Will half of the 2000 birth cohort reach 100? Yes, but probably only in the world's most longevous regions

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Introduction

Estimating maximum human longevity from a population perspective is not new (Christensen et al., 2009; Spijker, 2004). One could speak of two divergent views within the scientific community (Siegel, 2005): those who believe that life expectancy has reached a limit (e.g. Olshansky et al., 1990; 2005) and those who don't (e.g. Oeppen & Vaupel, 2002; Vaupel, 2010; Wilmoth, 1997). Leon (2011) points out in an editorial the centrality of political, socioeconomic and behavioural determinants of health in this debate as they have caused both increases and decreases in life expectancy in and within European countries. Oeppen and Vaupel (2002) argue that experts have repeatedly been proven wrong in the assertion that life expectancy is approaching a ceiling. Moreover, if life expectancy were close to a maximum, then the increase in the record expectation of life should be slowing. This had not been the case between 1840 and 2000 as best-performance life expectancy steadily increased by a quarter of a year per year (*ibid.*). However, life expectancy increases have slowed down, particularly over the last decade, as compared to long historical periods (Ho & Hendi, 2018; Kallestrup-Lamb et al., 2020; Leon et al., 2019). This current trend may therefore compromise the expectation that has reiteratively been made by some scholars that most children born this millennium (irrespective of sex) will celebrate their 100^{th} birthday (Christensen et al., 2009; Vaupel et al., 2021). If indeed life expectancy increases are decelerating in the best-practice low-mortality countries of the world, this could affect long-term mortality projections, with obvious implications for pensions, public health policy, etc.

Previous research has already shown that progress of the world's maximum life expectancies between 1840 and 2000 occurred in a segmented fashion, rather than in a straight line that Oeppen and Vaupel suggested in (2002). Reasons for this discrepancy include the use of questionable data (in particular Norwegian data from 1840 to 1860 due to incomplete death registration and data from New-Zealand non-Maori for the years 1875 to 1925, being a small and highly selective immigrant population in terms of health and economic status), the availability of more recent data and the shifting weight of age-specific survival rates (Shkolnikov et al., 2011; Vallin & Meslé, 2009). Regarding the latter, historical trends in both country-specific and maximum life expectancy result from a combination of trends in mortality at various ages that can be related to specific advances that first reduced infant and child mortality and subsequently adult and old-age mortality. However, as today there is very little scope for reductions at younger ages in low-mortality countries, increases mainly depend on reducing mortality at old and very old ages (Leon et al., 2019; Meslé, 2004). The shifting weight of age-specific survival rates is why Vallin and Meslé (2009) recommend analysing not only life expectancy changes at birth, but especially after age 60. In the above context, our study has three objectives:

First, we propose to break the Oeppen-Vaupel line into segments that correspond to the main historical phases of the health transition. This objective is motivated by the fact that Shkolnikov et al. (2011); Vallin and Meslé (2009) already showed that if the period of observation starts in 1870 and is updated trends to, respectively 2008 and 2005 life expectancy in the best-practice country did not increase by 0.25 years per year from 1960-2005/8 as it did between 1840 and 2000, but rather 0.23 years. Since then, however, increases in best-practice life expectancy have slowed even further as otherwise life expectancy at birth should have reached 90 in Japan by 2019. With the most recent data available, we aim to update these segmented trends.

Second, using different projection methods, we aim to estimate life expectancy at birth until the year 2100 as well as for birth cohorts up to the millennium cohort. Current life expectancy in the fore-runner Japan is 84.5 years, while it is much lower in other advanced countries such as Denmark (81.5) and the

US (79.2) (www.mortality.org). For life expectancy to increase by another 2 decades in most low-mortality countries implies extraordinary increases in old-age survival, given that mortality for younger ages is already very low. To do so, we take both a period and cohort approach. The latter is because the number of person years each cohort spends at older ages has been increasing faster than the total length of life. According to Shkolnikov et al. (2011) cohort life expectancy increased by 6 months per year between the latter part of the 19th century and 1930. Although this pace slowed down to 4 months per year for those born between 1930 and 1950, cohort improvements are still greater than period improvements. They estimated life expectancy of the best-practice cohort born in 1950 to be 83.8 years. Although, as with period life expectancy, future increases across younger cohorts will depend on future mortality reductions at older ages, we expect that cohorts born in the year 2000 compared to their 1950 counterparts will still have benefitted from lower infant mortality, even in the best-practice country (Switzerland), as it was still 26/1000 in 1950.

Third, we repeat the previous analyses for subnational regions. While we consider a life expectancy of 100 years still to be unattainable in most low-mortality countries, all countries observe regional variation in mortality, meaning that there may be "outliers" where becoming a centenarian is less of an exception. For instance, previous research has provided plausible evidence of so-called "blue zones", which are areas of extreme longevity, including Ogliastra (Sardinia, Italy), Ikaria (Greece), Nicoya Peninsula (Costa Rica) and Okinawa (Japan). These populations succeeded in maintaining a traditional lifestyle implying an intense physical activity that extends beyond the age of 80, a reduced level of stress and intensive family and community support for their oldest-old as well as the consumption of locally produced food. The question of course remains whether younger generations adhere to the same kind of lifestyle (Poulain et al., 2013).

Based on the above objectives we plan two to answer the following research questions:

1. Is it likely for 50% of the 2000 birth cohort to be alive at age 104 in Japan, 102 in Canada, France and Italy, 101 in the USA and age 100 in the UK as suggested by Christensen et al. (2009) if trends are extrapolated?
2. If not, could there be sub-national regions where this is may become the case?

Data

National population and mortality data according to sex, age and year of birth required to calculate period and cohort life expectancy come from the Human Mortality Database (HMD) (www.mortality.org) and Shkolnikov et al. (2011).

Regional-level life expectancy data has been obtained from the following websites:

https://ec.europa.eu/eurostat/databrowser/view/DEMO_R_MLIFEXP__custom_882818/default/table
https://stats2.digitalresources.jisc.ac.uk/#
https://www.mhlw.go.jp/toukei/list/list54-57.html
https://www.e-stat.go.jp/dbview?sid=0003109558

Once the best-practice sub-national regions over the last 3 decades have been identified, we will consult the respective national statistical offices to obtain the required sex, age and year of birth data to produce estimates of best-practice cohort life expectancy.

Method

In order to project period (until 2100) and cohort (until 2000) life expectancy at birth, the following methods will be applied and ensuing results compared:

First, based on past trends in life expectancy at birth, simple linear and logistic extrapolation.

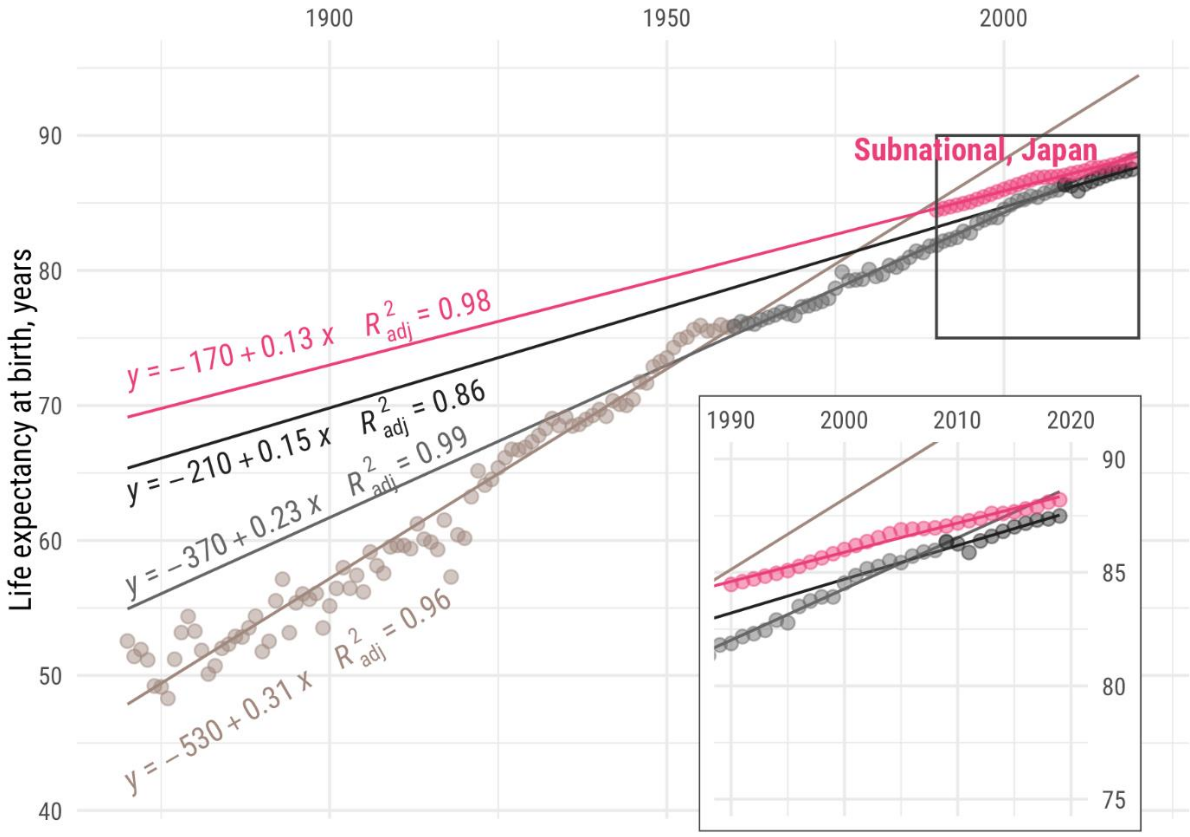
Second, we use a method called TOPALS. TOPALS is a "tool for projecting age-specific rates using linear splines" (De Beer, 2012).

The reason for using this method is the likelihood that future increases in life expectancy will be lower than in the past as the rate of decline in death rates at young ages are unlikely to continue as death probabilities have already reached very low levels (see Bongaarts (2006) and De Beer (2012) for further literature on this debate). According to this argument, only if declining age-specific probabilities at older ages accelerate, will it be possible for the linear improvement in life expectancy at birth to continue, albeit in segmented fashion. One reason is because the underlying non-linear declines in age-specific death probabilities have not been linear. De Beer (2012) therefore argues that time series of the underlying age-specific probabilities of death should be projected rather than projecting future life expectancy at birth based on the extrapolation of a time series of life expectancy. The most widely applied model for making projections of age-specific mortality rates is the Lee-Carter method (Booth et al., 2006; Lee & Carter, 1992). Long-term projections of the Lee-Carter model are lower than those of linear projections of the time series of life expectancy because the model projects an exponential decline in mortality rates. This implies that as mortality rates become low, the decline will slow down. However, one limitation of using the Lee-Carter model for making projections is that it assumes that the age pattern of changes in mortality rates in the future is the same as in the past. De Beer (2012) therefore proposes to use TOPALS, as this tool applies ratios of the age-specific probabilities of death of a given country and a standard age schedule by a linear spline, which is a piecewise linear curve.

Tentative results

Figure 1 shows the rate of improvement of best-practice life expectancy over time: Between 1870 and 1960, life expectancy increased by 0.31 years annually, between 1960 and 2009 by 0.23 years and between 2009 and 2019 by 0.15 years. If we would linearly project the 0.15 years of improvement in female life expectancy at birth that was observed in the best-practice country between 2009 and 2019, in the year 2100 life expectancy would be equal to 99.4 years.

Figure 1. Best period life expectancy, 1870 to 2019, females



Source: See section on Data. Note: Slopes pertain, from the bottom to the top, to the following periods: 1870-1960, 1960-2009, 2009-2019, 1990-2019 (subnational, Japan).

Adding the best-practice regional level female life expectancy at birth, one is able to observe that the slope is actually lower (0.13 years between 1990 and 2019) as differences between the best-practice region and best practice country has reduced over the last 3 decades from 2.6 years to 0.7 years. If this linear trend is extrapolated for the best-practice region, life expectancy will be 98.7 years in 2100, i.e. lower than the best-practice country. While this result is logically inconsistent, a reduction in regional differences in mortality is projected for European NUTS 2 level regions over the next two decades (Kashnitsky et al., 2017), meaning that it is unlikely that in the long-term there will be "outliers" in terms of life expectancy at birth, at least at the NUTS 2 level.

Preliminary discussion

In this research we have shown some critical issues regarding the pace of increase in the best-practice in life expectancy over the latest few decades. There appears to be some validity in Oeppen and Vaupel's (2002) statement that best (female) life expectancy increased by 2.5 years per decade for 160 years when one observes their graph for the first time. However, after examining the simple dots on the graph, it now appears to be a simplified observation of different realities.

In this work we chose to use data for the period from 1870 onwards, as earlier data casted doubt on the fairness of using Norwegian and New-Zealand data, as previously noted by Vallin and Meslé (2009). The Oeppen-Vaupel line should therefore be broken into segments that correspond to the main historical phases of the health transition. When the two earlier-mentioned countries are removed, three periods of improving life expectancy at birth since 1790 can be distinguished with the latter two periods being 1960-2009 and 2009-2019. Hence, if we take the increase in life expectancy of the best-practice county over the last decade, a simple linear extrapolation suggests that it is very unlikely life expectancy in all but the best-practice country will reach 100 years in 2100. Of course, these results derived from merely extrapolating one coefficient and assuming that it will remain constant over time is debatable and more refined methods need to be applied to be able to draw more robust conclusions. In addition, we still need to estimate whether this will be a possibility for the best-practice 2000 birth cohort, as well as verify or nullify the premise by Christensen et al. (2009) that half of them will get to 104 years of age. To increase chances of a positive outcome, we will also estimate this for best-practice sub-national populations.

One way to obtain more insight into future levels or limits of life expectancy at the population level, is therefore to study sub-populations. We have done this by analysing regions, and we will extend this part in the full version of the paper. Yet, there are many other ways to select subpopulations given the established differences in survival according to gender, socioeconomic status, race, marital status, smoking and BMI levels (see e.g. (Bongaarts, 2006; Case & Deaton, 2015; Laditka & Laditka, 2016; Permanyer et al., 2018; Sasson, 2016; Stewart et al., 2009)). For instance, Olshansky et al. (2012) found that in 2008 US adult men and women with fewer than twelve years of education had life expectancies not much better than those of all adults in the 1950s and 1960s. For future investigations it would be an interesting exercise to ascertain what the chances are of low-educated millenials to reach 100 years.

That said, the main reason why we think such a high life expectancy for millenials seems unlikely is because levels of infant and child mortality are already very low, meaning that further decreases in life expectancy can only happen with sharp declines in mortality at older ages, something which is increasingly difficult to attain given the declining annual improvements in life expectancy at birth, as we've shown here, and the lack of improvement in mortality at ages 100+ (will be shown in full paper). Still, we do not share the concern of those on the other side of the debate, i.e. that the increase in life expectancy in Europe and other high-income countries may come to an end (e.g. Olshansky et al., 2005). This is in part because evidence has shown that although the positive effects of smoking decline may be overwhelmed by the negative effects of increasing obesity, as has been observed in the US (Stewart et al., 2009), evidence also suggests that the mortality burden from obesity at middle- and old-age is small Reuser et al. (2008), though not morbidity (Reynolds et al., 2005). Another reason is because there is still no evidence that a limit in best-practice life expectancy at birth has been reached.

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