Average Remaining Lifetimes Can Increase as Human Populations Age

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LETTERS

Average remaining lifetimes can increase as human populations age

Warren C. Sanderson[1,2] & Sergei Scherbov[2,3]

Increases in median ages, the most commonly used measure of population ageing[1,2], are rapid in today's wealthier countries[2,3], and population ageing is widely considered to be a significant challenge to the well-being of citizens there[4]. Conventional measures of age count years since birth; however, as lives lengthen, we need to think of age also in terms of years left until death or in proportion to the expanding lifespan. Here we propose a new measure of ageing: the median age of the population standardized for expected remaining years of life. We show, using historical data and forecasts for Germany, Japan and the United States, that although these populations will be growing older, as measured by their median ages, they will probably experience periods in which they grow younger, as measured by their standardized median ages. Furthermore, we provide forecasts for these countries of the old-age dependency ratio rescaled for increases in life expectancy at birth[5]. These ratios are forecasted to change much less than their unscaled counterparts, and also exhibit periods when the population is effectively growing younger.

Population ageing differs from the ageing of an individual. People who survive grow older with each year they live. Populations, on the other hand, can grow younger. Because a wide variety of matters such as the cost of medical care[6–8], retirement[9], bequests[10], consumption[11] and the accumulation of human[12] and tangible[13,14] capital depend not only on age but also on time left to live, our understanding of population ageing must also reflect both of these factors. Because conventionally measured old-age dependency ratios (the ratio of the number of people at the retirement age and above divided by the number of people in the working ages) have caused worry about the sustainability of pensions[15], it is important to recognize that these ratios, rescaled for life expectancy increases, are forecasted to change comparatively little over the century, suggesting caution in our assessment of long-term pension problems.

Figure 1a–c and Supplementary Table 1 provide information about the unstandardized median age of the population, the standardized median age of the population, using the country's (Germany, Japan, United States) life table in 2000 for standardization, and the remaining life expectancy at the unstandardized median age. All figures pertain to both sexes combined and are calculated using period life tables. There are two types of data: the values through to 2000 are observed, whereas those for future years are based on 1,000 stochastic forecasts.

The median age is the age that divides a population into two numerically equal groups, with half of the people being younger than this age and half older. Life expectancy at the median age is the expected number of years to be lived by a person at the median age. It is also the median remaining life expectancy in the population, with half of the people being at ages with lower remaining life expectancies and half at ages with higher ones. Life expectancy at the median age is especially easy to use as an indicator of ageing because it is comparable both across countries and over time.

Medical care expenditures provide an example where calculating the median remaining life expectancy in a population is useful. Health care costs rise rapidly in the last years of a person's life. The change in the median remaining life expectancy between years is equal to the change in the median time to the onset of that phase of rapidly rising costs.

For many of the decades both the median age and the life expectancy at the median age increase. For the three countries, mortality rates at young ages are now quite low and most of the rise in life expectancies at birth derives from life expectancy increases at the older ages. If the median age of the population remained fixed, remaining life expectancy at the median age would surely increase. However, the essence of population ageing is the increase in median ages. If median ages increase slowly, remaining life expectancies at the median age will increase. On the other hand, median ages can increase so rapidly relative to improvements in mortality rates that remaining life expectancies fall.

An example of a rapid increase in median age outrunning survival rate increases can be seen for Japan between 2000 and 2040 (Fig. 1b). Here, the median age is expected to rise from 41.3 yr to 55.0 yr while the life expectancy at the median age falls from 41.1 yr to 35.0 yr. In the remaining 60 yr of the century, Japan provides an example of where slower increases in the median age are associated with gains in life expectancy at the median age. One broad conclusion from Fig. 1a–c for all three countries is that even in the presence of significant ageing, as measured by increases in the median age, life expectancies at the median age are likely to change only moderately.

Median ages in a country change because of prior changes in fertility, mortality and migration rates. In Japan, the median age is rising rapidly because of a combination of relatively low fertility, high life expectancy and little migration. The United States stands at the opposite end of the spectrum. Its slow increase in median age is a result of relatively high fertility, somewhat lower life expectancy and substantial migration. Germany has demographic rates between those of Japan and the United States.

One disadvantage of using life expectancy at the median age as a measure of ageing is that it is not directly comparable to the median age itself. For comparability it is useful to have another median age, one based on the expected number of years a person has left to live. This is the standardized median age.

The life expectancy standardized population is the hypothetical population that arises when the age of each individual in a specific year is changed to the age of the person in 2000 who had the same remaining life expectancy. For example, if a 40-yr-old person in 2050 had a remaining life expectancy of 50 yr, and a 30 yr old had the same remaining life expectancy (50 yr) in 2000, then the 40-yr-old person would be assigned an age of 30 in the life expectancy standardized population. By definition, when the standardization is done using the country's own life table, the median age and the standardized median age of the population are the same in 2000.

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Median ages in the three countries generally increase over time; however, standardized median ages show a different pattern of change. In the United States, the standardized median values of the forecasted distributions fall continuously from 2000 onwards, whereas in Germany and Japan, they first increase at the beginning of the century and then decrease. A decreasing standardized median age is far from a certainty in the United States. The 95% prediction intervals for all years from 2010 to 2100 include the value of the standardized median age in 2000 (see Supplementary Table 1). We also show in Supplementary Table 1 that an increase in the standardized median age in first decades of the century seems almost certain in Germany and Japan.

Although we are confident that ageing will occur throughout the century in all three countries as measured by the unstandardized median age, we are also sure that much less ageing or even some increase in youthfulness will be observed using the concept of the standardized median age. When considered from different perspectives, populations in some periods will be growing simultaneously younger and older.

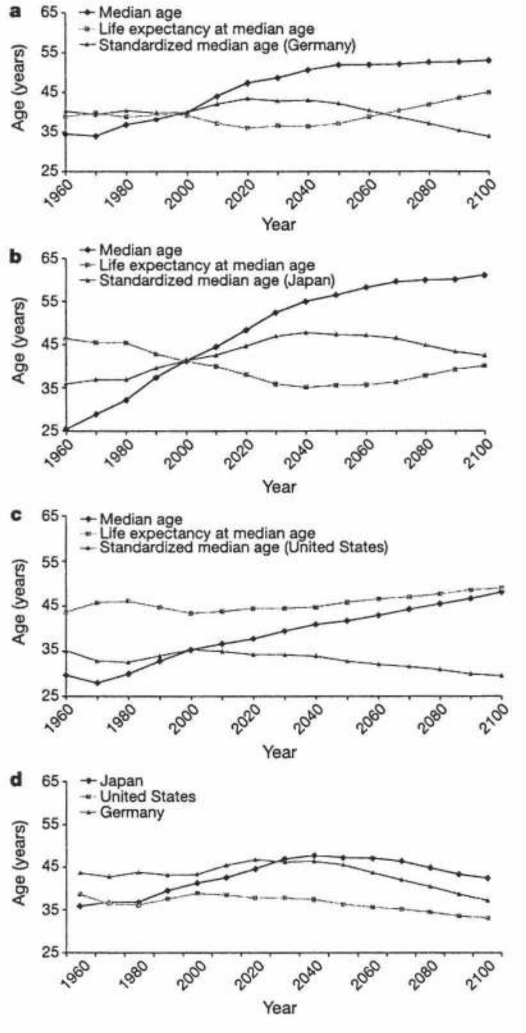

Figure 1 | Unstandardized and standardized median ages, and life expectancies at unstandardized median ages. **a**, Germany; **b**, Japan; **c**, United States. **a–c**, Standardized median ages based on country-specific life tables for 2000. **d**, Standardized median ages based on Japanese life table for 2000. The values through to 2000 are observed; later values are medians based on 1,000 simulations (for 95% prediction intervals see Supplementary Table 1). All values are based on period life tables.

In Fig. 1d, we plot the median ages for the three countries standardized using the 2000 Japanese life table. When the standardization is done with a single country's life table, standardized median ages are comparable across countries. We use Japan as the standard because it had the highest life expectancy among all the countries of the world in 2000. At the beginning of this century, the differences in standardized median ages across the countries were relatively small. The difference between the highest standardized median age (43.2 in Germany) and the lowest (38.8 in the USA) was 4.4 yr. At mid-century the gap in the median forecasts widens significantly to 10.9 yr, with Japan having the highest value and the USA continuing to have the lowest. In 2050, Japan's population will be considerably older than that of the USA both in terms of the unstandardized and standardized median ages.

Figure 2a–c provides a second perspective on ageing using the concept of proportional life cycle rescaling[5]. Proportional life cycle rescaling is a heuristic not a predictive concept. It provides one simple way of thinking about a complex future in which the lengths of life cycle phases will be influenced by social policies and demographic constraints not modelled here. We use proportional life cycle

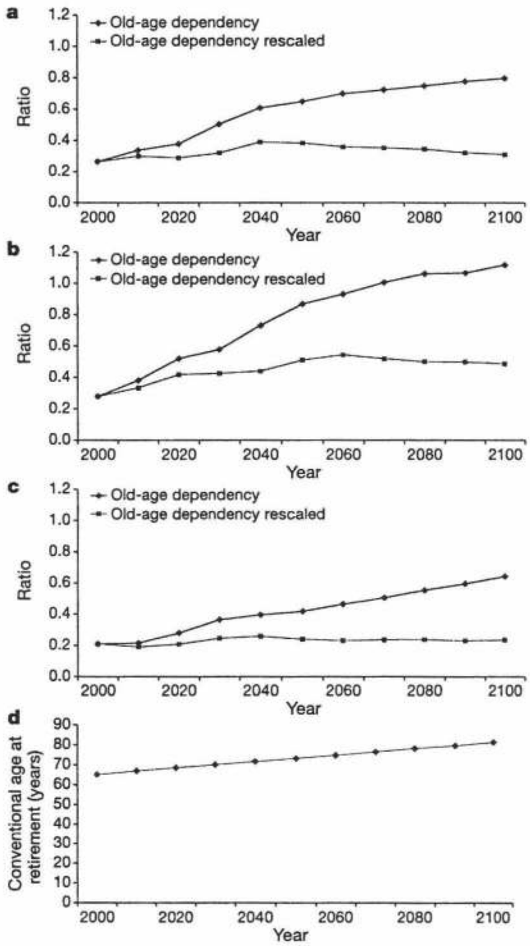

Figure 2 | Conventional and rescaled old-age dependency ratios. **a**, Germany; **b**, Japan; **c**, United States. The old-age dependency ratio is the ratio of the number of people at the retirement age and above divided by the number of people in the working ages. Rescaling increases ages at the beginning and end of working interval proportionally to changes in life expectancy at birth. **d**, Proportionally adjusted retirement ages in Japan. The values for 2000 are observed; later values are medians based on 1,000 simulations (for 95% prediction intervals see Supplementary Table 2). All figures are based on period life tables.

rescaling by adjusting the conventional start of the working age phase (assumed to be age 20 in the year 2000) and the conventional end of that phase (assumed to be age 65 in 2000) proportionally to changes in life expectancy from 2000 onward. Figure 2a–c contains conventional measures of the old-age dependency ratio and new versions of these measures calculated assuming proportional life cycle rescaling.

For all three countries the conventional old-age dependency ratio increases markedly over the century. In Germany, it rises from 0.261 in 2000 to a median forecasted value of 0.797 in 2100. In Japan, the increase is larger, going from 0.276 in 2000 to 1.118 in 2100. In the United States, the increase is smaller than in Germany, but the conventional measure still triples over the century.

The rescaled values show a different pattern. The rescaled old-age dependency ratios rise initially in all three countries and then fall. The rise is quite likely, with the 95% prediction interval in 2040 lying entirely above the ratio in 2000 for all three countries (see Supplementary Table 2). After the middle of the century, changes in the ratio are unclear because the magnitudes of the declines are small relative to the uncertainty involved. For all three countries, the rescaled old-age dependency ratios show considerably less change than the conventional ones.

The new measures presented here are not meant to supplant existing measures, but to supplement them. A perspective that incorporates the new measures presented here is crucial if we are to understand and react appropriately to the challenges of population ageing.

METHODS

The probabilistic forecasts make use of our previously published methodology[16,17] specialized to the individual countries. In our previous work, we used a mean total fertility rate (TFR) of 2.0 for North America in 2082. Here we use a mean TFR of 1.85 for the United States in that year. This is slightly lower than the one assumed by the United Nations. A lower TFR increases the standardized median age of the population because it results in a smaller number of young people. In our earlier work, we assumed a mean TFR of 1.6 in the region comprised of Japan, Australia and New Zealand in 2082, which is dominated by the population of Japan. We used the same TFR for Japan at that date. We also assumed a mean TFR of 1.7 for Western Europe in 2082. Here we assume a mean TFR of 1.6 for Germany in 2082, because its fertility has been below the average for Western Europe for the last three decades. We assume that distributions around the means are normal with a 90% chance of observing an outcome within half a child of the mean.

Our mortality assumptions are also very similar to those made for the corresponding regions in our earlier work. Life expectancy increases were assumed to have a mean value of 2 yr per decade with a 90% chance of an outcome within 1 yr of the mean. This is consistent with observations over the past four decades[18] and other recently published work[19]. Our migration assumptions were made using the same procedure as in our earlier work, except that they were based on observations for the specific countries.

Figure 2d shows the evolution of the rescaled conventional age at retirement in Japan. The paths for Germany and the USA are almost identical. By construction, this age is 65 in 2000. Using our life expectancy forecasts and the proportionality hypothesis, the median forecasted conventional age rises to 73 by 2050 and continues to climb for the remainder of the century. These rescaled conventional ages are used in the production of Fig. 2.

Forecasted data in Figs 1 and 2 are the median values of the forecast distributions based on 1,000 simulations. The median values and their 95% prediction intervals are presented in Supplementary Tables 1 and 2. In each year, we compute the median age of the population. These median ages depend on the age distribution of the population at the beginning of the forecast period and on the whole time paths of fertility, mortality and migration rates from the beginning of the forecast period to the year in question.

We calculate the distribution of remaining life expectancy at the median age in year t, for example, using the stochastic life table associated with that year. Thus, life expectancies at the median age in year t have uncertainty due to variability in median ages in year t and due to the randomness in the life tables for that particular year. The life table used in period t is closely associated with the time path of life tables before year t and therefore with the age structure and the median age of the population in that year. Standardized median ages are also subject to both sorts of uncertainty.

The uncertainty in the distributions of remaining life expectancy and the distributions of standardized ages are influenced by the correlations between the median age at time t and life expectancy at time t. The autocorrelation of life expectancies implies that a high life expectancy at time t is associated, on average, with a high median age in that year. High life expectancies and high median ages have opposing effects on the remaining life expectancy at the median age, reducing the uncertainty relative to what it would have been in the absence of those correlations.

The differences in sources of uncertainty can be seen in Supplementary Table 1 by comparing the size of the 95% prediction intervals for unstandardized and standardized median ages. For Germany in 2020, for example, the difference between the upper and lower bounds of the 95% prediction interval for the unstandardized median age is 1.8 yr. The comparable difference for the standardized median age (using either the German or Japanese standards) is 3.8 yr.

The observed median ages and the life expectancies at the median age move less regularly than the forecasted medians. The observed figures take baby booms and busts into account differently. The observed figures are from a single random path of realizations for each country. The forecasted medians essentially average across possible future paths and are therefore much smoother.

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Year	Median Age Unstandardized	Life Expectancy at Median Age	Median Age Standardized (Germany, 2000)	Median Age Standardized (Japan, 2000)
1960	34.5	38.9	40.3	43.6
1970	34.0	39.7	39.4	42.7
1980	36.8	38.7	40.4	43.7
1990	38.2	39.3	39.8	43.1
2000	39.9	39.2	39.9	43.2
2010	44.1 (43.9-44.2)	37.2 (36.3-38.0)	42.1 (41.1-43.0)	45.4 (44.5-46.3)
2020	47.4 (46.4-48.2)	35.9 (34.1-37.6)	43.4 (41.6-45.4)	46.7 (44.9-48.7)
2030	48.6 (46.9-50.4)	36.5 (33.7-39.2)	42.8 (39.9-45.8)	46.1 (43.2-49.1)
2040	50.6 (48.0-53.4)	36.3 (32.6-40.1)	43.0 (39.0-47.0)	46.3 (42.3-50.3)
2050	51.9 (47.9-56.6)	37.1 (32.3-41.9)	42.2 (37.0-47.4)	45.5 (40.3-50.7)
2060	51.9 (47.0-57.9)	38.8 (32.4-45.0)	40.3 (33.8-47.3)	43.7 (37.1-50.6)
2070	52.1 (46.6-58.9)	40.4 (33.2-48.0)	38.7 (30.7-46.4)	42.0 (34.0-49.7)
2080	52.6 (46.0-60.6)	41.9 (33.7-50.2)	37.1 (28.5-45.8)	40.4 (31.8-49.1)
2090	52.6 (45.4-62.1)	43.5 (34.4-53.5)	35.3 (25.1-45.0)	38.7 (28.4-48.3)
2100	53.0 (45.5-63.4)	45.0 (35.1-55.7)	33.8 (22.7-44.3)	37.1 (26.1-47.6)

Supplementary Table 1A: Unstandardized median age, life expectancy at the median age (median expected remaining years of life), standardized median age (German standard), and standardized median age (Japanese standard), Germany, 1960 to 2100.

Note: The figures through 2000 are observed. The figures from 2010 to 2100 are medians (and in parentheses 95 percent prediction intervals) based on 1,000 simulations. All figures are based on period life tables.

Year	Median Age Unstandardized	Life Expectancy at Median Age	Median Age Standardized (Japan, 2000)
1960	25.3	46.3	35.8
1970	28.8	45.3	36.8
1980	32.1	45.3	36.8
1990	37.4	42.8	39.5
2000	41.3	41.1	41.3
2010	44.4 (44.3-44.5)	39.9 (39.1-40.7)	42.5 (41.6-43.3)
2020	48.3 (47.8-48.8)	38.0 (36.2-39.6)	44.6 (42.8-46.4)
2030	52.4 (51.2-53.5)	35.8 (33.5-38.2)	46.8 (44.3-49.4)
2040	55.0 (52.6-57.3)	35.0 (32.0-38.3)	47.7 (44.2-51.0)
2050	56.4 (52.9-60.1)	35.5 (31.5-39.4)	47.2 (43.0-51.6)
2060	58.2 (53.6-62.5)	35.6 (30.5-41.2)	47.1 (41.1-52.7)
2070	59.5 (52.7-65.5)	36.3 (29.7-42.9)	46.3 (39.4-53.5)
2080	59.9 (51.7-67.9)	37.7 (30.4-45.8)	44.8 (36.3-52.8)
2090	60.1 (52.0-69.5)	39.2 (30.7-47.9)	43.3 (34.1-52.5)
2100	61.1 (51.5-71.2)	40.0 (31.1-50.5)	42.4 (31.4-52.1)

Supplementary Table 1B: Unstandardized median age, life expectancy at the median age (median expected remaining years of life), and standardized median age (Japanese standard), Japan, 1960 to 2100.

See note to Supplementary Table 1A.

Year	Median Age Unstandardized	Life Expectancy at Median Age	Median Age Standardized (USA, 2000)	Median Age Standardized (Japan, 2000)
1960	29.6	43.6	35.1	38.6
1970	27.9	45.7	32.8	36.4
1980	29.9	46.0	32.5	36.1
1990	32.7	44.7	33.9	37.5
2000	35.3	43.5	35.3	38.7
2010	36.6 (36.3-36.8)	43.8 (42.9-44.6)	34.9 (34.0-35.7)	38.4 (37.6-39.3)
2020	37.7 (36.9-38.5)	44.4 (42.6-46.3)	34.2 (32.2-36.2)	37.7 (35.8-39.7)
2030	39.4 (37.9-41.0)	44.5 (41.6-47.3)	34.1 (31.2-37.2)	37.7 (34.8-40.7)
2040	40.9 (38.3-43.8)	44.8 (41.1-48.9)	33.8 (29.4-37.7)	37.4 (33.1-41.2)
2050	41.7 (38.4-45.8)	45.8 (40.6-51.0)	32.7 (27.3-38.3)	36.3 (30.9-41.8)
2060	42.9 (38.6-47.7)	46.5 (40.0-53.2)	32.0 (25.0-38.9)	35.6 (28.7-42.4)
2070	44.2 (39.1-49.8)	47.0 (39.5-54.8)	31.5 (23.3-39.4)	35.1 (27.0-42.9)
2080	45.4 (39.6-52.4)	47.6 (39.3-56.4)	30.8 (21.6-39.7)	34.4 (25.4-43.2)
2090	46.6 (40.5-54.5)	48.5 (39.5-58.2)	29.9 (19.7-39.5)	33.5 (23.6-43.0)
2100	48.0 (41.3-56.6)	48.9 (39.0-60.0)	29.5 (17.8-40.0)	33.1 (21.7-43.5)

Supplementary Table 1C: Unstandardized median age, life expectancy at the median age (median expected remaining years of life), standardized median age (US standard), and standardized median age (Japanese standard), USA, 1960 to 2100.

Note: See note to Supplementary Table 1A.

Year	Old Age Dependency Ratio	Old Age Dependency Ratio (Rescaled)
2000	0.261	0.261
2010	0.335 (0.331-0.339)	0.297 (0.283-0.312)
2020	0.376 (0.357-0.395)	0.287 (0.259-0.320)
2030	0.504 (0.459-0.550)	0.318 (0.265-0.387)
2040	0.607 (0.524-0.699)	0.389 (0.304-0.484)
2050	0.648 (0.532-0.800)	0.382 (0.310-0.484)
2060	0.698 (0.548-0.909)	0.358 (0.266-0.488)
2070	0.722 (0.550-0.979)	0.351 (0.244-0.488)
2080	0.749 (0.543-1.057)	0.343 (0.236-0.490)
2090	0.777 (0.544-1.148)	0.320 (0.215-0.480)
2100	0.797 (0.553-1.209)	0.309 (0.185-0.479)

Supplementary Table 2A: Conventional and rescaled old age dependency ratios, Germany, 2000–2100.

Note: The figures for 2000 are observed. The figures from 2010 to 2100 are medians (and 95 percent prediction intervals in parentheses) based on 1,000 simulations. All figures are based on period life tables.

Year	Old Age Dependency Ratio	Old Age Dependency Ratio (Rescaled)
2000	0.276	0.276
2010	0.380 (0.377-0.383)	0.333 (0.314-0.352)
2020	0.518 (0.500-0.537)	0.417 (0.374-0.458)
2030	0.577 (0.535-0.619)	0.425 (0.384-0.475)
2040	0.730 (0.654-0.809)	0.438 (0.366-0.531)
2050	0.867 (0.747-1.010)	0.510 (0.397-0.638)
2060	0.929 (0.762-1.140)	0.543 (0.426-0.668)
2070	1.005 (0.773-1.326)	0.518 (0.395-0.657)
2080	1.062 (0.766-1.459)	0.499 (0.361-0.677)
2090	1.066 (0.741-1.557)	0.497 (0.350-0.695)
2100	1.118 (0.755-1.660)	0.487 (0.328-0.695)

Supplementary Table 2B: Conventional and rescaled old age dependency ratios, Japan, 2000–2100.
Note: See note to Supplementary Table 2A.

Year	Old Age Dependency Ratio	Old Age Dependency Ratio (Rescaled)
2000	0.209	0.209
2010	0.213 (0.211-0.215)	0.189 (0.177-0.200)
2020	0.276 (0.266-0.287)	0.206 (0.179-0.238)
2030	0.362 (0.335-0.391)	0.245 (0.198-0.297)
2040	0.394 (0.347-0.449)	0.257 (0.211-0.315)
2050	0.416 (0.352-0.501)	0.238 (0.187-0.311)
2060	0.462 (0.379-0.582)	0.230 (0.162-0.320)
2070	0.504 (0.400-0.651)	0.235 (0.155-0.333)
2080	0.553 (0.412-0.742)	0.237 (0.156-0.350)
2090	0.594 (0.432-0.855)	0.229 (0.148-0.356)
2100	0.641 (0.455-0.933)	0.234 (0.135-0.370)

Table 2C: Supplementary conventional and rescaled old age dependency ratios, USA, 2000–2100.
Note: See note to Supplementary Table 2A.