SEK 5,334,900 for men in the highest quintile, SEK 1,481,000 for women in the lowest quintile, and SEK 4,888,500 for women in the highest quintile. For the scenarios of changing retirement age, we shift the observed yearly pension income to younger or older ages by one or three years. In the case of earlier retirement by one year, the last year (i.e., age 105) of pension income is assumed to be the same as the pension income in the last observed year (i.e., age 104). In the case of later retirement by one year, the first year (i.e., age 60) of pension income is set to 0. For the mortality scenarios, we reduce mortality rates across all ages by 10%.
Source: Authors' calculation based on linked register data from Statistics Sweden.
[a] Units are in SEK 1,000 ≈ US$125.

Table C.11: Distribution of marital status within earnings quintiles, by cohort and gender (in %)

	Men				Women			
	Married	Divorced	Widowed	Never Married	Married	Divorced	Widowed	Never Married
1920 Cohort								
Lowest	60.5	8.2	1.3	30.0	97.0	0.6	0.3	2.1
Second	79.2	4.8	1.4	14.7	86.0	4.0	2.6	7.4
Third	85.5	4.2	1.2	8.8	85.6	4.6	5.9	3.9
Fourth	91.2	3.1	1.2	4.5	78.9	9.0	5.0	7.1
Highest	94.6	2.2	0.9	2.3	61.3	12.8	9.7	16.1
1925 Cohort								
Lowest	57.8	11.8	1.9	28.5	93.7	1.6	1.9	2.8
Second	71.9	9.7	2.3	16.1	78.8	7.4	7.4	6.4
Third	81.3	8.2	1.8	8.6	83.0	8.2	5.1	3.6
Fourth	86.8	6.8	1.8	4.6	68.0	15.7	8.9	7.4
Highest	90.3	6.1	1.6	2.1	54.4	16.2	15.3	14.0

Notes: Marital status was obtained from census data. The 1970 and 1980 census data were used for the 1920 and 1925 cohorts, respectively. Thus, marital status at age 50 was used for the 1920 cohort, and at age 55 was used for the 1925 cohort.
Source: Authors' calculation based on linked register data from Statistics Sweden.

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