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Research Article

Ageing and diversity: Inequalities in longevity and health in low-mortality countries

Cosmo Strozza

Viviana Egidi

Maria Rita Testa

Graziella Caselli

This publication is part of the Special Collection in the Memory of Professor James W Vaupel (1945–2022), founder and long-time publisher of Demographic Research. The Special Collection is edited by Jakub Bijak, Griffith Feeney, Nico Keilman, and Carl Schmertmann.

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Cosmo Strozza[1]

Viviana Egidi[2]

Maria Rita Testa[3]

Graziella Caselli[4]

Abstract

BACKGROUND
Longevity and old age are two aspects of the same phenomenon, representing a major concern for modern societies. There is universal consensus among scholars about the need for new frameworks and measures to define older people in a more effective and dynamic way.

OBJECTIVE
The aim of this paper is to compute prospective old-age thresholds (POATs) in six countries characterised by disparate progress in survival. To outline possible strategies to counter population ageing, the paper also examines trends in POAT and disability-free POAT (DF-POAT) in Italy by gender, geographical area, and education.

DATA AND METHODS
To compute the POAT, we use life tables from the Human Mortality Database (HMD) and the Italian National Institute of Statistics, Istat. In addition, to compute the DF-POAT, data on mortality and health by geographical area and education were retrieved from Istat.

RESULTS
During the period 1950–2020 the POAT advanced everywhere, albeit in different rhythms by country, gender, and period. However, great differences in POAT and DF-POAT have emerged, depending on place of residence, education, and health.

[1] Interdisciplinary Centre on Population Dynamics, University of Southern Denmark, Odense, Denmark
[2] Department of Statistics, Sapienza University, Rome, Italy
[3] Department of Political Science, Luiss University, Rome, Italy
[4] Corresponding author. 2Department of Statistics, Sapienza University, Rome, Italy.
Email: graziella.caselli@fondazione.uniroma1.it.

CONCLUSIONS
The POAT changes the evaluation of population ageing and could reduce the alarm caused by measures based on static chronological old-age thresholds. Using Italy as a case study, we show that overcoming geographical and social inequalities would counteract the population ageing process.

CONTRIBUTION
The paper highlights how individual and population ageing is a relative concept, as acknowledged by James W. Vaupel in his studies where he explores the equivalence between ages based on mortality risks.

1. Introduction

Over recent decades, adult and old-age mortality has declined remarkably throughout the developed world. More than half of the improvements in life expectancy in Europe (almost 70% in the United States) in the last two decades are attributed to reduction in mortality over age 60 (United Nations 2017). This phenomenon poses economic and public health challenges for modern societies, and opens up fresh horizons for researchers interested in life expectancy trends, particularly at older ages. Recent mortality developments have impacted the population age structure of modern societies, which nowadays are characterised by a higher proportion of older people. In demography and social, political, and health sciences, older people are conventionally considered those older than a fixed chronological age of 60 or, more recently, 65 (Europeas 2021). These age thresholds are routinely referred to in demographic evaluations, social interventions, health policies, economic policies, and public spending.

The implicit assumption of a fixed age threshold is that individual characteristics, such as health status and survival probabilities, remain unchanged from one cohort to the next. However, a 65-year-old person today expects to live longer and with better health conditions than did a person of the same age 70 years ago. Moreover, increases in life expectancy and lifespan extensions result not only from medical and health advances but also from economic and social developments that improve individual and collective living conditions. These factors have contributed to counteracting diseases, so that the entire individual life cycle has been affected by new survival opportunities (Lee and Goldstein 2003; Levin 2013). Although ageing is a universal process that affects all individuals, a degree of plasticity does exist across both individuals and cohorts, irrespective of the biological ageing theory assumed (Baudisch and Vaupel 2012; Burger, Baudisch, and Vaupel 2012; McDonald 2019; Vaupel 2010). The dramatic transformations that have taken place in the past question the validity of all fixed ages as thresholds of the transition from adulthood to old age (Demuru and Egidi 2016; Lee and Goldstein 2003).

A large body of literature exists on every facet of the daily lives of older people. Psychological, social, economic, demographic, health, and even existential issues have all been dealt with in great detail, keeping pace with the persistent increase in the number of older adults and their lengthening lifespan. Longevity and old age are two aspects of the same phenomenon and represent a major issue for modern societies. The contours and mechanisms of interaction between the two concepts are under-investigated, despite the wealth of existing literature on older adults. Several studies have outlined the impact of declining mortality on the increase in the older population (Arthur and Vaupel 1984; Canudas-Romo, Shen, and Payne 2021; Caselli and Vallin 1990; Fernandes, Turra, and Rios Neto 2023; Horiuchi and Preston 1988) and the impact of declining mortality at older ages on trends in survival and longevity (Aburto et al. 2020; Aburto and van Raalte 2018; Barbi 2003; Bohk-Ewald, Ebeling, and Rau 2017; Canudas-Romo 2010; Cheung et al. 2005; Diaconu, Raalte, and Martikainen 2022; Engelman, Canudas-Romo, and Agree 2010; van Raalte and Caswell 2013; Salinari and De Santis 2014; Vaupel 2010; Vaupel, Villavicencio, and Bergeron-Boucher 2021; Zheng 2014).

In addition to not accounting for improved survival, the conventional old-age thresholds hide major inequalities: between men and women, highly educated and low-educated, rich and poor, robust and fragile people. As such, they cannot provide useful information to design policies aimed at meeting the real needs of the older population, reducing inequalities, and appropriately channelling public spending. For this reason, there is universal consensus among scholars about the need for new frameworks and measures to define older adults in a more effective and dynamic way. Major efforts have been made to link the concept of older age to changing life course conditions and improved longevity. Recently, several authors have come up with new measures of population ageing, which are based on various aspects of the survival function (Alvarez and Vaupel 2023; Burger, Baudisch, and Vaupel 2012; Europeas 2021; Sanderson and Scherbov 2005; Vaupel, Villavicencio, and Bergeron-Boucher 2021; Zuo et al. 2018). The central idea behind these approaches is that the old-age threshold should be responsive to life expectancy improvements – particularly to remaining life expectancy at older ages. Thus, the old-age threshold should be allowed to change correspondingly. One approach introduces the concept of ‘prospective’ age (Demuru and Egidi 2016; Lutz, Sanderson, and Scherbov 2008; Sanderson and Scherbov 2005, 2019; Scherbov and Sanderson 2020), thereby reactivating a line of pioneering research that was widely discussed in the 1970s (Ryder 1975). As opposed to looking to the past (chronological age), prospective age looks to the future, because it is based solely on remaining life expectancy at a certain age. Furthermore, this and other approaches – based on various aspects of the survival function – have the advantage of emphasising that an individual’s life course is largely influenced by the context in which they live, which can either protect or deteriorate their health conditions and alter the pace and manner of their ageing. Although the new dynamic thresholds can overcome the static nature of conventional thresholds, when computed for the whole population they still have the limitation that inequalities between groups with different characteristics within the same population remain hidden.

The aim of this paper is to uncover these differences by computing the prospective old-age thresholds (POATs) in a range of countries and sub-populations that might have benefited differently from health and survival improvements. The POAT can be used to quantify, in relative terms, inequalities between and within populations (Caselli, Egidi, and Strozza 2021; Demuru and Egidi 2016). More specifically, we address the following research questions:

1. How have various pathways of reduced old-age mortality changed remaining life expectancy, age-at-death heterogeneity, and the measures of population ageing that account for changes in survival?
2. How do survival differentials by socioeconomic status, geographical area, and health conditions modify old-age thresholds and population ageing?
3. Is it possible to reverse the trend towards increasing population ageing by reducing social inequalities?

To answer these questions we will estimate the POAT not only for the whole population but also by geographical area of residence, socioeconomic status, and health conditions, to account for survival improvements at older ages and their inequalities. A gender perspective will be adopted throughout the study to highlight the different pathways of men's and women's mortality reduction and inequalities in exposure to the risk of death.

After the section presenting the data and methods, the results section is divided into four sub-sections. The first sub-section describes the long-term trends of the POAT, together with two main indicators of old-age mortality, remaining life expectancy and life-table entropy, both at age 65. All indicators refer to six countries with different trends in mortality and population ageing: Denmark, France, Italy, Sweden, the United Kingdom, and the United States. In the following sub-sections Italy is used as a case study because it allows addressing the impact of some major inequalities (i.e., geographical area of residence, education, and health conditions) on the POAT and population ageing. The results suggest how interventions to reduce inequalities in populations might alter the population ageing process. The final section discusses methods and results and draws conclusions.

2. Data and methods

In order to answer the research questions outlined above, this study draws on several data sources and methods.

To answer the first research question, we use sex-specific period life tables and populations for six low-mortality countries from 1950 to 2020, obtained from the Human Mortality Database (HMD) (Barbieri et al. 2015; HMD 2023). The countries are Denmark, France, Italy, Sweden, the United Kingdom, and the United States. Italy's life table and population in 2020 is from the Italian National Institute of Statistics database (Istat 2023). We selected six countries that were characterised by different mortality trends over the 70 years. From the life tables we retrieve the remaining life expectancy at age 65 (e_{65}) for each country and year by sex, representing the ultimate measure of mortality. At the same level of detail, we compute the life table entropy at age 65 ($\overline{H}_{65}$), as a relative measure of lifespan inequality, expressing the elasticity of life expectancy to changes in mortality (Keyfitz and Caswell 2005). To complete the mortality picture and assess population ageing, we estimate the prospective old-age threshold (POAT) for each country and year by sex (Scherbov and Sanderson 2020). The POAT represents the age at which remaining life expectancy for a standard population, used as reference, is observed in a certain calendar year or population. The POAT estimates are based on life expectancy smoothed with splines (Silverman 1985). To compare POAT trends for the six countries across the 70 years, we use as a reference for all the calculations the remaining life expectancy at age 65 for men in the UK in 1950, being the minimum among all the observed values at the beginning of the study period. Several scholars have recently investigated he relationship between life expectancy and lifespan inequality (Aburto et al. 2019, 2020; Vaupel, Zhang, and van Raalte 2011). We then graphically assess the relationship between $\overline{H}_{65}$ and POAT (see Figure A-1 in the Appendix). Furthermore, we use joinpoint regression, also known as change point or segmented regression, to analyse trends in POAT by estimating the points at which a series significantly changes its slope (evolutionary phases) (Kim et al. 2000). Then, in the estimated evolutionary phases, we observe trends in e_{65} and $\overline{H}_{65}$. This model is frequently used; for instance, to analyse changes in trends in disease-specific death rates (Qiu et al. 2009; Wilson, Bhatnagar, and Townsend 2017) or other population parameters (Egidi and Demuru 2018). In our analyses we investigate trends for the three indicators from 1950 to 2019, by country and sex. The year 2020 is omitted from the joinpoint regression analysis as it represents an outlier which, as the final observation of the series, cannot be compensated by later values. Finally, based on the chronological and prospective age (POAT), we use, respectively, a fixed (chronological, 65 years) and dynamic (prospective, POAT) old-age threshold to compute the share of older individuals in the populations included in the analysis.

To answer the second research question, we use life tables by sex, geographical area, and level of education for Italy, provided by Istat (Istat 2015b). They are based on census-linked data for 2011 with a 3-year mortality follow-up (2012–2014) and represent the most recent available data in Italy with such level of detail. Reflecting the data availability, the territory is divided into just four geographical areas: North-East, North-West, Centre, and the South including Sicily and Sardinia. This is an adaptation of the five NUTS-1 groups where the South and the islands are separate categories. Education is measured according to the highest educational attainment and is divided into three categories: low (elementary school diploma and lower), medium (middle school diploma), and high (high school diploma and higher). At the same level of detail, we compute disability prevalence based on pooled data (years 2012–2014) from the Italian survey Aspects of Daily Living. We apply sample weights to the data of each survey before pooling them together. Self-reported disability is defined according to the Global Activity Limitation Indicator (GALI), which measures long-term limitations in daily activities. This indicator is used to compute disability-free life expectancy (DFLE) at age 65 by sex, geographical area, and education. DFLE is estimated using the Sullivan method (Sullivan 1971), combining mortality and prevalence data by weighing age-specific person-years lived (L_x) with age-specific prevalence of disability (π_x). Based on remaining life expectancy at age 65, we estimate disability-free POAT (DF-POAT) by sex, geographical area, and level of education. We use e_{65} of men from the United Kingdom in 1950 to allow comparability of the analyses pertaining to the first and second research questions. We also compute DF-POAT, based on DFLE at the POAT age for Italian men in the years 2012–2014, to ensure the whole analysis is coherent.

To answer the third research question, we compute the share of individuals older than old-age thresholds in the Italian population in 2011 according to different hypotheses: (a) current mortality, (b) overcoming geographical inequalities, (c) overcoming social inequalities, (d) overcoming geographical and social inequalities. We do so by employing three different old-age thresholds; i.e., chronological (65 years), POAT, and DF-POAT. Specifically, to overcome geographical inequalities we consider the highest POAT and DF-POAT for Italy by geographical area, representing the ideal old-age thresholds if all the Italian areas were to catch up with the most advantaged (b). Similarly, we compute the highest POAT and DF-POAT by education, representing the ideal old-age thresholds if all the educational groups were to catch up with the most advantaged (c). Finally, we compute the highest POAT and DF-POAT by geographical area and education (d), combining the latter two hypotheses (b) and (c).

Most of the analysis is performed in R version 4.2.2 (R Core Team 2022), except for the joinpoint regression analysis, which is performed in SEER*Stat software, developed within the Surveillance Research Program, version 4.9.1.0. The code to replicate the part of the analysis for which the data are publicly accessible is available in the GitHub repository (https://github.com/cstrozza91/POAT-International-comparison).

3. Results

3.1 Increasing survival above age 65 and decreasing age-at-death variability slow down the ageing process

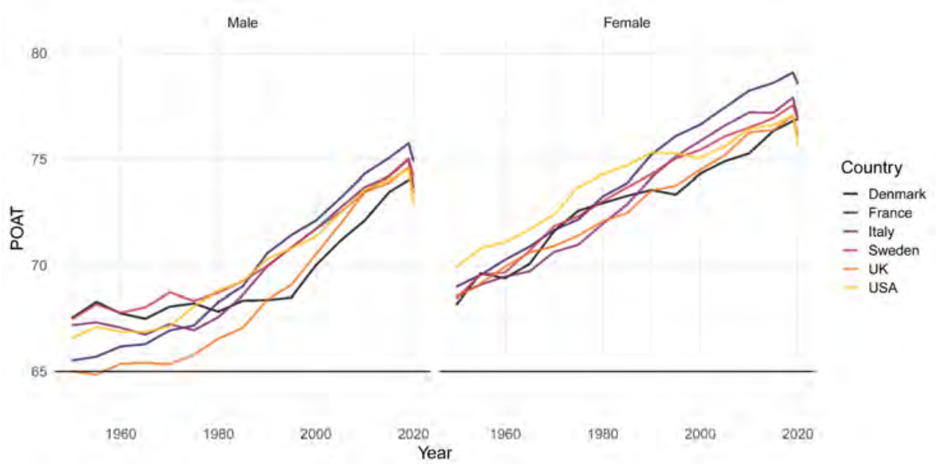
Although the POAT increased greatly over the 70 years in all the countries examined, this general trend followed very different paths across countries and genders.

Denmark and Sweden held the top positions in country ranking by male POAT after World War II, far above the United Kingdom and France. The ranking has changed 70 years later. Sweden maintained its high position but was overtaken by France, which had the highest POAT increase (9.4 years), followed by the United Kingdom (8.5 years). France gained the top position for its female POAT, which increased by 9.6 years in the 70-year period. Italy came second, immediately above all the remaining countries in the analysis. By contrast, at the end of the study period the United States and United Kingdom, which held leading positions in the early 1950s, have regressed and are at the bottom of the rankings, together with Denmark, which followed a similar path to that of the United States between the mid-1980s and the mid-1990s (Figure 1 and Table 1).

The evolution of POAT is strongly associated with remaining life expectancy at age 65 and age-at-death variability after age 65. Time trends for the latter two measures are presented in the Appendix (Figures A-2 and A-3). Several scholars have recently investigated the relationship between life expectancy and lifespan inequality (Aburto et al. 2019, 2020; Vaupel, Zhang, and van Raalte 2011). Results concerning the relationship between POAT and life table entropy at age 65 for the countries under investigation are displayed in the Appendix (Figure A-1).

In Table 1 we report the values of POAT at age 65, remaining life expectancy (e_{65}) and life table entropy ($\overline{H}_{65}$) at the same age, at the beginning, and the end of the period. As well as the year 2020, we also show values for the year 2019 to allow us to assess the consequences of the COVID-19 pandemic, which caused an abrupt change in the three indicators in many countries. We notice that, in the 70 years considered, while the increase in e_{65}, albeit differentiated, affected all countries and both sexes, $\overline{H}_{65}$ followed less homogeneous and regular paths. For women it decreased constantly and often remarkably, and in the most recent years it became lower than that of men. This trend is in line with the results shown by Aburto et al. (2019) over the entire life cycle. For men, $\overline{H}_{65}$ decreased in some countries (Denmark, Sweden, the United Kingdom) and increased in other countries (France and Italy), while in the United States it remained largely stable for long periods. In 2020, in all countries except Denmark, both remaining life expectancy and the POAT had decreased by more than one year. In the United States, the United Kingdom, and Italy this was the case for both men and women. In the same period the life table entropy increased after a long period of decrease, returning to values comparable to those of the immediate post-war period, or even higher for men in Italy and France.

Figure 1: Prospective old-age threshold (POAT) for selected countries, by gender, 1950–2020. Reference: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years)



Note. To provide smoothed patterns, we present results every 5 years from 1950 to 2020. We added the values for 2019 to emphasise the impact of the COVID-19 pandemic on the POAT.

Table 1: Prospective old-age threshold (POAT), remaining life expectancy at age 65 (e_{65}), and life table entropy ($\bar{H}_{65}$) in percentage points for selected countries for 1950, 2019, and 2020. Reference: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years)

Country	Year	Male			Female		
		POAT	e_{65}	$\bar{H}_{65}$%	POAT	e_{65}	$\bar{H}_{65}$%
Denmark	1950	67.5	13.6	35.4	68.2	14.1	36.6
	2019	74.0	18.3	34.6	76.8	21.0	31.8
	2020	74.0	18.3	34.5	76.9	21.1	31.6
France	1950	65.5	12.2	32.8	69.0	14.6	34.6
	2019	75.8	19.6	32.7	79.2	23.5	27.6
	2020	74.9	18.9	33.2	78.6	23.0	27.9
Italy	1950	67.2	13.3	32.2	68.5	14.3	34.9
	2019	75.0	19.4	32.8	77.9	22.5	28.4
	2020	73.7	18.3	34.3	76.9	21.7	28.8
Sweden	1950	67.5	13.5	36.0	68.4	14.3	36.7
	2019	75.0	19.5	32.5	77.6	22.0	29.7
	2020	74.2	18.9	32.6	76.9	21.5	30.0
United Kingdom	1950	65.0	11.9	35.8	68.5	14.3	36.5
	2019	74.6	19.0	33.8	77.1	21.3	31.1
	2020	73.4	18.0	34.3	76.1	20.6	31.4
United States	1950	66.6	12.8	34.7	69.9	15.1	36.5
	2019	74.6	18.4	34.0	77.1	21.0	32.0
	2020	72.9	17.1	34.2	75.7	19.8	32.6

The evolution of the POAT from the post-World War II period to the present has been anything but smooth. In Table 2 we show, for the six countries, the different phases of its evolution, identified via the joinpoint regression. Specifically, the boundaries are those years where the slope of the POAT changes significantly. Besides the average variation of the POAT in the different phases, we report variation in e_{65} and $\bar{H}_{65}$ to reflect their evolution within each phase. Estimates encompass the period 1950–2019, eliminating the impact of the pandemic outbreak. The more or less rapid evolution of POAT in the different periods is clearly determined by the joint evolution of average age at death and its variability: periods of stagnant or receding POAT are characterised by little or no change in remaining life expectancy and an increase in life table entropy. An example is provided by the POAT trend of Danish women in 1987–1995 and US women in 1992–2001, where remaining life expectancy stagnated or slightly declined while the relative variability of age at death increased. By contrast, the most rapid progress of the

POAT usually occurs when remaining life expectancy increases and life table entropy decreases. An example is provided by the rapid advance of the POAT by approximately 4 months a year for men in the United Kingdom from the end of the 1990s to the first decade of the 21st century. Nevertheless, the POAT may also increase when there is an increasing trend in life table entropy. This was the case for US men in the 1970s, when after the setback experienced in 1954–1969 the POAT continued to advance by more than 2 months a year, despite increasing life table entropy. Table 2 highlights two groups of countries. Sweden and France's evolution was regular (positive) throughout the period, with few break points in the time series, and ranked at the top of POAT for both sexes. On the other hand, the paths of Denmark, the United States, and the United Kingdom were more bumpy, with many significant evolutionary phases, and they lost their initial top positions in the ranking (Tables 1 and 2, Figure 1). Finally, looking at differences by gender, in the second decade of the 21st century the rate of increase in POAT slowed for women in Italy, the United States, and the United Kingdom. Only France and Denmark maintained a high rate of increasing POAT, while the POAT of Swedish women continued to increase steadily at a slightly slower pace than that of men. Men faced difficulties in the first half of the 1970s almost everywhere, but subsequently their POAT started to improve, leading to rapid progress in the most recent decades (Table 2).

The introduction of an old-age threshold based on prospective age (POAT) represents a paradigmatic shift in the study of population ageing, with profound implications for its levels, dynamic, and differences. In the past 70 years, conventional measures, which rely on the chronological age of 65 as the old-age threshold, have led to a doubling or even tripling of the share of older people. This is the result of improved longevity and the ageing of larger cohorts born post-World War II ('baby boomers'). The innovative measures, which define old age taking into account the evolution of remaining life expectancy, delineate a scenario characterised by much smaller increases in the share of older people, which remains below or at 10% almost everywhere. According to this measure, the proportion of old people has remained substantially stable over time, or has even decreased in France and the United Kingdom, compared to the immediate post-World War II period. The only exception is Italy, in which the share of 10% of old people is exceeded even when the POAT is applied. Italy experienced a dramatic population ageing because of remarkable improvements in survival, the ageing of large cohorts born immediately after the Second World War, and a major reduction in fertility.

Table 2: Phases of prospective old-age threshold (POAT) dynamics identified by joinpoint regression. POAT, e_{65}, and $\bar{H}_{65}$ slopes (in percentage points) by gender, 1950–2019. Reference: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years)

Country	Male				Female			
	Phase	POAT slope	e_{65} slope	$\bar{H}_{65}$ slope	Phase	POAT slope	e_{65} slope	$\bar{H}_{65}$ slope
Denmark	1950–1955	ns	0.05	0.15	1950–1966	0.11	0.08	–0.03
	1955–1964	–0.07	–0.05	0.09	1966–1971	0.34	0.27	–0.19
	1964–1995	0.04	0.03	0.03	1971–1987	0.11	0.07	–0.06
	1995–2019	0.23	0.06	–0.23	1987–1995	–0.03	–0.05	0.19
					1995–2019	0.14	0.15	–0.23
France	1950–1974	0.08	0.05	0.18	1950–1983	0.15	0.12	–0.09
	1974–2019	0.20	0.12	–0.09	1983–1991	0.25	0.22	–0.21
					1991–2019	0.14	0.13	–0.14
Italy	1950–1977	0.02	0.01	0.22	1950–1976	0.13	0.1	0.01
	1977–2019	0.19	0.15	–0.14	1976–2004	0.19	0.16	–0.16
					2004–2019	0.08	0.08	–0.14
Sweden	1950–1980	0.02	0.02	0.08	1950–1986	0.16	0.12	–0.10
	1980–2019	0.16	0.14	–0.17	1986–2019	0.10	0.09	–0.11
United Kingdom	1950–1975	0.04	0.02	0.15	1950–2003	0.12	0.09	–0.04
	1975–1998	0.18	0.12	–0.01	2003–2011	0.22	0.21	–0.27
	1998–2011	0.31	0.24	–0.33	2011–2019	ns	0.05	–0.10
	2011–2019	0.08	0.08	–0.09				
United States	1950–1954	0.14	0.10	0.27	1950–1972	0.11	0.08	–0.06
	1954–1969	–0.03	–0.01	0.02	1972–1977	0.36	0.26	–0.11
	1969–1979	0.20	0.14	0.16	1977–1992	0.08	0.05	0.00
	1979–2001	0.13	0.09	–0.07	1992–2001	–0.04	0.00	–0.10
	2001–2009	0.25	0.19	–0.33	2001–2009	0.16	0.15	–0.17
	2009–2019	0.10	0.06	–0.12	2009–2019	0.07	0.06	–0.11

The use of a dynamic POAT also has strong implications for differential ageing by gender. While the conventional measure suggests a more pronounced ageing of the female population, a dynamic POAT shows a substantial ageing equivalence in the female and male populations, or, in Denmark, an even greater ageing of men (Table 3). Finally, the analysis of the trends in 2019–2020 highlights the impact of the increased mortality caused by the COVID-19 pandemic on the measure of population ageing. Because the POAT stagnated or diminished between 2019 and 2020 (Table 1), the proportion of people older than the POAT increases, and in the countries most affected by the pandemic the increase is even greater than that captured by the proportion of people over the chronological age threshold (65 years).

Table 3: Population older than age 65 and a dynamic old-age threshold based on prospective age (POAT). Reference for POAT: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years). Values in per cent.

Country	Year	Male		Female	
		≥POAT	≥65	≥POAT	≥65
Denmark	1950	6.7	8.5	7.0	9.4
	2019	8.2	18.1	7.9	21.0
	2020	8.6	18.4	8.0	21.3
France	1950	9.0	9.4	9.3	13.2
	2019	7.0	18.0	8.3	22.4
	2020	7.7	18.4	8.6	22.7
Italy	1950	6.1	7.5	6.0	8.5
	2019	9.6	20.4	10.9	25.2
	2020	11.0	20.8	12.0	25.5
Sweden	1950	7.6	9.5	8.0	10.8
	2019	7.7	18.4	8.0	21.4
	2020	9.0	18.5	8.7	21.5
United Kingdom	1950	9.4	9.4	8.9	12.1
	2019	7.6	17.0	7.8	19.8
	2020	8.8	17.2	8.7	19.9
United States	1950	6.6	7.7	5.2	8.5
	2019	5.9	14.6	6.2	17.7
	2020	7.2	14.9	7.2	17.9

3.2 Geographical and social inequality in old-age thresholds: The case of Italy

Of all the examined countries, Italy has experienced the most pronounced ageing process, irrespective of whether a fixed or dynamic old-age threshold is used (Table 3). In the 70 years after the end of the Second World War the share of women aged 65 years and over increased by 17.0 percentage points, reaching a quarter of the total population. Among men the share increased by 13.3 percentage points, reaching one-fifth of the total population. The dynamic threshold (always referring to the remaining life expectancy of 65-year-old UK men in 1950, to allow comparison of all the analyses) has increased more slowly in Italy than in the other countries (6.5 years for men and 8.4 years for women). The values for France, the country with the highest increase, are 9.4 years for men and 9.6 years for women (Table 1). Because of the smaller increase in the old-age threshold the Italian population has a higher degree of population ageing, including when considering the dynamic threshold (people aged more than the POAT increased by 4.8 points for men and 6.0 points for women).

For this reason, it is worth assessing the dynamic of the POAT in Italy at both the national and sub-national level. Investigating inequalities between geographical areas and socioeconomic statuses might shed light on the degree of existing inequalities in mortality and longevity, and help us understand the consequences of overcoming them.

Table 4 shows the POAT in Italy by geographical area and educational attainment for the period 2012–2014 (Istat 2015b). Geographical differences are quite small and do not exceed 0.5 years among men (between the Centre and the South) and 0.8 years among women (between the North-East and the South). By contrast, in all geographical areas and for both genders the POAT is characterised by a wide educational gradient, with higher POAT for those with higher levels of education. In the two northern areas there is a clear educational gradient in POAT. On the other hand, in the Centre and the South there is a greater divide between the highest educational level and the other two levels, whose POATs are very close to each other. In all three educational levels, the South, which is the least economically developed region, lags behind the other geographical areas, with lower POAT for both men and women. At the national level, high-educated men become older 1.4 years later than low-educated men, while high-educated women become older just 0.8 years later than low-educated women. Moreover, among men the educational divide is wider in the richer north than in the poorer south (1.8 years in the North-West and 1.5 years in the North-East versus 1.2 years in the South), while among women it is slightly wider in the south than in the north (1.1 years in the former versus 0.9 years in the latter). Considering the most and least favoured groups, both geographically and socially, the distance reaches 1.8 years for men and 1.5 years for women.

Table 4: Prospective old-age threshold (POAT) by geographical area, education, and gender. Italy, 2012–2014. Reference for POAT: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years)

Geographic area	Male				Female			
	High	Medium	Low	Total	High	Medium	Low	Total
North-West	75.3	74.3	73.5	74.0	78.3	77.8	77.4	77.6
North-East	75.3	74.6	73.8	74.1	78.2	77.8	77.6	77.7
Centre	75.3	74.4	74.0	74.3	78.2	77.6	77.4	77.6
South	74.7	73.8	73.5	73.8	77.8	77.3	76.7	76.9
Italy	75.1	74.3	73.7	74.0	78.1	77.6	77.2	77.4

3.3 When do Italians become old taking health into account?

Focusing on the functional dimension of health in the years 2012–2014, we compute the disability-free prospective old-age threshold (DF-POAT). It represents the age at which disability-free life expectancy equals that observed for Italian men at age 74.0, or their POAT in those years with respect to remaining life expectancy of UK men in 1950. At this age Italian men had a DFLE of 4.9 years, the reference used for Table 5, out of a total life expectancy of 11.9 years, the reference used for Table 4. The higher values of DF-POAT compared to POAT for the most favoured geographical areas and social groups indicate that inequalities in survival and health are consistent and amplified, favouring or penalising the same geographical areas and social groups. Conversely, the reference to DFLE rather than life expectancy reverses the longevity advantage of women into a disadvantage. The worse functional health of women is reflected in a DF-POAT which on average is 4 years lower than their POAT (respectively 73.1 and 77.4 years). As a consequence, when looking at total remaining life expectancy, women are considered old 3.4 years later than men, but 1.1 years before men if life expectancy without disability is considered. Furthermore, differences across geographical areas become more pronounced, i.e., 4 years among men and more than 5 years among women, with higher DF-POAT registered in the north than in the south. Differences by educational attainment are also wider: 4.4 years among men and 4.7 years among women. Overall, comparing the extreme values of DF-POAT, the most educated men resident in the North-East (the most advantaged region) would age about 8 years later than the least educated men residing in the South. Among women, the maximum divide is slightly more than 9 years, and the most advantaged geographical area is the North-West.

Table 5: Disability-free prospective old-age threshold (DF-POAT) by geographical area, gender, and education. Italy, 2012–2014. Reference for DF-POAT: age 74 of Italian men in 2012–2014 (POAT comparative to age 65 of UK men in 1950) with a remaining disability-free life expectancy of 4.9 years

Geographic area	Male				Female			
	High	Medium	Low	Total	High	Medium	Low	Total
North-West	77.1	78.0	73.9	75.4	77.7	73.6	73.7	74.2
North-East	77.9	77.8	73.7	75.2	75.8	75.1	74.4	74.7
Centre	77.4	74.7	73.9	74.8	77.4	72.9	72.9	73.4
South	76.2	72.9	70.2	71.4	76.2	71.0	68.3	69.4
Italy	77.0	75.8	72.6	74.0	76.8	73.3	72.1	72.8

3.4 Closing the gap between social groups makes the Italian population younger

As previously described, in Italy the use of the POAT halves the share of people considered old, computed using a chronological age threshold set at 65 years (Table 3). In 2011, the reference year for the social differences and health conditions in Italy, 19.6% of men and 22.9% of women are aged 65 and above. The dynamic old-age threshold brings these proportions to around 10% for both genders. Even considering the sharp decline of the age threshold conditional on the good health of women (from 77.4 to 72.8 years, Tables 4 and 5) and the consequent revaluation of the proportion of elderly people by 4.6 percentage points (from 9.9% to 14.5%, Table 6), the dynamic old-age threshold remains more than 8 percentage points below that estimated using conventional measures. For men, taken as reference for thresholds conditional on good health, this effect cannot be assessed.

As reported in Tables 4 and 5, the social and geographical differences in survival and health strongly affect the POAT. The results displayed in Table 6 assess how overcoming these inequalities might affect the estimated ageing of the Italian population. Overcoming the existing geographical differences in the country would have a very limited impact on national ageing for both men and women. It would be more pronounced if the condition on good health thresholds (from 10.4% to 9.1% among men and from 14.5% to 12.5% among women) were considered. Much more noticeable is the effect of overcoming social inequalities, especially when considering remaining disability-free life expectancy. In that case, the proportion of old-age people drops by almost 3 percentage points for men (from 10.4% to 7.7%) and by more than 4 points for women (from 14.5% to 10.4%). This means that if adequate social and health policies made it possible to overcome both geographical and social inequalities, the reduction in ageing would be even more accentuated (around 9% for both men and women), and even stronger for men, as long as only remaining life expectancy in good health is considered (6.9%).

Table 6: Prospective old-age threshold (POAT), disability free old-age threshold (DF-POAT), and people older than the thresholds according to different hypotheses, by gender. Italy, 2011*

Hypothesis	Male				Female			
	Old-age threshold		Population share (%)		Old-age threshold		Population share (%)	
	POAT	DF-POAT	≥ POAT	≥ DF-POAT	POAT	DF-POAT	≥ POAT	≥ DF-POAT
Current values	74.0	74.0	10.4	10.4	77.4	72.8	9.9	14.5
Overcoming geographic inequalities	74.3	75.4	10.1	9.1	77.7	74.7	9.6	12.5
Overcoming social inequalities	75.1	77.0	9.3	7.7	78.1	76.8	9.3	10.4
Overcoming geographic and social inequalities	75.3	78.0	9.2	6.9	78.3	77.7	9.1	9.7

Notes: * Reference for POAT: age 65 of UK men in 1950 (remaining life expectancy = 11.9 years); for DF-POAT: disability-free life expectancy of Italian men in 2012–2014 (5.0 years). Percentage values.

4. Discussion and conclusion

As far back as 1975, Ryder questioned chronological age as a reliable indicator of the individual ageing, noting that the implicit assumption of measures of population ageing based on chronological age and static thresholds is that individuals' potential and risk (including survival and health) remain unchanged from one cohort to the next. On the contrary, the health transition completely changed those risks, especially at older ages: Growing old in a world where over 90% of the people reach the age of 65 with a time-horizon of more than 20 years (doubling that of their grandparents or great-grandparents) cannot but have strong consequences for everyone's perception of their potential and aspirations. Because the social and economic concern with respect to age depends on the consequences it has for people's health and autonomy, Ryder proposed measuring age by the years remaining until death instead of the years elapsed since birth. In particular, he proposed using the age with a remaining life expectancy of 10 years as a dynamic old-age threshold (Ryder 1975). A value that was very close to life expectancy at age 65 at the beginning of the health transition, thus proposing the first comparative prospective old-age threshold (POAT), was taken up with much greater success in later studies (Sanderson and Scherbov 2005, 2019; Scherbov and Sanderson 2020).

Using the remaining life expectancy at age 65 for UK men in 1950 as the reference – the lowest at the beginning of the period we considered – the POAT advanced everywhere, albeit with different rhythms and depending on country, gender, and period, reaching 76–78 years for women and 73–75 years for men. The trend was marked by country-specific development phases for men and women. In some phases the POAT advanced very rapidly: for instance, for men in the United Kingdom in 1998–2011, when it increased at a rhythm of 1 year in every 3. In other less frequent phases the POAT fell back equally rapidly, as happened for men in the United States between 1954 and 1969. For women, the fastest rhythm of increase, which again was approximately 1 year in every 3, was in Denmark in 1966–1971. However, the most frequent rhythms of advance are 1 year in every 4. The contrasting trends in many countries for men and women in the first decades of this century are noteworthy. The POAT advanced extremely rapidly almost everywhere (except for the United Kingdom and the United States) in the first decade, making up for the lower rates in the past. However, in the next decade there was a sharp slowdown, or even a complete halt in some countries.

Although the POAT is based on remaining life expectancy and its modifications at different ages, there is also a strong association with life table entropy ($\overline{H}_{65}$), a reduction in which is usually associated with a more rapid advance of the threshold. For men in many countries there was a long period in which the POAT remained around 66–67 years (and remaining life expectancy at age 65 around 13–14 years), along with a growing trend of life table entropy that reached a maximum of 38%–40%. Later, the POAT began to advance decisively, along with a rapid growth in remaining life expectancy and an equally rapid reduction in entropy (Figures A2 and A3 in the Appendix). To the best of our knowledge, this paper represents a first attempt at exploring jointly the POAT and measures of lifespan inequality. Further investigation of this relationship is needed and might open up interesting research scenarios. Immediately after World War II, women showed higher entropy values than men in every country, and the diminishing trend generally started from values of the POAT of around 70 years (and a remaining life expectancy of 15–16 years), but the reduction was stronger than for men. Indeed, at present life table entropy values are lower for women than men, and in recent decades the gender gap for e_{65} and the POAT has been diminishing.

One of the conceptual advantages of prospective age – and of the thresholds based on it – is that, unlike the chronological measure, it is related to the survival level of the population in which individuals live. It thus underlines that individual survival does not depend exclusively on personal characteristics, but also on the context in which people live. Clearly, this is also the fundamental limitation of prospective age: estimates at the individual level are relative to the population to which the individual belongs, and at the individual level the prospective age is only defined after a person's death. Therefore, it cannot replace the chronological age of a single individual. Nevertheless, measurements based on prospective age highlight some issues that are not visible when using measures based on chronological age. Following the same principle, other proposals have been advanced in recent years: equivalent age (Burger, Baudisch, and Vaupel 2012), percentile age (Zuo et al. 2018), and s-age (Alvarez and Vaupel 2023), to mention a few. However, POAT's objective of setting equivalence in survival over time, across countries, and by gender is more consistent. Equivalent age, despite its high correlation with POAT (see Figure A-4 in the Appendix), considers equivalence at specific ages. Besides being more sensitive to random fluctuations, it lacks the prospective mortality risks captured by remaining life expectancy. People make decisions about their future based on how long they expect to live. In this context, POAT, which relies on remaining life expectancy, incorporates this perspective and offers individuals a means to project themselves into the future. Conversely, s-age, based on equivalence in the number of survivors at different ages, focuses on variation occurring at earlier ages, which is beyond the scope of this article.

Using a dynamic old-age threshold modifies remarkably the evaluation of population ageing. For example, the proportion of people older than the POAT has not changed since immediately after World War II, or has even decreased, e.g., in France. This contradicts the alarming population ageing reported by the indicators based on a fixed chronological age. The only country in which the proportion of old people remains very high, even considering the dynamic threshold, is Italy, where, despite the rapid advance of the POAT, the proportion of elderly people doubled over the 70-year period. The reasons for this are related to the country's history: the improved survival of older people, accompanied by the ageing of the particularly numerous cohorts from the immediate post-war period; the strong reduction in fertility that continues today; a long-standing negative net migration, which only reversed in the last decades. Such circumstances make Italy a useful case study to assess the responsiveness of population ageing to certain policies. While social and regional inequalities in survival and, even more, in survival in good health are narrower in Italy than in other countries, they produce a marked modification of old-age thresholds and leave space for social and health policy interventions aimed at guaranteeing better survival for all (Caselli, Egidi, and Strozza 2021; Moretti and Strozza 2022). These interventions, as well as being obviously desirable in terms of equity and social justice, would also indirectly produce a noticeable rejuvenation of the population. Our results suggest that overcoming geographical and social inequalities would noticeably reduce the proportion of older individuals in the population as identified by the dynamic old-age threshold. Looking at other health dimensions (e.g., presence of chronic diseases or self-rated health) would lead to different results. However, all health measures consistently indicate a positive trend in the elderly population and highlight inequalities that penalise the same geographical areas and social groups (Demuru and Egidi 2016; Egidi and Demuru 2018).

After millennia in which the positive and negative components of demographic dynamics have modelled a relatively young population age structure, the dramatic reduction in mortality, along with an equally dramatic reduction in fertility, has profoundly changed the age structure of the most developed countries in the world. With the increasing number of older people, the consequences of ageing populations represent the key challenge for all social, health, and economic policies (Christensen et al. 2009).

Speculating on the consequences of increased longevity for the timing of the individual life course, Lee and Goldstein (2003) emphasise how at an individual and collective level these consequences largely depend on how the additional years of life are distributed across the various social and economic life-course stages. To conceptualise the impact of the health transition on the life course they propose the proportional rescaling theory, assuming that every life stage expands in proportion to increasing life expectancy. Although several barriers, both physical and social, militate against a simple reproportioning – some of which are included in certain variants of the theory – their reflections prompt broader considerations that affect not only the onset of old age but also the organisation of the entire life course, which is also influenced by improved survival conditions. On the one hand, the response to the reduced risk of death in the early years of life and in childhood has allowed an increasing investment in education and the emergence of children and adolescents as new social subjects. On the other hand, the onset of adulthood and entry into the world of work have been delayed, while improved health conditions have made it possible to maintain an active life well beyond the ages that were previously considered 'old', so that the old-age threshold is expected to advance even further in response to the improved survival conditions of the elderly. Life has become both longer and less uncertain, allowing individuals to better plan how to live it, even at ages once regarded as very advanced. As suggested by Lee and Goldstein in 2003, the life cycle has opened like a fan, extending all its phases as a function of the increasing length of life and its greater reliability. Of course, the reorganisation of the life cycle is not only a matter of survival: social, economic, and cultural conventions modulate when young people's education starts and finishes, when people reach working age and marry, and, finally, when they grow old and their active life comes to an end.

Based on the evolution of the life course allowed by the new mortality regime and with the aim of making the pension system sustainable, an increasing number of European countries are moving towards a dynamic retirement age that takes into account life expectancy and its dynamics. However, although the evaluation suggested by average conditions is positive, a very different image emerges when we consider diversity between individuals. Referring to Italy as a case study, we show that by conditioning the old-age threshold on good functional health, a highly educated person living in the north ages almost 8 years later (more than 9 years if a woman) than a low-educated person living in the south.

This is probably one of the main reasons that generates dissent for any policy aimed at establishing a realignment to the new survival regime, particularly when it concerns advancing the retirement age. Pension reforms based on estimates obtained based on the general population tend not to consider, or to consider only partially, the already existing inequalities of survival between individuals of the same population (Alvarez, Kallestrup-Lamb, and Kjærgaard 2021; Sanchez-Romero, Lee, and Prskawetz 2020; Strozza et al. 2022). This should not be used as an argument against realignment, but rather as an invitation to consider social inequalities in survival when introducing reforms in the pension system and to intervene to reduce them (Caselli and Lipsi 2018). Acting on these inequalities may open up new possibilities for improvement in both survival and – even more – in advancing the threshold of ageing in good health. Unfortunately, it is exactly the development of social inequalities that generates the greatest concern for the future (Mackenbach, Karanikolos, and McKee 2013). In all countries – even the wealthiest – serious conditions of deprivation are impacting the lives of a growing number of people, creating the premises for entire generations of young people growing up in worse conditions than those that would ensure healthy survival at older ages. This is the essential condition for the population ageing of tomorrow to be sustainable, both economically and socially. A first step to meet this challenge is to better measure the magnitude of population ageing without aggravating concerns with unnecessary (and unjustified) exaggeration, with the risk of producing negative consequences in terms of prejudice and intolerance. Old-age thresholds based on prospective age can be useful tools for measuring population ageing in a way that is more consistent with actual conditions and the needs of today’s older people. They represent a change of metrics which has deep implications for the levels, dynamics, and differences of population ageing. Moreover, they have the advantage of being less rigid than the conventional thresholds, and by reflecting the dynamics of survival and health they emphasise that ageing is relative and dynamic and not an absolute and static concept, and that the way of becoming and being an older person varies over time and space and between individuals.

5. Limitations

The study has limitations that need to be acknowledged. The calculations of the POAT and DF-POAT are based on period life tables. The basic assumption behind them is that individuals are exposed to period death rates throughout their lives, based on current mortality. In reality, unless there is an important trend reversal in mortality, those death rates, and consequently our estimates of the POAT, represent a lower boundary of what they will be for future cohorts. The DF-POAT estimated for the Italian population is based on disability rates that do not include institutionalised individuals. However, they only represented 2% of the Italian population older than 65 (Istat 2015a). Moreover, disability-free life expectancy is computed via the Sullivan method (Sullivan 1971). This methodology incorporates the limitation of the stationarity of death rates (of period life tables) as well as that of the disability rates used in the calculations. Incidence-based methods (e.g., multistate methods) perform better than prevalence-based methods (e.g., Sullivan method) as they can capture transitions between health states and pathways to death. However, the former are more data-demanding, as they require longitudinal data that nowadays, in Italy, are not easily accessible to scholars external to the Italian national statistical system due to privacy regulations safeguarding sensitive topics. There are longitudinal studies which are based on linked data from the National Health Survey and mortality in subsequent years (e.g., Ardito 2021; Caranci et al. 2018; Marinacci et al. 2013; Serrano-Alarcón et al. 2023). However, they focus on topics that are far from the objective of this study. As an alternative, Moretti et al. (2023) estimate disability-free life expectancy for Italy using the longitudinal dataset of the European Survey on Income and Living Conditions (EU-SILC). However, as EU-SILC collects information on families' economic conditions, the representability of the elderly population and their health conditions is questionable. Despite not being able to evaluate the impact that adopting an incidence-based method would have on results, several studies have argued that the most widely prevalence-based method used in the literature (Sullivan method) provides similar estimates when changes in population health over time are regular (Mathers and Robine 1997; Murakami et al. 2018; Bergeron-Boucher et al. 2022).

Another limitation is represented by the variable used to highlight social differences in survival and health. Among the numerous indicators of socioeconomic status (e.g., education, income, wealth, occupation, deprivation, etc.), the education level is the only one available for Italy. However, due to the strong correlation between various socioeconomic variables (Darin-Mattsson, Fors, and Kåreholt 2017; Duncan et al. 2002; Galobardes, Lynch, and Smith 2007), it is generally agreed that this indicator provides a satisfactory representation of existing socioeconomic differences in the population that are relevant to health conditions. This is particularly true for functional health, as considered in this study (Herd, Goesling, and House 2007).

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Appendix

Figure A-1: Association between prospective old-age threshold (POAT) and life table entropy ($\bar{H}_{65}$) in percentage points for selected countries, by gender, 1950–2020

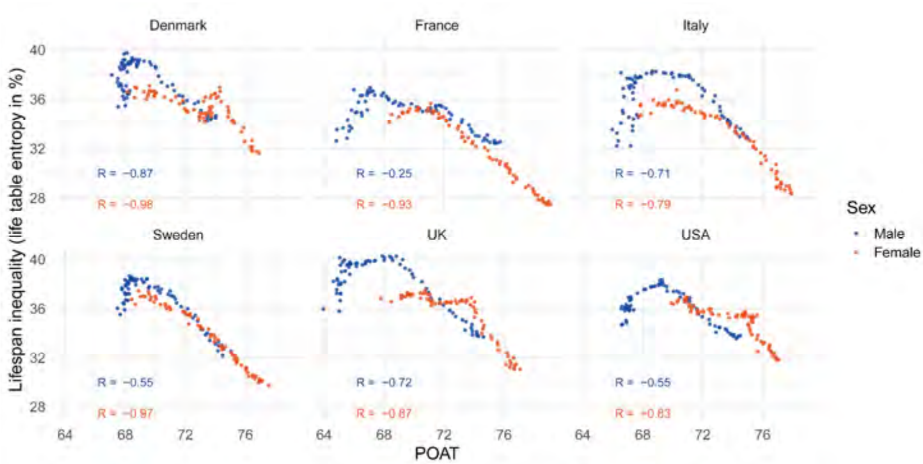
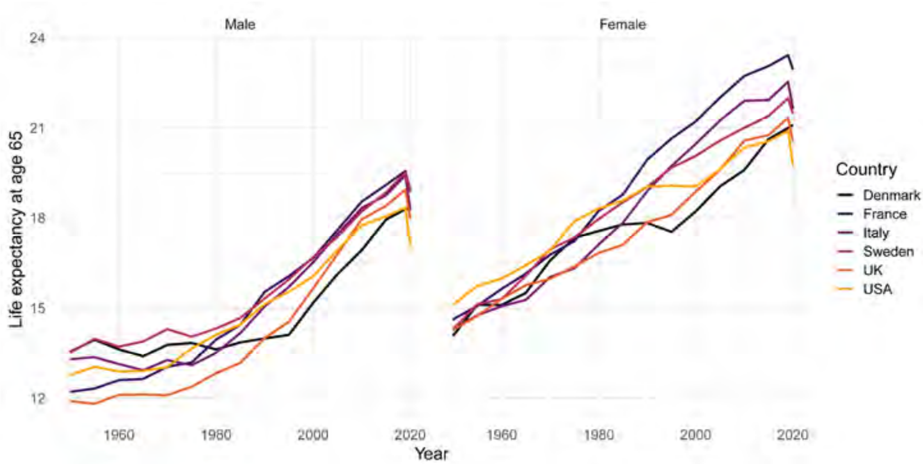
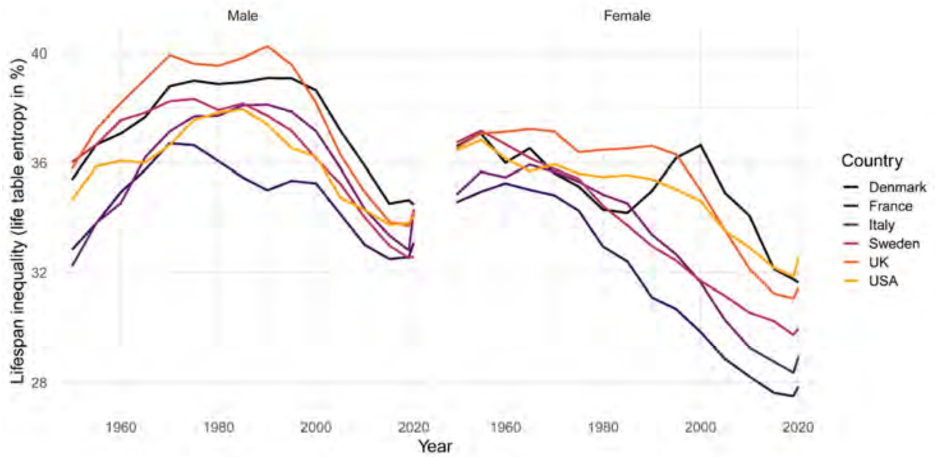


Figure A-2: Remaining life expectancy at age 65 (e_{65}) for selected countries, by gender, 1950–2020



Note. To provide smoothed patterns, we present results every 5 years from 1950 to 2020. We added the values for 2019 to emphasise the impact of the COVID-19 pandemic on e_{65}.

Figure A-3: Life table entropy ($\overline{H}_{65}$) in percentage points for selected countries, by gender, 1950–2020



Note. To provide smoothed patterns, we present results every 5 years from 1950 to 2020. We added the values for 2019 to emphasise the impact of the COVID-19 pandemic on $\overline{H}_{65}$.

Figure A-4: Association between prospective old-age threshold (POAT) and equivalent age for selected countries, by gender, 1950–2020