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

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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. The paper also examines trends in POAT and disability-free POAT (DF-POAT) by gender, geographical area, and education in Italy, to outline possible strategies to counter population ageing.

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 have been retrieved from Istat on mortality and health by geographical area and education.

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.

CONCLUSIONS

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

CONTRIBUTION

The paper enhances the use of a dynamic old-age threshold, as embraced by Vaupel in some of his works, and highlights the impact of survival and health inequalities on ageing more neatly than studies based on chronological age.

Introduction

Over recent decades, adult and old-age mortality 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 characterized by a higher proportion of older people. In both 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 the 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 seventy years ago. Moreover, increases in life expectancy and lifespan extensions result not only from medical and health advances, but also economic and social developments that have improved living conditions, both individually and collectively. These factors have contributed to contrast 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 threshold 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 indeed two aspects of the same phenomenon and, moreover, they 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 the 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; Salinari and De Santis 2014; Van Raalte and Caswell 2013; Vaupel 2010; Vaupel, Villavicencio, and Bergeron-Boucher 2021; Zheng 2014).

In addition to not accounting for survival improvements, the conventional old-age thresholds hide major inequalities: between men and women, highly- 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 channelling public spending appropriately. 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 the changing life course conditions and the 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 of them 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 largely 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 emphasizing 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 the conventional ones, 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 who might have benefited in a different manner 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 will address the following research questions:

1. How have various reduction pathways of old-age mortality changed the remaining life expectancy, the 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 an 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 mortality reduction of men and women, and to highlight inequalities in exposure to the risk of death.

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

Data and Methods

This study draws on several sources of data and methods to answer the abovementioned research questions.

To answer the first research question, we use sex-specific period life tables and populations for six European countries obtained from the Human Mortality Database (HMD) from 1950 to 2020 (Barbieri et al. 2015; HMD 2023). Those countries are Denmark, France, Italy, Sweden, the United Kingdom, and the United States. Italy life table and population in 2020 is obtained from the Italian National Institute of Statistics (Istat) database (Istat 2023). We selected six countries that are characterized by different mortality trends over the last 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 from 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 trends in POAT for the six countries and across the 70 years, we use remaining life expectancy at age 65 for men in the UK in 1950 as a reference for all the calculations. The relationship between life expectancy and lifespan inequality has been recently investigated by several scholars (Aburto et al. 2019, 2020; Vaupel, Zhang, and van Raalte 2011). We then graphically assess the relationship between $\overline{H}_{65}$ and POAT (see Figures S3 in the Supplementary Materials). Furthermore, we use the 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 (Demuru and Egidi 2016). In our analyses, we investigate trends for the three indicators from 1950 to 2019 by country and sex. The year 2020 has been 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 three-year mortality follow-up (2012-2014) and represent the most recent available data with such level of detail in Italy. Reflecting the data availability, territory is divided into only four geographical areas: North-east, North-west, Center, and South – including Sicily and Sardinia islands. This is an adaptation of the five-category NUTS-1 grouping, in which South and Islands are distinguished. 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”. 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 the comparability of the analysis 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 coherence of the whole analysis.

To answer the third research question, we compute the share of older individuals in the Italian population in 2011 in different scenarios: (a) current mortality, (b) overcoming geographical inequalities, (c) overcoming social inequalities, and (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, we consider the highest POAT and DF-POAT for Italy overall (a), by geographical area (b), by education (c), and by geographical area and education.

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 (will be made available after peer review).

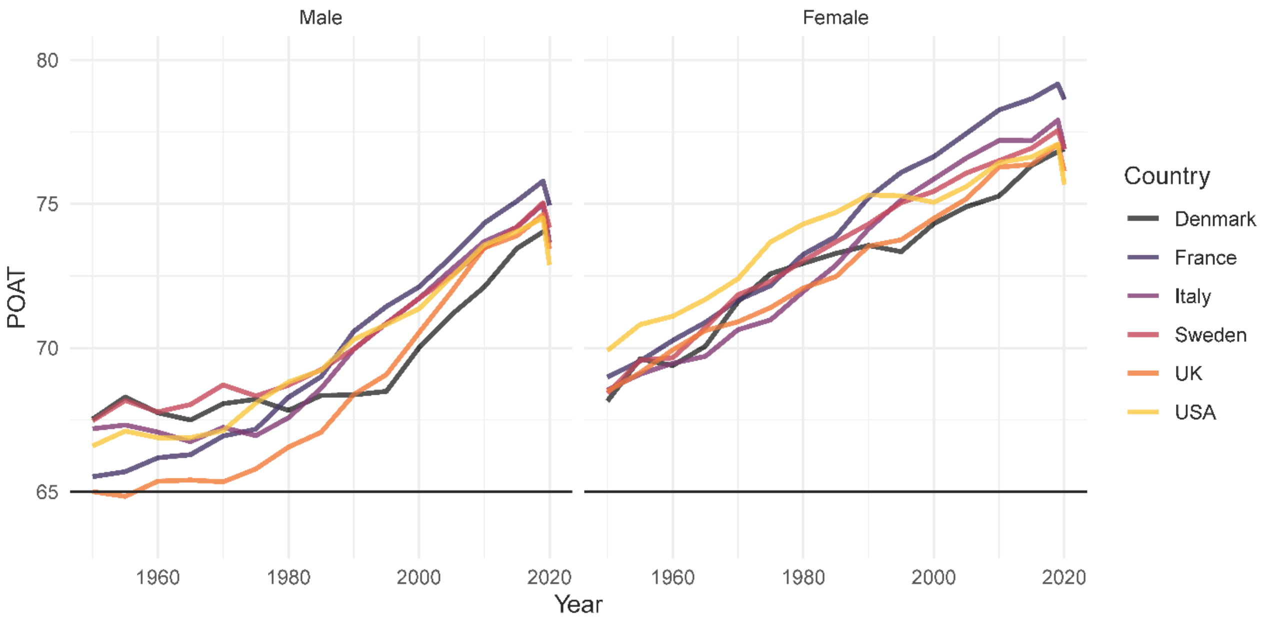
Results

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

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

Denmark and Sweden were in the top positions of the country ranking by male POAT after World War II, far above the United Kingdom and France. Seventy years later, the ranking changed. Sweden keeps its high position but is surpassed by France, the country with the highest POAT increase (9.4 years), followed by the United Kingdom (8.5 years increase). France reaches the top position for its female POAT, which increases by 9.6 years in the period. Italy is positioned second, immediately above all the remaining countries in the analysis. By contrast, the United States and United Kingdom, which held leading positions in the early 1950s, have receded conspicuously and are placed at the bottom of the rankings at the end of the study period, together with Denmark, which has followed a similar path to that of the United States between the mid-1980s and the mid-1990s (Figure 1 and Table 1).

Figure 1. Prospective old-age threshold (POAT) for selected countries, by gender. Years 1950-2020. Reference: age 65 of UK men in 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 emphasize the impact of the COVID-19 pandemic on the POAT.

The evolution of POAT is because of the joint action of the remaining life expectancy at age 65 and the age-at-death variability after age 65. The relationship between life expectancy and lifespan inequality has been recently investigated by several scholars (Aburto et al. 2019, 2020; Vaupel, Zhang, and van Raalte 2011). Results concerning the relationships between POAT and life table entropy at age 65 for the countries under investigation are displayed in the Supplementary Materials (Figures S3).

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. Besides the year 2020, we also show values for the year 2019, to allow us assess the consequences of the COVID-19 pandemic, which has caused an abrupt change in the three indicators in many countries. We notice that, in the seventy years considered, while the increase in e_{65}, albeit differentiated, affected all countries and both sexes, $\overline{H}_{65}$ has followed less homogeneous and regular paths. For women, it has decreased constantly, often remarkably, and in the most recent years has become 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, and the United Kingdom), and increased in other countries (France and Italy), while it has remained substantially stable for long periods in the United States. In 2020, in all countries except Denmark, both remaining life expectancy and the POAT, have 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, jumping back to values comparable to those of the immediate post-war period, or even higher, in relation to men in Italy and France.

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

Country	Year	Male			Female		
		POAT	e_{65}	$\overline{H}_{65}\%$	POAT	e_{65}	$\overline{H}_{65}\%$
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 $\overline{H}_{65}$ 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 in average age at death and its variability combined: periods of stagnant or receding POAT are characterized 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 1987-95, and that of US women in 1992-2001, for which remaining life expectancy stagnated or slightly declined, while the relative variability of age at death increased. By contrast, a 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, approximately four months a year, for men in the United Kingdom from the end of the 1990s to the first decade of this century. Nevertheless, an increase in the POAT may also occur under an increasing trend in life table entropy. It was the case for US men in the 1970s, when, after the setback experienced in 1954-69, the POAT continued to advance, by more than two months a year, despite growing life table entropy. Table 2 highlights two groups of countries. On the one hand, there are those that followed a regular (positive) evolution throughout the period, with few breaking points in the time series, such as Sweden and France, that went up to the top of the rankings of POAT for both sexes. On the other hand, there are those countries that experienced more bumpy paths, with many significant evolutionary phases, like Denmark, the United States and United Kingdom, which have lost their initial top positions in the ranking (Tables 1 and 2, Figure 1). Finally, looking at differences by gender, a slowing down of the rate of increase in POAT of women is observed in Italy, the United States and the United Kingdom in the second decade of this century. In this period, only France and Denmark hold their high rate of increase in POAT, while the POAT of Swedish women continues to increase steadily at a slightly slower pace than that of men. Men faced difficulties in the first half of the 1970s almost everywhere; subsequently, they started to experience an improvement, leading to a rapid progress in their POAT in the most recent decades (Table 2).

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

	Male				Female			
Country	Phase	POAT slope	e_{65} slope	$\overline{H}_{65}$ slope	Phase	POAT slope	e_{65} slope	$\overline{H}_{65}$ slope
Denmark	1950-55	ns	0.05	0.15	1950-66	0.11	0.08	-0.03
	1955-64	-0.07	-0.05	0.09	1966-71	0.34	0.27	-0.19
	1964-95	0.04	0.03	0.03	1971-87	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	1950-74	0.08	0.05	0.18	1950-83	0.15	0.12	-0.09
	1974-2019	0.20	0.12	-0.09	1983-91	0.25	0.22	-0.21
					1991-2019	0.14	0.13	-0.14
Italy	1950-77	0.02	0.01	0.22	1950-76	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	1950-80	0.02	0.02	0.08	1950-86	0.16	0.12	-0.10
	1980-2019	0.16	0.14	-0.17	1986-2019	0.10	0.09	-0.11
United Kingdom	1950-75	0.04	0.02	0.15	1950-2003	0.12	0.09	-0.04
	1975-98	0.18	0.12	-0.01	2003-11	0.22	0.21	-0.27
	1998-2011	0.31	0.24	-0.33	2011-19	ns	0.05	-0.10
	2011-19	0.08	0.08	-0.09				
United States	1950-54	0.14	0.10	0.27	1950-72	0.11	0.08	-0.06
	1954-69	-0.03	-0.01	0.02	1972-77	0.36	0.26	-0.11
	1969-79	0.20	0.14	0.16	1977-92	0.08	0.05	0.00
	1979-2001	0.13	0.09	-0.07	1992-2001	-0.04	0.00	-0.10
	2001-09	0.25	0.19	-0.33	2001-09	0.16	0.15	-0.17
	2009-19	0.10	0.06	-0.12	2009-19	0.07	0.06	-0.11

The introduction of an old-age threshold based on prospective age (POAT) represents a paradigmatic shift in the study of population ageing, which had profound implications for its levels, dynamic and differences. Conventional measures, which rely on the chronological age of 65 as old-age threshold, lead to a doubling or even tripling of the share of older people in the past seventy years. This is the result of improved longevity and the ageing of larger cohorts born during the post-World War II period (also known as baby boomers). The innovative measures, which take into account the evolution of remaining life expectancy to define old age, delineate a scenario characterized by much smaller increases in the share of older people, which always 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 for 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 its remarkable improvements in survival, the ageing of large cohorts born immediately after the Second World War, and a major reduction in fertility.

The use of a dynamic POAT also has strong implications for differential ageing by gender. From the more pronounced ageing of the female population, as suggested by the conventional measure, we switch to a substantial equivalence in the share of older people in the female and male populations, or an even greater ageing of men in Denmark (Table 3). Finally, the analysis of the trends in the years 2019-2020 allows us to highlight the impact of the increase in mortality caused by the COVID-19 pandemic on the measure of population ageing. Because of the stagnation or reduction of the POAT that occurred between 2019 and 2020 (Table 1), the proportion of people older than the POAT increases and, in 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 in 1950 (remaining life expectancy = 11.9 years). Values in percent.

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

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

Italy has experienced the most pronounced ageing process among the selected countries, irrespective of the old-age threshold used, either fixed or dynamic (Table 3). In the seventy years from the Second World War to the present, the share of women aged 65 years and above has increased by 17.0 percentage points, reaching one fourth of the total population. Among men, the share has 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 years old UK men in 1950, to allow comparisons of the results of all the analyses) has increased in Italy at a slower pace, as compared to the other countries (6.5 years for men and 8.4 years for women). For example, 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 old-age threshold increase, the Italian population is marked by a higher degree of population ageing, also when considering the dynamic threshold (the people who are aged more than the POAT raised by 4.8 points for men and 6.0 points for women).

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

In Table 4, we show the POAT by geographical area and educational attainment in Italy for the period 2012-2014 (Istat 2015b). Geographical differences are quite small and do not exceed 0.5 years among men (between Center and South) and 0.8 years among women (between North-east and 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 South, there is a greater divide between the highest educational level and the other two levels, whose POAT are very close each other. In all three educational levels, the South, which is the least economically developed area in the country, 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, the educational divide is wider in the richer North than in the poorer South among men (1.8 years in the North-West and 1.5 years in the North-East versus 1.2 years in the South), while it is slightly wider in the South than in the North among women (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, years 2012-2014. Reference for POAT: age 65 of UK men in 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
Center	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

When do Italians become old, when health is taken into account?

Focusing on the functional dimension of health in the years 2012-2014, we compute disability-free prospective old-age threshold (DF-POAT). It represents the age at which disability-free life expectancy equals that observed for Italian men in at age 74.2, that is their POAT in those years with respect to remaining life expectancy of UK men in 1950. At this age, the disability-free life expectancy of Italian men was 4.9 years out of 11.9 of total life expectancy.

Conditioning old-age thresholds to good health amplifies geographical and educational differences, and reverses the longevity advantage of women. The worse functional health of women is reflected in a DF-POAT which is 4 years lower on average, compared to their POAT (respectively 73.1 and 77.4 years). As a consequence, women are considered older 3.4 years later than men, by looking at the total remaining life expectancy, 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 compared to the South. Differences by educational attainment are also wider: 4.4 years among men and 4.7 year 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, years 2012-2014. Reference for DF-POAT: age 74 of Italian men in 2012-14 (POAT comparative to age 65 of UK men in 1950)

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
Center	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

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 to be older, as computed by using a chronological age threshold set at 65 years (Table 3). In 2011, reference year for the social differences and health conditions in Italy, the proportion of people aged 65 and above is 19.6% among men and 22.9% among women. 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), it 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. 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 this 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% both for men and women), and even stronger for men, as long as only remaining life expectancy in good health is considered (6.9%).

Table 6: Italian people older than the prospective old-age threshold (POAT) and disability free old-age threshold (DF-POAT) according to different hypotheses, by gender in 2011. Reference for POAT: age 65 of UK men in in 1950 (remaining life expectancy = 11.9 years); for DF-POAT: disability-free life expectancy of Italian men in 2012-14 (5.0 years). Percentage values.

Hypothesis	Males		Females	
	≥POAT	≥65	≥POAT	65
Current values	10.4	10.4	9.9	14.5
Overcoming geographic inequalities	10.1	9.1	9.6	12.5
Overcoming social inequalities	9.3	7.7	9.3	10.4
Overcoming geographic and social inequalities	9.2	6.9	9.1	9.7

Discussion and Conclusion

Overall, in the period 1950-2020, the prospective old-age threshold advanced everywhere, albeit with different rhythms, depending on country, gender and period. Using the remaining life expectancy at age 65 for UK men in 1950 as reference – the lowest at the time, the POAT for women reached 76-78 years, as opposed to 73-75 years for men. The trend was marked by country-specific phases of development between men and women. In some phases, the POAT advanced very rapidly, as happened for men in the United Kingdom in the period 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 greatest rhythm of increase, which again was approximately 1 year in every 3, was found in Denmark in the period 1966-71. However, the most frequent rhythms of advance are of 1 year in every 4. Noteworthy were the contrasting trends for men and women in the first decades of this century in many countries. 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. In the next decade, though, there was a sharp slowdown (or even a complete stop in some countries) among those who had remarkable progress in the previous decade.

Although the POAT is based on remaining life expectancy and its modifications at different ages, we can also see a strong association with the life table entropy ($\overline{H}_{65}$), the reduction in which is 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 S1 and S2 in the Supplementary Materials). To our knowledge, this 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 around 70 years (and a remaining life expectancy of 15-16 years), but the reduction was stronger than for men. Indeed, women's values of life table entropy are at present lower than those of men, and the gender gap for e_{65} and the POAT has been diminishing in recent decades.

One of the conceptual advantages of the prospective age – and of the thresholds based on it – is that, unlike the chronological measure, it is related to the level of survival 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 individual level are relative to the population to which individuals belong. Therefore, it cannot replace the chronological age of a single individual. Like other proposals that have been advanced in recent years (the percentile age of Zuo et al. 2018; or the s-age of Alvarez and Vaupel 2023, to mention two examples), the measurements based on prospective age nevertheless highlight some issues that are not visible by using measures based on chronological age.

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 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 last 70 years. The reasons for this relate to the country's history: the improvement in survival of the older people was accompanied by the ageing of the particularly numerous cohorts from the immediate post-war period, the strong reduction in fertility that continues today, and a long-standing negative net migration which reversed only in the last decades. Such circumstances make Italy a useful case study to assess the responsiveness of the ageing process to certain policy actions. 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 evidently desirable in terms of equity and social justice, would also indirectly produce a noticeable rejuvenation of the population. Our results suggest that overcoming both geographical and social inequalities would indeed noticeably reduce the proportion of older individuals in the population, identified by the dynamic old-age threshold.

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). However, the elderly people of today are very different from those of the past, and probably those of the future. 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 2003, the life cycle has opened like a fan, extending all its phases in function of the increasing length of life and its greater reliability. Of course, the reorganization 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 older and their active life comes to an end.

If the evaluation suggested by the average conditions is positive, a very different image emerges when we consider the diversity between individuals. This is probably the reason that generates dissent for any policy aimed at establishing a realignment to the new survival regime, particularly when it concerns advancing the retirement age. Actually, pensions reforms based on estimates obtained on the general population tend not to consider, or consider only partially, the already existing inequalities of survival between individuals of the same population (Strozza et al. 2022). This should not be used as an argument against the realignment, but rather as an invitation to consider the existing inequalities in survival and intervene to reduce them. Acting on these inequalities may open up new possibilities for improvement, both in 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 concerns for the future (Mackenbach, Karanikolos, and McKee 2013). In all countries – even the wealthiest – serious conditions of deprivation impact 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.

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 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 institutionalized individuals. However, they only represented 2% of the Italian population older than 65 in Italy (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.

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