Healthy Ageing Trends in England Between 2002 to 2018 : Improving but Slowing and Unequal*

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Abstract

Growing life expectancy and a rising proportion of older people make the issue of whether cohorts are ageing better a key individual, social and economic issue. Using data from the English Longitudinal Study of Ageing we characterise how frailty develops with age, how this differs across demographic groups, whether more recent cohorts are ageing better and what the key areas of focus for health policy should be. We find cohort effects such that frailty at each age has been decreasing over time but that this trend shows modest signs of slowing and is less pronounced for those with lower wealth. Improvements across cohorts reflect improvements in ADLs, cognitive function, and mobility but limited progress in reducing the incidence of diseases such as cancer, cardiovascular disease, etc. We find mobility and ADLs the main driver of average differences across regions but cross-regional differences are driven more by within than between group inequality.

Keywords: ADLs, Ageing, Frailty, Healthy Ageing, Health Inequalities
JEL Classification: I10; I12; I18; J14

1 Introduction

Like most countries the UK has experienced a long-term trend of rising life expectancy and a growing proportion of older people. Life expectancy at birth has risen from 78.2 years in 2002 to 81.1 in 2018 (ONS 2019b). The number of people aged 50 years and over has risen from 17 million (31% of the population) in 1970 to 25 million (37%) in 2018 and is expected to reach 31 million (42%) by 2043 (ONS 2019a).

These trends make achieving healthy longevity a key individual, social, and policy priority (Scott 2023). Aside from the potential benefits to individuals (Scott, Ellison, and Sinclair 2021), if longer lives are also healthier then employment at older ages can rise, thus boosting GDP (Banks, Muriel, and Smith 2011; Berkman and Truesdale 2023). Similarly, improvements in health at older ages can reduce the costs associated with age-related diseases and care (Kingston et al. 2018). Given the UK Office for Budget Responsibility predicts an increase in

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age-related spending by nearly 4% of GDP in the years ahead (Office for Budget Responsibility 2018), the potential savings are substantial. Combined, these effects point to the multi-billion-dollar benefits of achieving healthy longevity.

Unfortunately, there are growing concerns that UK health outcomes are deteriorating (Marshall et al. 2015), that healthy life expectancy is not keeping pace with increases in the State Pension age (Lynch et al. 2022) and that withdrawals of older workers from the labour market are being driven by long term illness (Haskel and Martin 2022). These concerns are particularly acute around widening health inequality (Marmot 2020), as life expectancy improvements stall and even reverse for some groups (Rashid et al. 2021), while the number of years spent in poor health increases (Welsh, Matthews, and Jagger 2021). These inequalities are increasingly a policy concern, and the UK government has committed to reduce regional health inequalities as part of the "Levelling Up" program (UK Government 2022).

To examine whether cohorts are ageing better, this paper utilises nine waves of the English Longitudinal Study of Ageing (ELSA) dataset, covering the period 2002 to 2018, to answer the following questions: i) how does health vary with age for those aged over 50 years and how does this compare with other countries? ii) what are the trends over time in how people are ageing and has there been any improvement? iii) what are the differences in these trends due to sex, regions, income, and education? iv) which aspects of health have driven any improvements or deteriorations? v) which areas of health improvements should be the focus of policy? vi) what factors lie behind regional inequalities?

As an empirical proxy for healthy ageing we follow the Frailty Index approach advocated by Mitnitski, Mogilner, and Rockwood (2001) and Searle et al. (2008) which has proved popular in the economics literature. This offers a convenient way of summarising overall health and functionality across a broad range of indicators. We compare not just how ageing is varying across cohorts in England but also draw comparisons with the results of Abeliansky and Strulik (2018) and Abeliansky and Strulik (2019) for Europe and Abeliansky, Erel, and Strulik (2020) for the United States. Compared to previous studies on English data (Marshall et al. 2015; Niederstrasser, Rogers, and Bandelow 2019), we make use of longer time spans and control for unobserved but systematic individual level selection effects rather than relying only on fixed effects or control variables. This leads to important differences in results. We also decompose the trends in the aggregate frailty index by studying the contribution made by different sub-components to understand the main drivers of changes in frailty at each age and illuminate the areas which require greater policy focus.

2 Data

We use data from waves 1 through 9 of the English Longitudinal Study of Ageing (ELSA) covering the period 2002 to 2018. Both the original sample and all replacement samples are part of the analysis. Survey responses on disease conditions, ADLs/IADLs, depression, and cognitive function are used to construct a measure of individual frailty (Mitnitski, Mogilner, and Rockwood 2001; Searle et al. 2008). This frailty index measures the proportion of health conditions or limitations an individual is experiencing at a specific age. In constructing our index we use the same items as Rogers et al. (2017), subject to data availability constraints.

Our frailty index contains potentially 50 items covering mobility difficulties, functional disabilities (ADLs/IADLs), general health, depressive symptoms, the prevalence of health conditions, and cognitive function. For a comprehensive description of the construction of our frailty index, see Appendix A.1.

Following the literature (Searle et al. 2008; Abeliansky, Erel, and Strulik 2020) we impose several restrictions on our sample. We include only individuals i) aged between 50 and 90 years (the number of observations and so the precision of statistical estimation decreases at higher ages) ii) born in the UK (to ensure results are not driven by immigration and the influence of childhood years) iii) for whom we have available data on at least 30 out of the 50 items so as to ensure reliability of the frailty index. Thus, from a total of 90,068 observations on 19,801 individuals, we use 78,858 observations on 17,269 individuals. The process of the sample selection is summarised in a flow chart in Appendix Figure A.1.

We are not only interested in the relationship between frailty and age and how this may have changed over time, but also the role of socio-economic determinants, which we include as covariates in the analysis. To identify regional trends, we obtained confidential ELSA data on individuals' region of residence, which we aggregate up to nine NUTS-1 level regions. For education, we use the internationally standardized classification of completed education up to less than secondary level (38% in our sample), upper secondary level and vocational training (47%) and tertiary education (15%). For wealth, we follow Marshall et al. (2015) and use the natural logarithm of the sum of financial and housing wealth for a given household.

Before proceeding to estimation results it is helpful to look at the raw data. Table 1 shows the mean value of our frailty index for different age bands from Waves 1 (2002), 5 (2010) and 9 (2018). Our study is focused on two issues: the relationship between frailty and age and whether this has changed over time. On the former, as expected, Table 1 shows frailty increases with age within every wave. On the latter, the mean values broadly point to reductions in frailty for each age band across cohorts.

Table 1: Mean frailty index values by age group, waves 1-9

↓ Wave Age→	50-54	55-59	60-64	65-69	70-74	75-79	80+
1	0.091	0.106	0.118	0.126	0.149	0.171	0.223
5	0.094	0.097	0.108	0.122	0.142	0.170	0.241
9	0.083	0.096	0.115	0.110	0.131	0.160	0.216

Notes: The table shows the mean of the frailty index (measured as the proportion of health deficits reported by an individual, and ranging from 0 to 1) by age groups and ELSA waves.

Table 2 shows further evidence on changing health dynamics for three different waves of ELSA by detailing the cumulative distribution of frailty levels for different age bands. It shows two somewhat discordant trends: on the one hand, across a variety of age bands, the number of people experiencing lower levels of frailty has increased, often substantially. Focusing on frailty levels below 0.3 for every age group there has been an increase between Waves 1 and 9 in the proportion of people at these lower levels of frailty, with only one exception. On the other hand, among older sections of the population, the share of individuals with very high levels of frailty has also increased, albeit at a smaller rate. Focusing on higher frailty levels above 0.5 there has been an increase in every age group between Waves 1 and 9 in the mass at these high levels. The shift in mass to lower levels of frailty is much larger than the shift to the higher levels but the increase in highest levels of frailty is especially marked for those aged over 80. This latter result is consistent with suggestions that improvements in medical and care services may serve to increase the survival of individuals with greater levels of frailty (Marshall et al. 2015). In other words, there has been an increase in the tails of the frailty distribution, with a larger increase at lower levels of frailty than in the upper tails.

Table 2: Cumulative distribution of frailty across age bands and waves

Frailty Index	50 to 64			65 to 79			80+		
	Wave 1	Wave 5	Wave 9	Wave 1	Wave 5	Wave 9	Wave 1	Wave 5	Wave 9
0.00	12.2%	11.7%	13.1%	4.2%	4.6%	5.2%	0.8%	1.1%	0.3%
0.05	42.8%	43.6%	46.2%	23.4%	26.0%	27.6%	6.7%	7.8%	8.3%
0.10	62.3%	63.8%	67.3%	43.8%	46.6%	50.9%	19.5%	18.4%	25.2%
0.15	77.2%	78.1%	80.6%	63.6%	65.9%	70.5%	38.2%	35.9%	44.3%
0.20	82.8%	84.2%	85.1%	72.9%	74.2%	78.3%	48.4%	47.5%	55.7%
0.25	88.6%	89.4%	89.1%	82.1%	82.3%	85.6%	61.9%	60.3%	67.1%
0.30	91.2%	92.0%	91.6%	86.2%	86.6%	88.9%	70.7%	65.9%	74.9%
0.40	95.9%	95.6%	95.3%	93.5%	94.3%	94.7%	85.6%	81.8%	85.5%
0.50	98.9%	98.7%	98.1%	98.2%	98.2%	98.0%	96.2%	92.7%	93.1%
0.60	99.7%	99.7%	99.3%	99.5%	99.1%	99.2%	98.5%	95.9%	96.1%
0.70	100.0%	100.0%	99.9%	100.0%	99.6%	99.7%	100.0%	98.5%	98.2%
0.80	100.0%	100.0%	100.0%	100.0%	99.9%	99.9%	100.0%	99.9%	99.8%

Notes: The table shows the cumulative distribution of frailty for three age groups, in waves 1, 5, and 9 of ELSA. The table is read in columns, such that each number represents the share of invididuals with a frailty index value up to the level noted in the leftmost column.

3 Results

To better understand how frailty varies with age and other characteristics, we estimate the following relationship:

$$\ln F_{iw} = \alpha + \beta \cdot \text{age}_{iw} + \boldsymbol{\gamma_1} \boldsymbol{X}_{1iw} + \boldsymbol{\gamma_2} \boldsymbol{X}_{2i} + \varepsilon_{iw} \tag{1}$$

where F_{iw} denotes the frailty index for individual i in wave w, age_{iw} denotes the age of the individual, $\boldsymbol{X}_{1iw}$ is a set of individual time-varying controls (region and wealth), $\boldsymbol{X}_{2i}$ is a set of individual controls that is time-invariant in our data (sex and education), and ε_{iw} represents an error term reflecting other factors which may be individual-specific and time-varying. We follow Searle et al. (2008) in using a logarithmic model for frailty rather than the linear framework of Marshall et al. (2015). A logarithmic formulation follows naturally from the Gompertz-Makeham law, facilitates easier interpretation of coefficients (the coefficient on age is the percentage increase in frailty each year), and is also preferred by a Box-Cox test for functional form.

The results are pictured in Figure 1a.[1] and show that age is a statistically significant predictor for individual frailty. The results reveal a wide range of variation in frailty at each age depending on demographic characteristics. Females have higher levels of frailty than males, frailty is decreasing in household wealth and higher education has a marked negative impact on frailty. There are also marked regional differences: conditional on age, gender, education and wealth, living in the North East, North West, or East Midlands of England, among others, is associated with significantly more frailty (although these effects are not found for individuals who migrate between regions).

While Figure 1a shows that the *level* of frailty differs across a variety of demographic characteristics, in Figure 1b, we investigate whether the *rate* of ageing itself (e.g the slope of the frailty function with respect to age) differs across these characteristics. Since sex, education, and wealth are likely correlated with unobserved individual characteristics that influence the speed of ageing, we modify Equation 1 to:

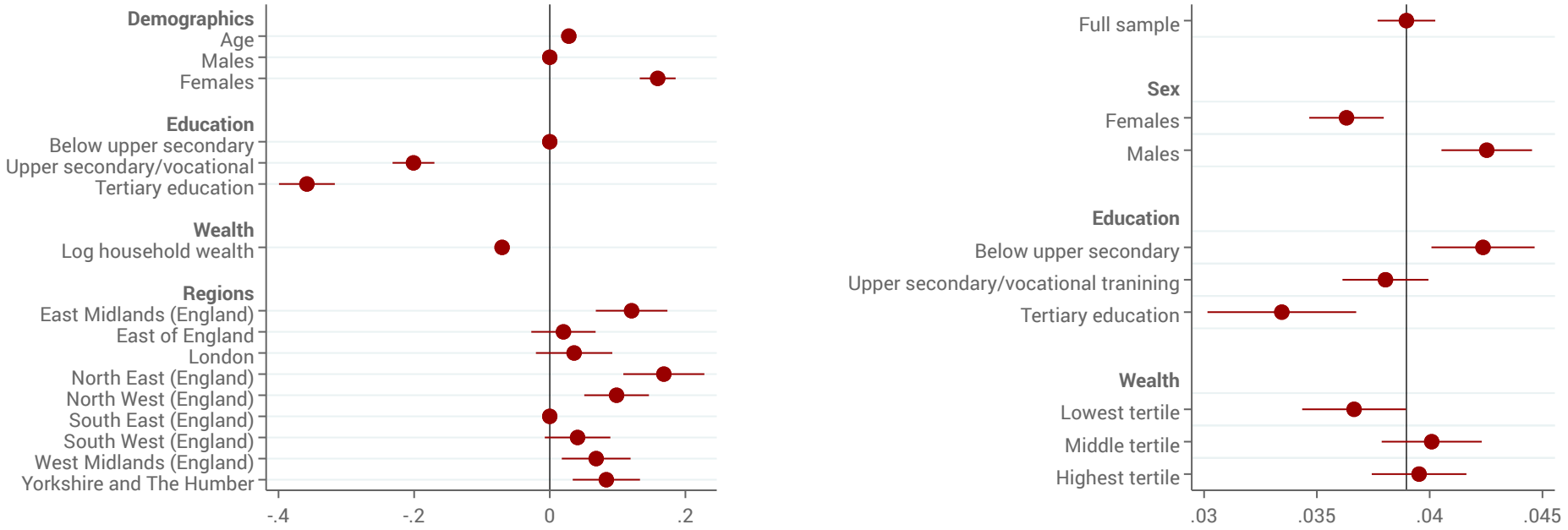
$$\ln F_{iw} = \alpha_i + \beta \cdot \text{age}_{iw} + \boldsymbol{\gamma_1} \boldsymbol{X}_{1iw} + \varepsilon_{iw} \tag{2}$$

where α_i is now an individual-specific fixed effect. The time-invariant controls $\boldsymbol{X}_{2iw}$ cannot be included in this fixed-effects regression so we estimate this regression for the full sample and then separately by sex, education level, and the wealth tertile of the individual based on their first appearance in the sample.

For the full sample, we estimate an age-related frailty accumulation of 3.9% per year. This rate of ageing is similar to that found for a range of European countries (Abeliansky and Strulik 2018; Abeliansky and Strulik 2019), but less than the 5% rate estimated for the U.S (Abeliansky, Erel, and Strulik 2020). Comparing coefficients in Figure 1b shows that, in line with previous studies, males accumulate health deficits faster than females (4.3% per year vs. 3.6% per year). Given that females tend to have higher levels of initial frailty, this points towards health converging at later ages.[2] In addition, individuals with higher education see their frailty levels rise more slowly than individuals with low levels of education (3.3% per year vs. 3.8% and 4.2%). We find no statistical evidence of the rate of ageing varying across wealth tertiles although Appendix Table B.1 shows that within each tertile the level of frailty is diminishing with wealth.

[1] Full regression results for both Figure 1a and Figure 1b are detailed in Appendix Table B.1.

[2] Using these fixed effects estimates we estimate male and female frailty to converge at a rather distant 109 years, broadly in line with the age of convergence estimated by Abeliansky, Erel, and Strulik (2020) for the US.



(a) Determinants of frailty

(b) Speed of ageing (coefficient on age) by key characteristics

Figure 1: Determinants and speed of frailty

Notes: Coefficients shown as dots, 95% confidence intervals shown as lines. The left panel shows coefficients from estimating Equation 1. The right panel shows the coefficient on age from fixed-effects regressions as in Equation 2, run for the full sample and separately by sex, education, and wealth.

Combined these effects shows marked inequalities across England in terms of frailty. An example of these inequalities is visualized in Figure 2, which plots the fit of a local polynomial regression of frailty on age based on the latest three waves of ELSA, along with 95% confidence bands. The figure compares individuals in the North East in the lowest tertile of wealth who left school at 16, compared with college graduates in the South East in the highest wealth tertile. A wide gap opens up from 50 years onwards, this gap remains large and broadly constant between 60 and 70 years of age before starting to narrow at oldest ages. A similar pattern of health inequities has been found for the US (Case and Deaton 2005), where health status smoothly deteriorates for the richest income quartile, whereas, for the poorest quartile, it increases rapidly until retirement, after which the deterioration of health flattens off. Recently, Abeliansky and Strulik (2023) used data across Europe and found large positive impacts of retirement on health for workers in low-status occupations, and negligible impacts for high-status occupations. The pattern in Figure 2 is consistent with these patterns, and suggests a partial "catch-up" in frailty for high-SES individuals at later ages.

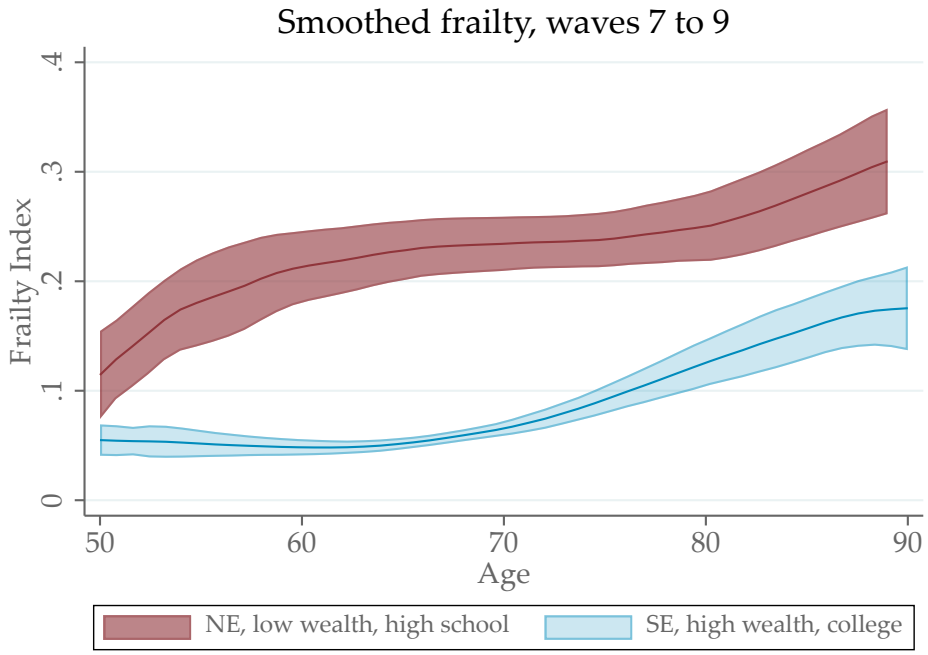


Figure 2: Frailty accumulation: smoothed local regression fit with 95% confidence bands, using Epanechnikov kernel with bandwidth=4.

3.1 Are cohorts ageing better?

Table 2 characterises ageing across all nine waves of ELSA, but a key question is whether there have been improvements across cohorts in the rate at which frailty accumulates. There is evidence that this has happened for the US (Levine and Crimmins 2018; Abeliansky, Erel, and Strulik 2020) and Europe (Abeliansky and Strulik 2018; Abeliansky and Strulik 2019), and we now investigate whether the same occurs for England. Other studies, including on ELSA, have found evidence of frailty deteriorating across cohorts (Marshall et al. 2015; Yang and Lee 2010; Stephan et al. 2020).

To estimate cohort effects, we modify Equation 1 by including a linear year of birth trend to capture age-specific improvements in frailty over time. Identifying cohort effects requires allowing for various unobserved characteristics. To do so, we follow Abeliansky, Erel, and Strulik

(2020) and use three different estimators – pooled OLS, random effects regression, and Mundlak estimation (Mundlak 1978).

Since the year of birth does not vary over time for individuals, standard fixed-effects models to account for individual heterogeneity cannot be used when estimating cohort effects. Hence, it is sensible to use random effects. However, if there is individual heterogeneity that is systematically related to both frailty and cohort, random effects would be inconsistent. We therefore follow Mundlak (1978) and add the mean of all time-varying covariates as additional regressors (Mundlak 1978; Wooldridge 2021). In particular, we include the mean age of individual i as a control variable. If this variable is significant (as it is in our analysis) then systematic individual heterogeneity is present and these Mundlak estimates are the most reliable.[3] For purposes of robustness we also show results with other estimators. Reassuringly our main results are repeated across all estimation methods but the significance of the mean age variable means the Mundlak ones are the focus of our attention in the discussion below.

Table 3 shows our estimation results, where columns are separate regressions estimated with pooled OLS, random effects, and Mundlak estimation, with and without controls, respectively. There is strong evidence of a cohort effect whereby frailty is improving over time, indicated by the negative and significant coefficients on the year of birth. Focusing on the Mundlak estimates with a full set of controls (column 6), being born one year later for a given age goes along with a roughly six month improvement ($0.019/0.038 \times 12 = 5.89$ months, 95% CI: [4.65-7.13]) in frailty. That is about twice the rate of improvement previously found for the U.S (Abeliansky, Erel, and Strulik 2020). To summarize the cohort effects, we calculate the age at which an individual in 2018 is expected to have the same level of frailty as a 70-year-old individual in 2002. This is shown in the last row of Table 3, which indicates that 75 (in 2018) is the new 70 (in 2002) (Levine and Crimmins 2018).

Table 3: Estimating birth cohort trends in frailty

	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.033***	0.036***	0.038***	0.039***	0.038***	0.038***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
Year of birth	−0.026***	−0.023***	−0.028***	−0.025***	−0.029***	−0.019***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.002)
Mean Age					−0.002	0.008***
					(0.003)	(0.002)
Observations	72,705	65,694	72,705	65,694	72,705	65,694
Sample	All	All	All	All	All	All
Method	P-OLS	P-OLS	RE	RE	Mundlak	Mundlak
Controls	None	All	None	All	None	All
What is the new 70?	77.1	76.3	76.7	76.2	76.9	75.3

Notes: Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%. Age is demeaned at individual level. Controls: Sex, NUTS1 region dummies (+ mean for Mundlak specifications), education, log wealth (+ mean for Mundlak specifications). The last row displays the predicted age in 2018 in which frailty equals the frailty level of a 70-year-old in 2002.

In finding evidence of cohort improvements our results differ from Marshall et al. (2015), who use the first five waves of ELSA and a multilevel growth model for frailty. Given we still

[3] Following Bell and Jones (2015), we demean age at the individual level in these regressions to facilitate interpretation of the mean age coefficient. Neither our findings of significant Mundlak terms nor the predicted cohort trends are sensitive to this.

find evidence of cohort improvements when we restrict our estimation to the first five waves, the variance in results must reflect other specification differences such as their use of a linear model, five-year age intervals and inclusion of a quadratic term in age. Including the quadratic term does not change our results and neither does specifying our model in linear terms (with our logarithmic specification preferred statistically). Attempting to replicate their methods but using logarithms and one year age intervals gives weaker evidence for cohort improvements. Another important difference in our study is the use of the Mundlak terms in estimation. Given the theoretical argument for their inclusion and their significance in our estimation, this points to the importance of allowing for systematic heterogeneity. Reassuringly though the plausibility of cohort improvements does not rest solely on selection of a particular estimator based on the inferred presence of unobserved heterogeneity. As shown in Appendix B.2, raw data from various waves also shows clear and simple support for the notion of improving frailty across cohorts. In addition, Appendix Table B.4 presents a series of robustness checks showing that the results are not driven by details on the construction of the frailty index, sample selection issues, and missingness patterns in the data.

Table 3 assumes a constant rate of cohort improvement. To investigate whether this rate varies over time, we include a quadratic term in year of birth in the analysis, summarized in Table 4 and visualized in Figure 3. All specifications include the full set of control variables. Both coefficients in the quadratic expression are statistically significant, suggesting that later cohorts are ageing better in terms of frailty than past cohorts and that the rate of improvement is slowing. Using the historical estimates from this quadratic specification, a 75.5-year-old in 2018 (born in 1943) has the frailty of a 70-year-old in 2002 (born in 1932) (shown in column 3). However, we can use our model to project forward frailty for future cohorts. The projections for the next sixteen years, the same duration as in our data, are shown in the bottom row of Table 4 and visualized in Figure 3. Based on these projections, a 74.5-year-old in 2034 is expected to have the frailty of a 70-year-old in 2018. Thus, frailty improvements are slowing at a relatively modest rate (from a five-and-a-half year improvement over 16 years to a four-and-a-half year improvement). Further evidence supporting this conclusion is shown in Appendix Figure B.1, which shows estimated values for the year of birth effect when a full set of year of birth dummies is included in the estimation rather than simply relying on linear or quadratic trends.

Table 4: Frailty trends: With quadratic in year of birth

	(1)	(2)	(3)
Age	0.037***	0.039***	0.038***
	(0.002)	(0.003)	(0.003)
Year of birth	−0.857***	−1.018***	−0.625***
	(0.175)	(0.192)	(0.171)
(Year of Birth^2)/1000	0.215***	0.256***	0.156***
	(0.045)	(0.049)	(0.044)
Observations	65,694	65,694	65,694
Sample	All	All	All
Method	P-OLS	RE	Mundlak
What is the new 70 in 2018?	76.5	76.4	75.5
What is the new 70 in 2034?	75.2	74.9	74.5

Notes: Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%. Age is demeaned at individual level. Controls: Sex, NUTS1 region dummies (+ mean for Mundlak specifications), education, log wealth (+ mean for Mundlak specifications).
The last two rows use the regression results to calculate the age in 2018 of a person with the same projected frailty level as a 70 year old in 2002 and the age in 2034 of a person with the same projected level of frailty as a 70 year old in 2018.

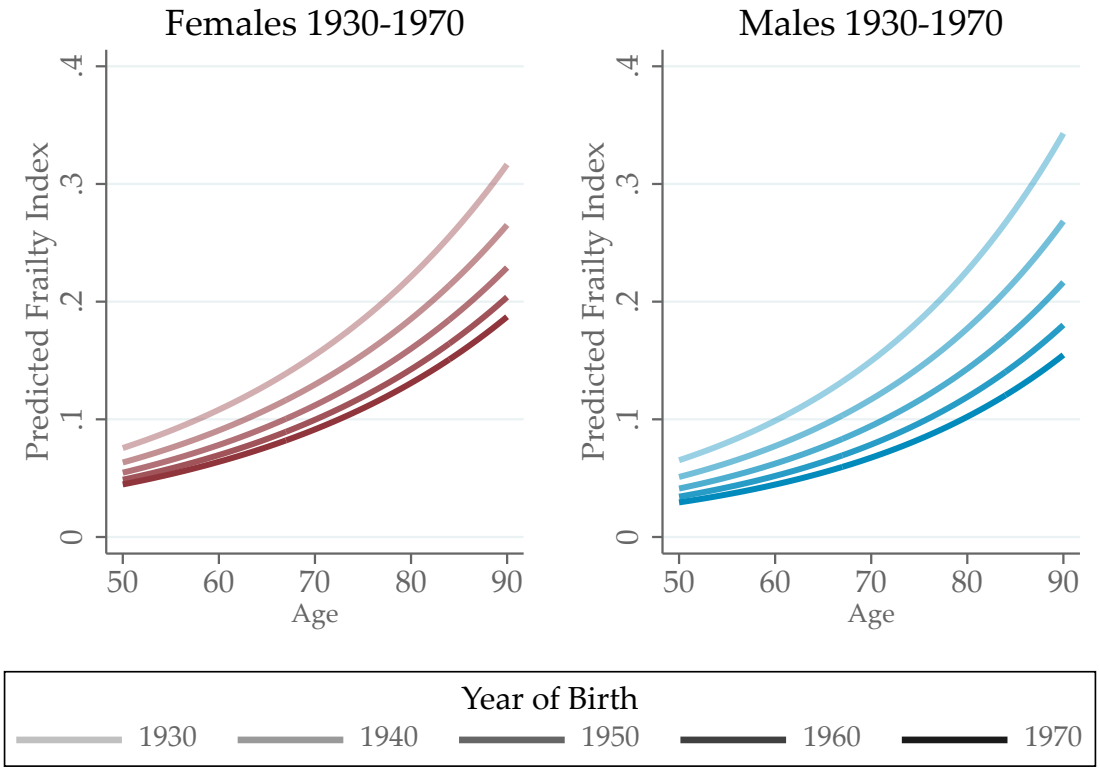


Figure 3: Fitted changes in frailty profiles across birth cohorts, specifications with squared year of birth term

3.2 What is driving the improvement?

To identify the proximate drivers of these cohort improvements, we follow Rogers et al. (2017) and separate the frailty index into five mutually exclusive domains: Mobility difficulties (e.g., problems walking, or lifting objects), ADL/IADLs (e.g., difficulties getting dressed or making phone calls), depressive symptoms, self-reported health conditions (e.g., whether a respondent had or has had cancer or diabetes), and cognitive function (e.g., word recall)[4]

Table 5 shows the results from Mundlak regressions with controls for these five domains estimated separately. Because we use the log of each component (to echo the specification for the overall frailty index) the number of observations varies across domains as we need to exclude all zero observations. As a consequence, Table 5 only provides evidence on the intensive rather than extensive margin, i.e. variations in the severity of conditions rather than changes in who has the conditions. For robustness purposes we did estimate results using the transform ln(1+frailty) as our dependent variable and found essentially unchanged results (see Appendix Table B.5).

Table 5: Cohort trends by sub-components of frailty index

	(1) Mobility (10)	(2) ADL/IADL (13)	(3) Depression (8)	(4) Conditions (12)	(5) Cognitive (6)
Age	0.026***	0.030***	0.002	0.039***	0.018***
	(0.002)	(0.003)	(0.001)	(0.001)	(0.002)
Year of birth	−0.017***	−0.024***	−0.012***	−0.002*	−0.014***
	(0.002)	(0.003)	(0.001)	(0.001)	(0.002)
Mean Age	−0.007***	−0.020***	−0.011***	0.007***	−0.003*
	(0.002)	(0.003)	(0.001)	(0.002)	(0.002)
Observations	39,044	18,565	38,285	53,916	24,870
Mean of DV	0.351	0.234	0.321	0.170	0.279

Notes: All columns show Mundlak regressions. Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%. Age is demeaned at individual level. Controls: Sex, NUTS1 region dummies (+ mean), education, log wealth (+ mean). Number of items in each sub-component listed in parentheses in the column headers.

With the exception of the depression component, frailty in each domain rises with age in a statistically significant manner, albeit at differing rates. There is also evidence for improvements across cohorts in all domains. For the mobility, ADL/IADL, and cognitive components, the cohort effect is substantial at around eight to nine months per year. However, the evidence for improvements in underlying physical conditions is weak and numerically very small.

Recent research has found that the evidence on improving frailty in Europe may be driven by sample selectivity bias (Börsch-Supan, Ferrari, and Salerno 2021). Reassuringly, the declining frailty trend in our data is not due to any one dimension, and the trend in our data is no different for the dimensions with non-trivial shares of missing data, as visualized in Appendix Figure A.2.

[4] We drop one item from our analysis at this stage: self-reported general health status as it is not included in the sub-indices leaving us with 49 components).

3.3 Which demographic groups have seen the most progress?

To investigate whether these cohort trends differ across groups we ran separate Mundlak regressions (with control variables) for different demographic characteristics. Numerical estimates suggest that males have experienced more rapid improvements than females although a Wald test finds the difference in trend to be not statistically significant.

Whilst higher levels of education are associated with slower rates of frailty accumulation, Table 6 suggests that it is lower levels of education that have seen the fastest rates of improvements although the effect is relatively small and of only borderline statistical significance. Conversely, whilst we found that across wealth tertiles the rate of ageing was broadly similar when we allow for cohort differences we find strong evidence of faster rates of improvements for those in the highest wealth tertile. In Appendix Table B.6, we repeat the same specification and include quadratic terms in year of birth, which point to some degree of convergence, as groups with lower levels of frailty and better trends see a larger slowdown in the year-of-birth effects.

Table 6: Longevity trends: Heterogeneous effects

	Gender		Education			Baseline wealth		
	(1) Males	(2) Females	(3) Low	(4) Middle	(5) High	(6) Low	(7) Middle	(8) High
Age	0.041***	0.036***	0.042***	0.038***	0.033***	0.036***	0.040***	0.038***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Year of birth	−0.022***	−0.016***	−0.016***	−0.022***	−0.012***	−0.010***	−0.020***	−0.025***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.005)	(0.004)	(0.003)	(0.003)
Mean Age	0.004	0.012***	0.009***	0.005	0.021***	0.010**	0.009***	0.007*
	(0.003)	(0.003)	(0.004)	(0.003)	(0.005)	(0.005)	(0.004)	(0.004)
Observations	30,046	35,648	23,530	31,953	10,211	20,934	21,754	23,006
Method	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak
What is the new 70?	75.6	74.8	74.5	75.9	74.3	73.6	75.4	76.3
p-value Interaction term	0.083		0.05			<0.001		

Notes: All columns show Mundlak regressions. Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%. Age is demeaned at individual level.
Education levels are: Low: below upper secondary, Middle: upper secondary/vocational training, High: tertiary education. Baseline wealth is split in tertiles relative to five-year age group in the first occurrence in the survey. Controls: Sex, NUTS1 region dummies (+ mean), education, log wealth (+ mean). In the specifications for sex and education, the respective variable is not included as a control. The last row is from a joint specification in which year of birth was interacted with all levels of the respective variable. The p-value is from a Wald-test on the interaction terms of year of birth and the respective variable levels, with the null hypothesis that the interaction terms are jointly zero.

3.4 Individual and Regional Frailty Dynamics

We can use our frailty index and its sub-components to identify the major contributors to frailty at each age and the most important causes of deterioration between different ages. To do so Table 7 shows two statistics for each sub-component (defined over different numbers of items, listed in parantheses in the column heading): the median (P50), and the mean of the highest frailty quartile in each sub-component (HFQ). The largest single contributor to median frailty for people in their 50s and 60s (both weighting each sub-component by the number of items it contains and also in unweighted terms) is depression (including restless sleep, feeling depressed/sad, feeling not being able to get going, etc.). Note though that depression does not increase with age but is simply a substantial contributor to frailty at all ages.[5]. In moving from the 50s age group into the 60s, declines in mobility are the most important contributor to increases in overall frailty, and in transiting from the 60s to the 70s, increased incidence of disease conditions is the most important factor in explaining increased median frailty. In the 70s, these disease conditions are the largest single component contributing to the level of median frailty and in the 80s that role is taken by mobility restrictions. Mobility restrictions are also the main cause of frailty deteriorating in the 70s, followed by an increase in cognitive problems.

Table 7: Median (P50) and average of highest frailty quartile (HFQ) of frailty sub-components and overall frailty index, by age group.

	Mobility (10)		ADL(13)		Depression (8)		Conditions (12)		Cognitive (6)		Overall Index	
Age Group	P50	HFQ	P50	HFQ	P50	HFQ	P50	HFQ	P50	HFQ	P50	HFQ
50-59	0	0.435	0	0.038	0.125	0.492	0.083	0.21	0	0.054	0.06	0.242
60-69	0.1	0.436	0	0.045	0.125	0.464	0.083	0.224	0	0.243	0.08	0.283
70-79	0.1	0.605	0	0.216	0.125	0.447	0.167	0.301	0	0.285	0.111	0.338
80-89	0.3	0.744	0.077	0.437	0.125	0.564	0.167	0.304	0.167	0.465	0.18	0.447

Table 2 showed that focusing on median outcomes omits important distributional details, so Table 7 also shows evidence around the upper tail of frailty by showing the average value amongst the quartile with the highest level of frailty for each domain (columns labelled HFQ). This is a way of capturing which components of frailty are explaining the worst outcomes at each age. For those in their 50s and 60s, depression is highest for the lower frailty quartile. Mobility restrictions is another important factor as well as the dominant driver of frailty in the bottom quartile of the distribution in the 70s and 80s.

To understand the drivers of regional inequalities, Figure 4 shows the coefficients on the regional dummies in the Mundlak regressions by subcomponents. The South East of England is the designated reference group (as it has the lowest level of average frailty across all regions). The coefficients point to systematic regional differences across a variety of factors. Cross-regional inequalities in mobility and ADL/IADL are most pronounced, with lesser variation amongst disease conditions (aside from the North East) and relatively small differences in depression and cognitive abilities.

Whilst Figure 4 points to differences in regional averages across various frailty components, closer inspection reveals that the major drivers of these regional differences are within-region effects. In support of this argument, Figure 5 presents for different age groups the distribution of frailty for the top three regions compared with the bottom three regions. These show relatively small differences in modes and medians, but what leads to better average outcomes in the best regions are much larger tails at low levels of frailty and lower tails at high levels of

[5] The fact that in this case we find no strong evidence that depression increases with age raises the interesting issue of whether it should be included in a frailty index given the methodology of Searle et al. 2008 and the emphasis on selecting components that increase with age

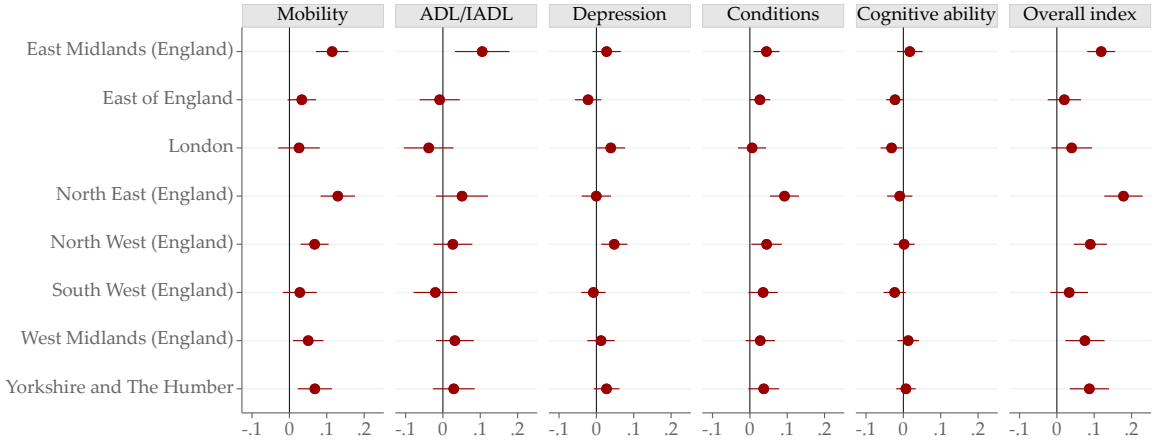


Figure 4: Coefficients on regional dummies from Mundlak regressions

frailty. In other words, the better regions are substantially better in terms of the best and worst outcomes but only moderately more successful in terms of median outcomes.

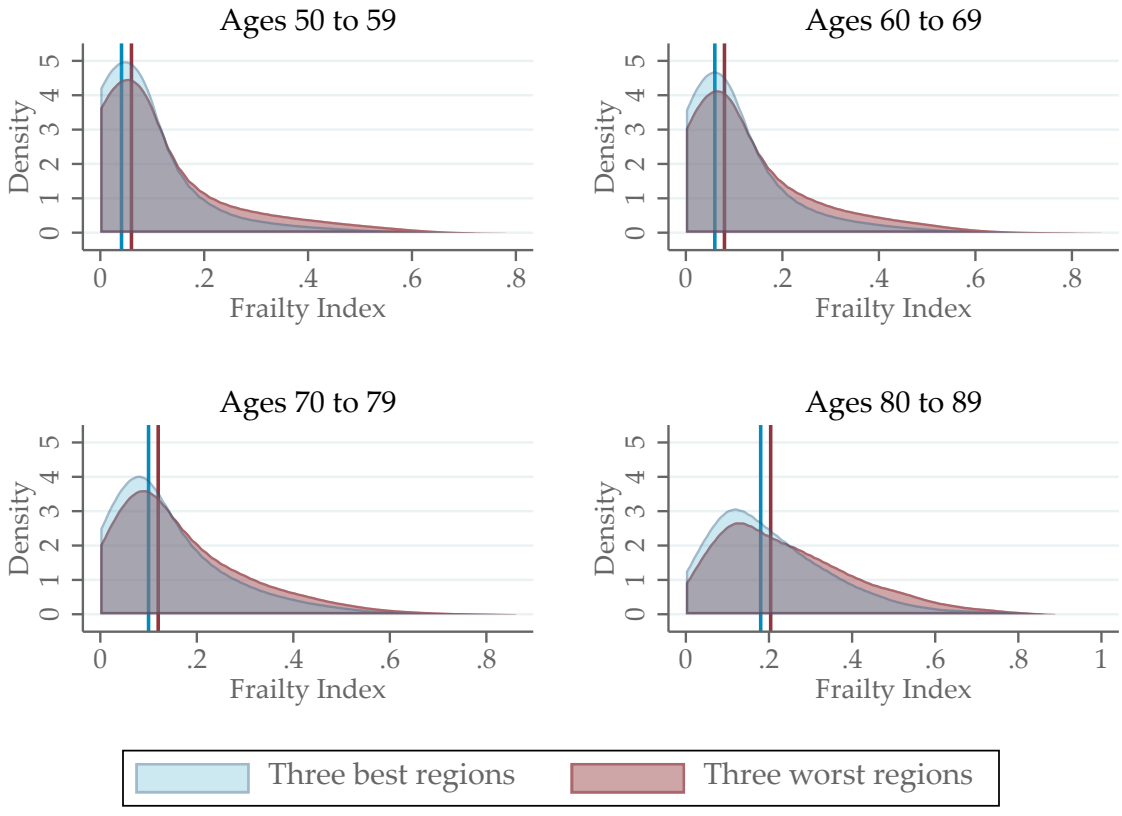


Figure 5: Distribution of frailty: Comparing high and low frailty regions. Epanechnikov kernel density estimates, vertical lines show medians.

4 Conclusion

Using nine waves of ELSA from 2002 to 2018 we find : i) frailty rises at an approximate rate of 3% to 4% per annum, similar to many EU countries but at a slower rate than the U.S ii) there are stark differences in frailty based on sex, region, education and wealth such that those with better education and wealth have substantially lower frailty at older ages, iii) frailty at each age has been improving over time but there is evidence the rate of improvement may be slowing albeit modestly iv) the rate of improvement varies significantly across different groups and has been highest for those with the highest levels of wealth v) improvements in frailty have been driven mostly by improvements in mobility and ADLs but very little by reductions in underlying disease conditions vi) depression is the largest component of frailty in the 50s and 60s but mobility is most important in explaining deteriorating frailty in the 50s, disease conditions in the 60s and mobility again in the 70s, and vii) differences in mobility and ADLs are most important in explaining differences in regional averages but regional variations are mainly due to greater dispersion in health within rather than across regions.

Our results provide some good news in terms of health trends in England, especially around the substantial cohort improvement trends we estimate. However, our results also explain why a number of studies express concern over recent health trends in the U.K. Whilst there have been large improvements in the lower tail of frailty, there has also been an increase in the upper tail. The former dominates the latter, leading to average improvements but both in terms of levels and trend improvements there are significant differences in frailty based on education and wealth.

Our results cover frailty trends before Covid-19 and so shed no light on the impact of the pandemic on frailty amongst the English population aged over 50 years. Both the immediate and long term impact of Covid-19 on older people's health is likely to be substantial and may significantly affect the trends documented here. Our study also only documents trends and so provides no insight as to the measures that have led to reductions in frailty and neither does it identify steps to achieve further reductions or tackle the profound differences in frailty by region and education. Further, whilst frailty measures are a convenient way to capture health and functionality of older adults they fail to capture the intrinsic capacity that individuals can draw on or how they are affected by these health deficits. If different frailty components have differential impacts on individual's depending on their education or wealth then our results based on equal weighted frailty components will tell an incomplete story.

Our results have a number of implications. Firstly they emphasise the potential malleability of how health deficits accumulate over time. That malleability manifests itself in two ways. The first is the clear impact of socio-economic variables such as education and wealth in influencing frailty. The second is in the trend improvements across cohorts we find consistently and robustly across a wide range of specifications. Given the increasing importance of ageing well as people live longer (Goldman et al. 2013; Scott, Ellison, and Sinclair 2021), this finding suggests that much is at stake and outcomes can be affected. The need to exploit this malleability is made all the greater by the evidence this paper reveals regarding the slowdown in these trends and substantial inequalities. Finally our breakdown of regional differences suggests policies to narrow these should focus on achieving greater improvements in mobility and ADLs amongst poorer performing regions and tackling within region inequality. Finally the fact that our results suggest there have been only limited improvements in the incidence of age-related diseases and conditions points to the importance of better understanding the underlying biology of these diseases and the development of potential therapeutics (Campisi et al. 2019).

References

Abeliansky, Ana Lucia, Devin Erel, and Holger Strulik (2020). "Aging in the USA: Similarities and Disparities across Time and Space". In: *Scientific Reports* 10.1. DOI: 10.1038/s41598-020-71269-3.

Abeliansky, Ana Lucia and Holger Strulik (2018). "How We Fall Apart: Similarities of Human Aging in 10 European Countries". In: *Demography* 55.1, pp. 341–359. DOI: 10.1007/s13524-017-0641-8.

— (2019). "Long-Run Improvements in Human Health: Steady but Unequal". In: *The Journal of the Economics of Ageing* 14, p. 100189. DOI: 10.1016/j.jeoa.2019.01.003.

— (2023). "Health and Aging before and after Retirement". In: *Journal of Population Economics*. URL: https://doi.org/10.1007/s00148-023-00951-3.

Banks, James, Alastair Muriel, and James P Smith (2011). "Attrition and Health in Ageing Studies: Evidence from ELSA and HRS". In: *Longitudinal and life course studies : international journal* 2.2, 10.14301/llcs.v2i2.115. DOI: 10.14301/llcs.v2i2.115.

Bell, Andrew and Kelvyn Jones (2015). "Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data". In: *Political Science Research and Methods* 3.1, pp. 133–153. DOI: 10.1017/psrm.2014.7.

Berkman, Lisa F. and Beth C. Truesdale (2023). "Working Longer and Population Aging in the U.S.: Why Delayed Retirement Isn't a Practical Solution for Many". In: *The Journal of the Economics of Ageing* 24, p. 100438. DOI: 10.1016/j.jeoa.2022.100438.

Börsch-Supan, Axel, Irene Ferrari, and Luca Salerno (2021). "Long-Run Health Trends in Europe". In: *The Journal of the Economics of Ageing* 18, p. 100303. DOI: 10.1016/j.jeoa.2020.100303.

Campisi, Judith, Pankaj Kapahi, Gordon J. Lithgow, Simon Melov, John C. Newman, and Eric Verdin (2019). "From Discoveries in Ageing Research to Therapeutics for Healthy Ageing". In: *Nature* 571.7764 (7764), pp. 183–192. DOI: 10.1038/s41586-019-1365-2.

Case, Anne and Angus S Deaton (2005). "Broken down by Work and Sex: How Our Health Declines". In: *Analyses in the Economics of Aging*. University of Chicago Press, pp. 185–212.

Goldman, Dana P., David Cutler, John W. Rowe, Pierre-Carl Michaud, Jeffrey Sullivan, Desi Peneva, and S. Jay Olshansky (2013). "Substantial Health and Economic Returns from Delayed Aging May Warrant a New Focus for Medical Research". In: *Health Affairs (Project Hope)* 32.10, pp. 1698–1705. DOI: 10.1377/hlthaff.2013.0052. pmid: 24101058.

Haskel, Jonathan and Josh Martin (2022). *Economic Inactivity and the Labour Market Experience of the Long-Term Sick*. Working Paper.

Kingston, Andrew, Adelina Comas-Herrera, Carol Jagger, and MODEM project (2018). "Forecasting the Care Needs of the Older Population in England over the next 20 Years: Estimates from the Population Ageing and Care Simulation (PACSim) Modelling Study". In: *The Lancet. Public Health* 3.9, e447–e455. DOI: 10.1016/S2468-2667(18)30118-X. pmid: 30174210.

Levine, Morgan E. and Eileen M. Crimmins (2018). "Is 60 the New 50? Examining Changes in Biological Age Over the Past Two Decades". In: *Demography* 55.2, pp. 387–402. DOI: 10.1007/s13524-017-0644-5.

Lynch, Marty, Milica Bucknall, Carol Jagger, and Ross Wilkie (2022). "Projections of Healthy Working Life Expectancy in England to the Year 2035". In: *Nature Aging* 2.1, pp. 13–18. DOI: 10.1038/s43587-021-00161-0.

Marmot, Michael (2020). "Health Equity in England: The Marmot Review 10 Years On". In: *BMJ* 368. URL: https://www.bmj.com/content/368/bmj.m693.

Marshall, Alan, James Nazroo, Gindo Tampubolon, and Bram Vanhoutte (2015). "Cohort Differences in the Levels and Trajectories of Frailty among Older People in England". In: *Journal of Epidemiology and Community Health* 69.4, pp. 316–321. DOI: 10.1136/jech-2014-204655.

Mitnitski, Arnold B., Alexander J. Mogilner, and Kenneth Rockwood (2001). "Accumulation of Deficits as a Proxy Measure of Aging". In: *The Scientific World Journal* 1, pp. 323–336. DOI: http://dx.doi.org/10.1100/tsw.2001.58.

Mundlak, Yair (1978). "On the Pooling of Time Series and Cross Section Data". In: *Econometrica* 46.1, pp. 69–85. JSTOR: 1913646. URL: http://www.jstor.org/stable/1913646.

Niederstrasser, Nils Georg, Nina Trivedy Rogers, and Stephan Bandelow (2019). "Determinants of Frailty Development and Progression Using a Multidimensional Frailty Index: Evidence from the English Longitudinal Study of Ageing". In: *PloS One* 14.10, e0223799. DOI: 10.1371/journal.pone.0223799. pmid: 31665163.

ONS (2019a). *National Population Projections - Office for National Statistics*. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2018based.

— (2019b). *Past and Projected Period and Cohort Life Tables, 2018-Based, UK - Office for National Statistics*. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/bulletins/pastandprojecteddatafromtheperiodandcohortlifetables/1981to2068.

Office for Budget Responsibility (2018). *Fiscal Sustainability Report 2018*. URL: https://obr.uk/download/fiscal-sustainability-report-july-2018/.

Rashid, Theo, James E. Bennett, Christopher J. Paciorek, et al. (2021). "Life Expectancy and Risk of Death in 6791 Communities in England from 2002 to 2019: High-Resolution Spatiotemporal Analysis of Civil Registration Data". In: *The Lancet Public Health* 6.11, e805–e816. DOI: 10.1016/S2468-2667(21)00205-X. pmid: 34653419.

Rogers, Nina T., Alan Marshall, Chrissy H. Roberts, Panayotes Demakakos, Andrew Steptoe, and Shaun Scholes (2017). "Physical Activity and Trajectories of Frailty among Older Adults: Evidence from the English Longitudinal Study of Ageing". In: *PLOS ONE* 12.2, e0170878. DOI: 10.1371/journal.pone.0170878.

Scott, Andrew J. (2023). "The Economics of Longevity – An Introduction". In: *The Journal of the Economics of Ageing* 24, p. 100439. DOI: 10.1016/j.jeoa.2022.100439.

Scott, Andrew J., Martin Ellison, and David A. Sinclair (2021). "The Economic Value of Targeting Aging". In: *Nature Aging* 1.7 (7), pp. 616–623. DOI: 10.1038/s43587-021-00080-0.

Searle, Samuel D., Arnold Mitnitski, Evelyne A. Gahbauer, Thomas M. Gill, and Kenneth Rockwood (2008). "A Standard Procedure for Creating a Frailty Index". In: *BMC Geriatrics* 8.1, p. 24. DOI: 10.1186/1471-2318-8-24.

Stephan, Anna-Janina, Ralf Strobl, Lars Schwettmann, et al. (2020). "The Times We Are Born into and Our Lifestyle Choices Determine Our Health Trajectories in Older Age - Results from the KORA-Age Study". In: *Preventive Medicine* 133, p. 106025. DOI: 10.1016/j.ypmed.2020.106025.

UK Government (2022). *Levelling Up the United Kingdom - GOV.UK*. URL: https://www.gov.uk/government/publications/levelling-up-the-united-kingdom.

Welsh, Claire E., Fiona E. Matthews, and Carol Jagger (2021). "Trends in Life Expectancy and Healthy Life Years at Birth and Age 65 in the UK, 2008–2016, and Other Countries of the EU28: An Observational Cross-Sectional Study". In: *The Lancet Regional Health - Europe* 2, p. 100023. DOI: 10.1016/j.lanepe.2020.100023.

Wooldridge, Jeffrey M. (2021). "Two-Way Fixed Effects, the Two-Way Mundlak Regression, and Difference-in-Differences Estimators". In: *SSRN Electronic Journal*. DOI: 10.2139/ssrn.3906345.

Yang, Yang and Linda C. Lee (2010). "Dynamics and Heterogeneity in the Process of Human Frailty and Aging: Evidence From the U.S. Older Adult Population". In: *The Journals of Gerontology: Series B* 65B.2, pp. 246–255. DOI: 10.1093/geronb/gbp102.

A Appendix A: Data construction and details

The English Longitudinal Study of Ageing (ELSA) is available for download from the UK Data service (UKDS) at the following link:
`https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=200011#!/access-data`.
The data in this study required Special License Access and so cannot be shared but is accessible by request to ELSA.

A.1 Data construction

Construction and description of Frailty Index

We use the complete ELSA respondent sample over waves 1-9 as the basis for the sample in this study. Following Abeliansky, Erel, and Strulik (2020), we restrict the sample to observations fulfilling the following criteria:

- Place of birth must be in the United Kingdom
- Must be respondent in a given survey wave
- Age must be non-missing and between 50 and 90
- At least 35 out of the 50 items in the frailty index must be non-missing

The frailty index is generated following Rogers et al. (2017); we end up with 50 items. Summary statistics for these items are provided in Table A.1.

Additional variables

In addition, we include the following variables in our analysis:

- **Wealth**: Following Marshall et al. (2015), the wealth variable is the natural logarithm of the sum of financial and housing wealth for a given household. Negative and zero values are coded as 1 for the logarithm to be defined. We define sample splits based on the tertile in the wave-5-year-age-group wealth distribution in which an individual is in the first time they are recorded in the survey.
- **Education**: The analysis uses the internationally standardized education variable that records three levels of education: Less than secondary (38% in our sample), upper secondary and vocational training (47%), and tertiary education (15%).
- **Regions**: We obtained confidential data on individuals' region of residence, which we aggregated up to the NUTS-1 level (comprising 9 regions in England)

Table A.1: Summary statistics for items on frailty index

		count	mean	sd
	Mobility			
1	Some difficulty walking 100 yards	78,850	0.125	0.331
2	Some difficulty sitting for 2 hours	78,850	0.131	0.337
3	Some difficulty getting up from chair	78,850	0.249	0.433
4	Some difficulty climbing several flights of stairs	78,850	0.341	0.474
5	Some difficulty climbing one flight of stairs	78,850	0.145	0.352
6	Some difficulty kneeling/stooping/crouching	78,850	0.372	0.483
7	Some difficulty reaching/extending arms	78,850	0.108	0.310
8	Some difficulty pushing/pulling large object	78,850	0.173	0.378
9	Some difficulty lifting 10lbs	78,850	0.229	0.420
10	Some difficulty picking up a dime	78,850	0.057	0.231
	ADLs/IADLs			
1	Some difficulty getting dressed	78,855	0.128	0.334
2	Some difficulty walking across room	78,855	0.034	0.181
3	Some difficulty taking a bath or shower	78,855	0.100	0.300
4	Some difficulty eating	78,855	0.023	0.149
5	Some difficulty going into/out of bed	78,855	0.060	0.237
6	Some difficulty using toilet	78,855	0.035	0.185
7	Some difficulty reading map	78,855	0.048	0.214
8	Some difficulty preparing hot meals	78,855	0.047	0.211
9	Some difficulty grocery shopping	78,855	0.089	0.284
10	Some difficulty using telephone	78,855	0.025	0.155
11	Some difficulty taking medications	78,855	0.023	0.149
12	Some difficulty managing money	78,855	0.031	0.173
13	Some difficulty doing work around house or garden	78,855	0.152	0.359
1	Poor self-reported health	78,855	0.152	0.359
	Depression			
1	CESD: Felt depressed	75,681	0.138	0.344
2	CESD: Felt everything was an effort	75,681	0.198	0.399
3	CESD: Sleep was restless	75,683	0.397	0.489
4	CESD: Not happy	75,506	0.099	0.299
5	CESD: Felt lonely	75,676	0.120	0.324
6	CESD: Does not enjoy life	75,509	0.092	0.289
7	CESD: Felt sad	75,645	0.192	0.394
8	CESD: Could not get going	75,644	0.200	0.400
	Self-reported conditions			
1	Ever had High blood pressure	78,854	0.416	0.493
2	Ever had heart problem	78,854	0.194	0.395
3	Ever had Diabetes	78,854	0.100	0.300
4	Ever had Stroke	78,854	0.046	0.209
5	Ever had Lung Disease	78,855	0.064	0.246
6	Ever had asthma	78,855	0.130	0.337
7	Ever had Arthritis	78,854	0.366	0.482
8	Ever had Cancer	78,855	0.096	0.295
9	Ever had Parkinson's disease	78,855	0.007	0.086
10	Ever had Psychiatric problem	78,855	0.100	0.300
11	Ever had Alzheimers	78,855	0.004	0.061
12	Ever had Dementia	78,855	0.011	0.106
	Cognitive measures			
1	Remembers day incorrectly	75,606	0.171	0.377
2	Remembers month incorrectly	75,712	0.022	0.147
3	Remembers year incorrectly	75,715	0.021	0.145
4	Remembers day of week incorrectly	75,729	0.019	0.135
5	Delayed recall: <=2/10 words	75,894	0.158	0.365
6	Immediate recall: <=4/10 words	75,792	0.196	0.397

A.2 STROBE-Flowchart: Sample Selection and sample size

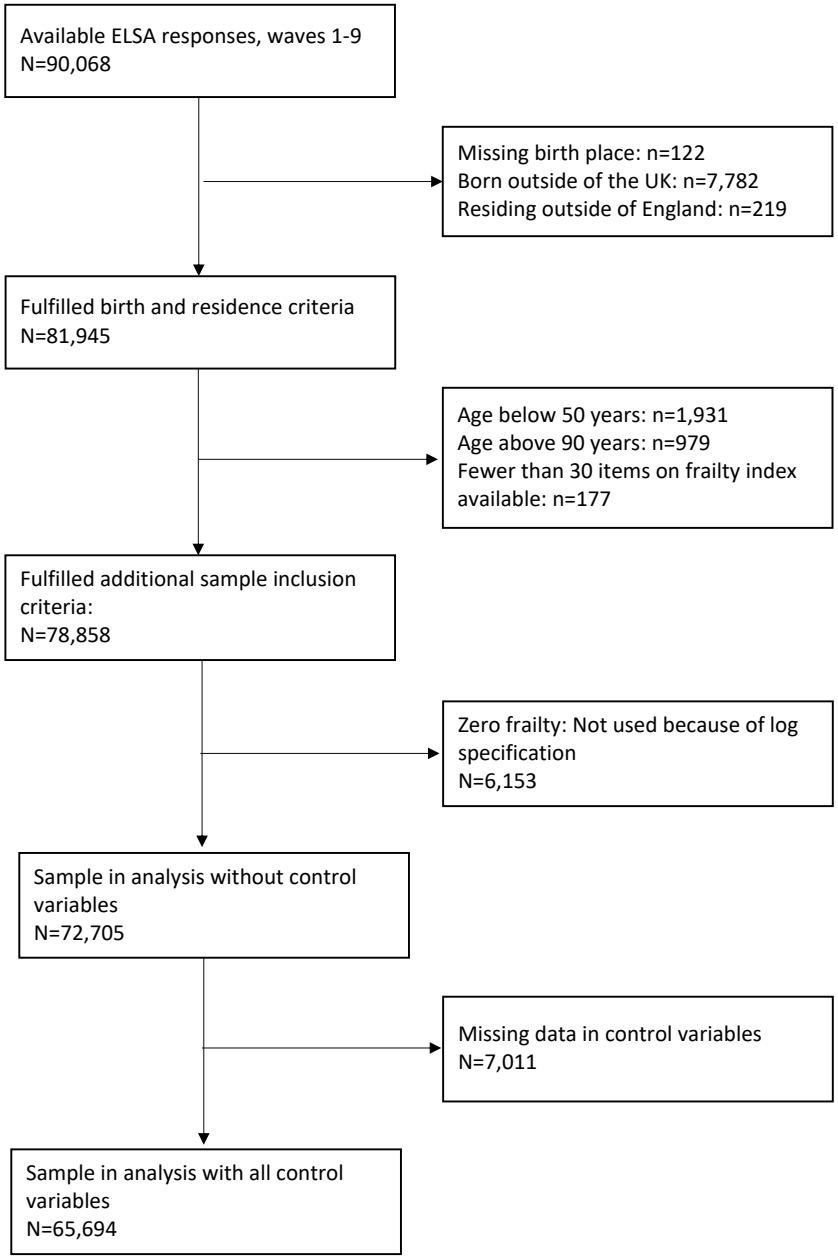


Figure A.1: Flow chart showing sample inclusion criteria and their successive impact on the sample size.

A.3 Frailty Index – Availability over time

Figure A.2 shows the availability of the 50 items in our frailty index for the nine waves of ELSA included in this study. Most of the items have very few missing values throughout all waves. The self-reported health measure is not included in wave 3. For the items on depression and on cognitive function, the share of missing observations is increasing over time, with around 6% missing values in waves 7, 8, and 9.

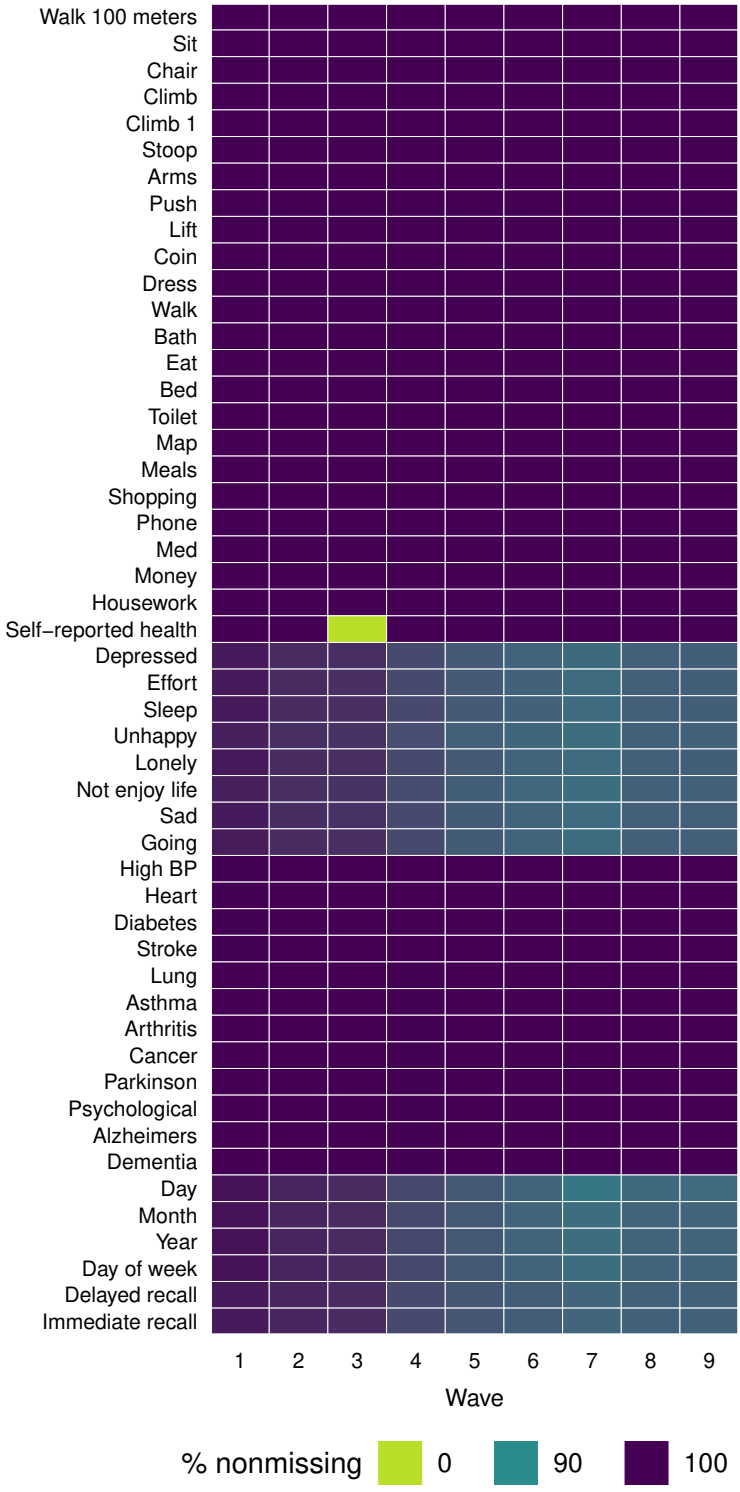


Figure A.2: Data availability of items in the frailty index.

B Appendix B: Robustness and additional analysis

B.1 Full regression results for determinants and speed of ageing

Table B.1 shows the full regression results from estimating equations 1 and 2. The corresponding results are visualized in the main text in Figure 1a and 1b.

Table B.1: Determinants of frailty and speed of ageing

	All		Gender		Education			Wealth		
	OLS	FE	Females	Males	Low	Middle	High	Low	Middle	High
Age	0.028***	0.039***	0.036***	0.043***	0.042***	0.038***	0.033***	0.039***	0.040***	0.040***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Female	0.159***									
	(0.013)									
Upper Secondary /	−0.201***									
Vocational Training	(0.016)									
Tertiary education	−0.358***									
	(0.021)									
Log HH wealth	−0.070***	−0.018***	−0.018***	−0.018***	−0.019***	−0.017***	−0.013**	−0.012***	−0.002	−0.054***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.006)	(0.002)	(0.027)	(0.017)
East Midlands	0.121***	0.088	−0.000	0.181*	0.102	0.210*	0.025	0.327	−0.045	0.011
	(0.027)	(0.077)	(0.104)	(0.109)	(0.210)	(0.111)	(0.140)	(0.202)	(0.151)	(0.100)
East of England	0.020	−0.006	0.002	−0.029	0.039	0.110	−0.230	0.142	−0.062	−0.003
	(0.024)	(0.061)	(0.084)	(0.087)	(0.103)	(0.100)	(0.161)	(0.168)	(0.118)	(0.101)
London	0.036	0.049	0.090	−0.005	0.136	0.106	−0.034	0.204	0.096	0.044
	(0.029)	(0.053)	(0.066)	(0.086)	(0.101)	(0.086)	(0.096)	(0.138)	(0.098)	(0.072)
North East	0.168***	0.277*	0.001	0.615***	0.517*	0.364	0.010	0.312	0.215	−0.125
	(0.030)	(0.143)	(0.141)	(0.208)	(0.280)	(0.257)	(0.165)	(0.419)	(0.133)	(0.134)
North West	0.099***	−0.071	−0.044	−0.091	0.077	0.138	−0.336**	0.263	−0.239	−0.034
	(0.024)	(0.091)	(0.107)	(0.147)	(0.189)	(0.162)	(0.132)	(0.269)	(0.205)	(0.132)
South West	0.041*	0.025	0.027	0.015	−0.025	0.084	0.024	0.004	0.016	0.039
	(0.025)	(0.048)	(0.068)	(0.068)	(0.081)	(0.079)	(0.087)	(0.163)	(0.086)	(0.068)
West Midlands	0.068***	0.030	0.043	0.005	0.014	0.131	−0.088	−0.060	−0.124	0.124
	(0.026)	(0.075)	(0.092)	(0.122)	(0.128)	(0.108)	(0.145)	(0.205)	(0.161)	(0.098)
Yorkshire & Humber	0.083***	0.142	0.082	0.197	0.202	0.139	0.255	0.413*	−0.011	0.096
	(0.025)	(0.091)	(0.114)	(0.137)	(0.214)	(0.140)	(0.160)	(0.221)	(0.163)	(0.125)
Observations	65,694	71,872	40,021	31,851	23,530	31,953	10,211	24,824	24,007	23,041
R-squared	0.216	0.118	0.109	0.130	0.141	0.111	0.089	0.118	0.108	0.106
Method	OLS	FE	FE	FE	FE	FE	FE	FE	FE	FE

Notes: Column (1) reports pooled OLS estimates. Other columns report fixed-effects estimates. Robust standard errors clustered at respondent level in parentheses. Significance levels: *10%, **5%, ***1%.
Age is demeaned at individual level. Education levels are: below upper secondary, upper secondary/vocational training, and tertiary education, with the first being the reference level in column (1). Reference region is South East. Wealth is split in tertiles relative to five-year age group in the first occurrence in the survey.

B.2 Comparing with literature

To provide further evidence for our finding that in England later cohorts are ageing better than earlier cohorts in contrast to Marshall et al. (2015) we replicate across three different waves some of the raw summary statistics that they present. Table B.2 repeats the message from Table 2 that for each age band, there have been improvements in mean frailty across waves. Table B.3 repeats, for our data, Table 1 in Marshall et al. (2015). Reading down the columns shows how frailty increases with age so that those who were 50-54 in wave 1 with mean frailty of 0.091 have mean frailty of 0.101 in wave 5, by which point they are aged 60-64. However, whilst this group have seen their frailty rise with age their mean frailty is below that of 60-64-year-olds in wave 1. Similar comparisons for other ages show the same cohort improvement.

Table B.2: Mean frailty index values by age group, waves 1-9

Wave	50-54	55-59	60-64	65-69	70-74	75-79	80+
1	0.091	0.106	0.118	0.126	0.149	0.171	0.223
5	0.094	0.097	0.108	0.122	0.142	0.170	0.241
9	0.083	0.096	0.115	0.110	0.131	0.160	0.216

Table B.3: Mean frailty index values by 2002 cohort group, as in Marshall, waves 1-9

Wave	50-54	55-59	60-64	65-69	70-74	75-79	80+
1	0.091	0.106	0.118	0.126	0.149	0.171	0.223
5	0.101	0.117	0.136	0.152	0.199	0.248	0.297
9	0.117	0.136	0.163	0.201	0.265		

B.3 Robustness

In order to test the robustness of our results, we performed the analysis: 1) using only individuals who survived throughout the sample, 2) restricting the analysis to individuals with at least 35 or 3) at least 40 non-missing items when constructing the frailty index, 3) restricting the analysis to observations between 50 and 80 years of age, or 5) between 55 and 90 years of age, 6) calculating the frailty index only using items with at least 99% coverage throughout the sample, 7) restricting the analysis to individuals which never had any missing value on the frailty index from the first to the last time they were surveyed, 8) excluding individuals with fewer than non-missing frailty index observations, and 9) using, for every individual, the largest set of non-missing items available throughout their inclusion in ELSA to calculate their individual frailty index. This removes any potential bias from the inclusion of new items on the frailty index over time, and thus only looks at changes in the frailty index coming from changes in the items available in all survey waves for a given individual.

The results are presented in Table B.4. The coefficients for age and year of birth are very similar across these robustness checks. This shows that neither longitudinal attrition and death nor missing items in the frailty items, nor age inclusion criteria substantively change our main result.

Table B.4: Robustness check: Varying sample inclusion criteria

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Age	0.038***	0.038***	0.036***	0.032***	0.041***	0.045***	0.039***	0.038***	0.038***
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
Year of birth	−0.014***	−0.019***	−0.018***	−0.019***	−0.021***	−0.018***	−0.012***	−0.030***	−0.019***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.007)	(0.002)
Mean Age	0.012***	0.008***	0.007***	0.005**	0.006**	0.006***	0.014***	−0.009	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.008)	(0.002)
Observations	63,971	65,693	63,167	58,317	59,802	59,079	52,149	48,101	65,122
Sample	Survived	35 items	40 items	Below 80	Above 55	>99% items	Complete indiv.	>=5 records	Common items
What is the new 70?	74.4	75.3	75.4	75.9	75.4	74.5	73.8	77.0	75.4

Notes: All columns show results from Mundlak regressions. Robust standard errors clustered at year of birth level in parentheses. Age is demeaned at individual level. Significance levels: *10%, **5%, ***1%. Included controls: Sex, education, log wealth (+ mean), NUTS-1 region dummies (+ mean).
The last row displays the predicted age in 2018 in which frailty equals the frailty level of a 70-year-old in 2002.

B.4 Fully flexible estimation: year of birth fixed effects

Figure B.1 implements a Mundlak specification where one dummy variable for each year of birth cohort is added instead of a continuous year-of-birth variable. The estimated coefficients are fitted with a quadratic fit, weighted by the number of observations in each year-of-birth cohort. The figure confirms the quadratic trend observed in the data: the level of frailty is declining with more recent cohorts, and this is slowing down at a moderate rate.

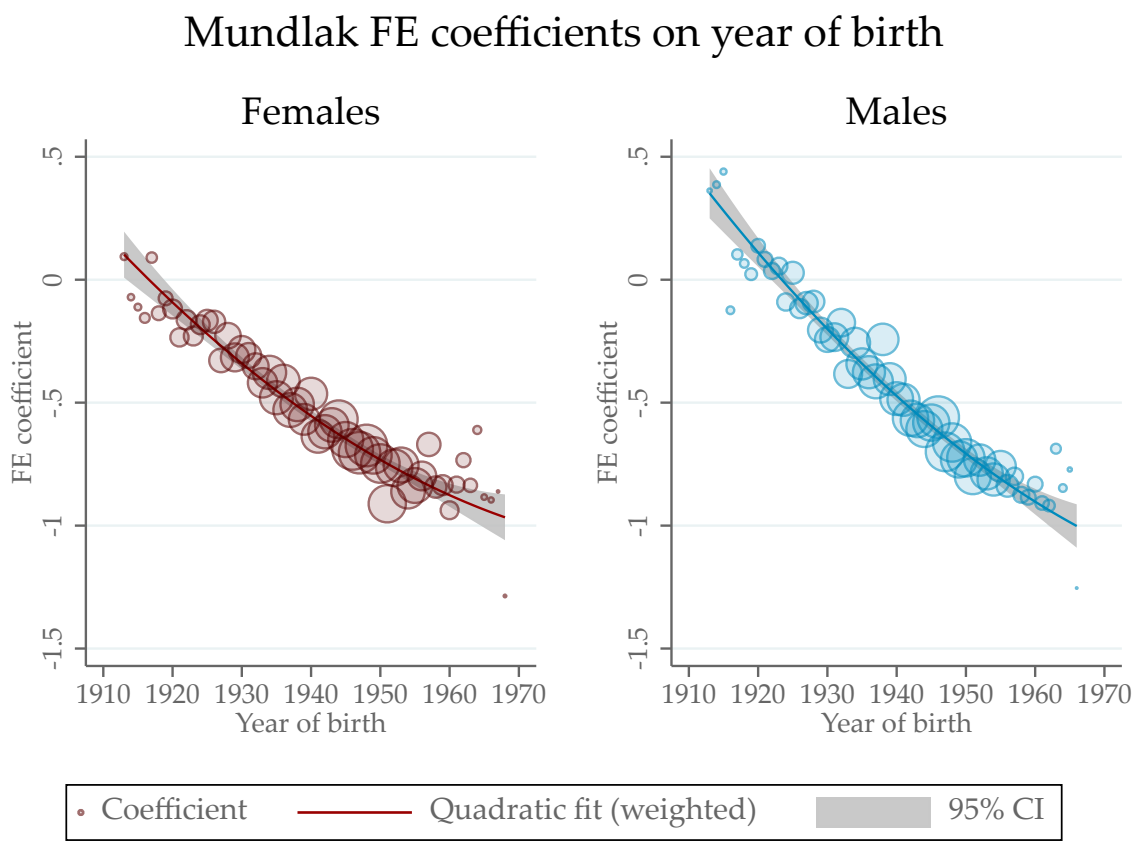


Figure B.1: Coefficients on year of birth fixed effects from Mundlak regression with full set of controls, with quadratic fit (weighted by number of observations). The area of the markers is proportional to the number of observations

B.5 Additional results

Table B.5 estimates specifications on the five sub-components of the frailty index. Compared to the main text (Table 5), the log of the sub-components +1 is used as dependent variable. In this way, observations with zero frailty in any of the sub-components are not dropped, leading to a larger sample size. Direction and statistical significance of the coefficients are unchanged.

Table B.6 estimates Mundlak specifications by sex, education, and baseline wealth tertile. In addition to the main text (Table 6), quadratic terms are included. The results poiint to a general slowdown in the rate of frailty improvement, but high SES groups (high education, high initial wealth) see a larger slowdown in the rate of frailty improvement than groups with low education or initial wealth.

Table B.5: Cohort trends by sub-components of frailty index – ln(x+1)

	(1) Full Index	(2) Mobility (10)	(3) ADL/IADL (13)	(4) Depression (8)	(5) Conditions (12)	(6) Cognitive (6)
Age	0.004***	0.005***	0.003***	0.001	0.006***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Year of birth	−0.002***	−0.003***	−0.002***	−0.001***	0.000	−0.004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mean Age	0.001***	0.002***	0.000	−0.001	0.002***	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	71,289	71,285	71,286	68,551	71,288	68,794
Mean of DV	0.132	0.192	0.061	0.179	0.128	0.101

Notes: All columns show Mundlak regressions. Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%. Age is demeaned at individual level. Controls: Sex, NUTS1 region dummies (+ mean), education, log wealth (+ mean). Number of items in each sub-component listed in parentheses in the column headers.

Table B.6: Longevity trends: Heterogeneous effects with quadratic year of birth

	Sex		Education			Wealth		
	(1) Males	(2) Females	(3) Low	(4) Middle	(5) High	(6) Low	(7) Middle	(8) High
Age	0.041***	0.036***	0.042***	0.038***	0.033***	0.036***	0.040***	0.038***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Year of birth	−0.625**	−0.609***	−0.482*	−1.071***	−1.600***	−0.111	−0.509*	−1.176***
	(0.272)	(0.183)	(0.273)	(0.225)	(0.356)	(0.294)	(0.265)	(0.287)
(Year of Birth^2)/1000	0.155**	0.153***	0.120*	0.270***	0.408***	0.026	0.126*	0.296***
	(0.070)	(0.047)	(0.070)	(0.058)	(0.091)	(0.076)	(0.068)	(0.074)
Mean Age	0.003	0.011***	0.009**	0.003	0.017***	0.010*	0.008**	0.005
	(0.003)	(0.002)	(0.004)	(0.003)	(0.005)	(0.005)	(0.003)	(0.004)
Observations	30,046	35,648	23,530	31,953	10,211	20,934	21,754	23,006
Method	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak	Mundlak
What is the new 70 in 2018?	75.8	75.1	74.5	76.6	75.9	73.6	75.7	76.8
What is the new 70 in 2034?	75.0	74.0	73.6	75.1	72.0	73.4	74.9	75.1
p-value Interaction term	0.082		<0.001			<0.001		

Notes: Robust standard errors clustered at year of birth level in parentheses. Significance levels: *10%, **5%, ***1%.
Education levels are: Low: below upper secondary, Middle: upper secondary/vocational training, High: tertiary education. Wealth is split in tertiles relative to five-year age group in the first occurrence in the survey. Age is demeaned at individual level. Controls: Sex, NUTS1 region dummies (+ mean), education, log wealth (+ mean). In the specifications for sex and education, the respective variable is not included as a control.
The p-value is from a Wald-test on the interaction term of year of birth squared and the heterogeneity variable.