Broken Limits to Life Expectancy, slower but stronger than expected

Giacomo Lanfiuti Baldi

Abstract

"Is life expectancy approaching its limit?" asked Oeppen and Vaupel in their 2002 milestone *Science* paper. Back then, record life expectancy had risen linearly since 1840, showing no sign of slowing. Twenty years later, extending the series to the most complete data up to 2024 reveals a different picture: progress continues, but the linear rise has flattened. This has fueled speculation that human longevity is nearing a ceiling. Yet, by examining the full distribution of ages at death, we show that mortality improvements remain strong, driven by survival gains at older ages. Longevity is not ending—only changing: its rise is slower, but stronger.

Rethinking the limits of longevity

Is life expectancy approaching its limit? wondered Oeppen and Vaupel in 2002 opening their milestone work. Their analysis showed that, since 1840, the best practice in life expectancy, i.e. the highest national life expectancy at birth each year, had increased in a strikingly linear fashion, with no evidence of slowing. This finding, widely cited and widely debated, became a benchmark for how demographers and policymakers thought about the future of human survival.

Two decades later, the question deserves to be revisited. Extending the series of record life expectancy up to 2024 shows that progress has not stopped, but the linear rise once described has bent (Figure 1). Gains are still occurring, but at a slower pace than the straight line projected in 2002.

This change has raised concerns that human longevity is nearing its biological ceiling (Olshansky et al., 2024; Olshansky and Carnes, 2019; Dong et al., 2016). Recent research documents stagnation in life expectancy across several high-income countries (Dowd et al., 2025), including the United States (Abrams et al., 2023), the United Kingdom (Raleigh, 2018), and Italy (Salinari et al., 2023). Some countries have even experienced reversals , prompting speculation that the exceptional improvements of the twentieth century may not continue in the twenty-first. This question matters: whether life expectancy will keep rising, slow down, or plateau shapes how societies plan pensions, health systems, and the very structure of intergenerational life.

But such interpretations rely on a single summary indicator: life expectancy at birth. While this measure has become a global standard for assessing population health, it compresses the full complexity of mortality into a single number (Wachter, 2014). In particular, it gives disproportionate weight to mortality at younger ages, where gains are now nearly exhausted in low-mortality countries (Vaupel, 2010). While underplaying changes at older ages, which are increasingly driving progress (Rau et al., 2008). By focusing only on life expectancy, we risk mistaking the slowing of one indicator for the slowing of longevity itself.

In this paper, we expand the perspective by analyzing the entire distribution of ages at death in record-holding populations. This approach provides a deeper view of how mortality is changing, and whether the apparent slow-down reflects a biological boundary or simply the limitations of the metric we use. Looking beyond life expectancy allows us to ask not just whether longevity continues to rise, but in what form.

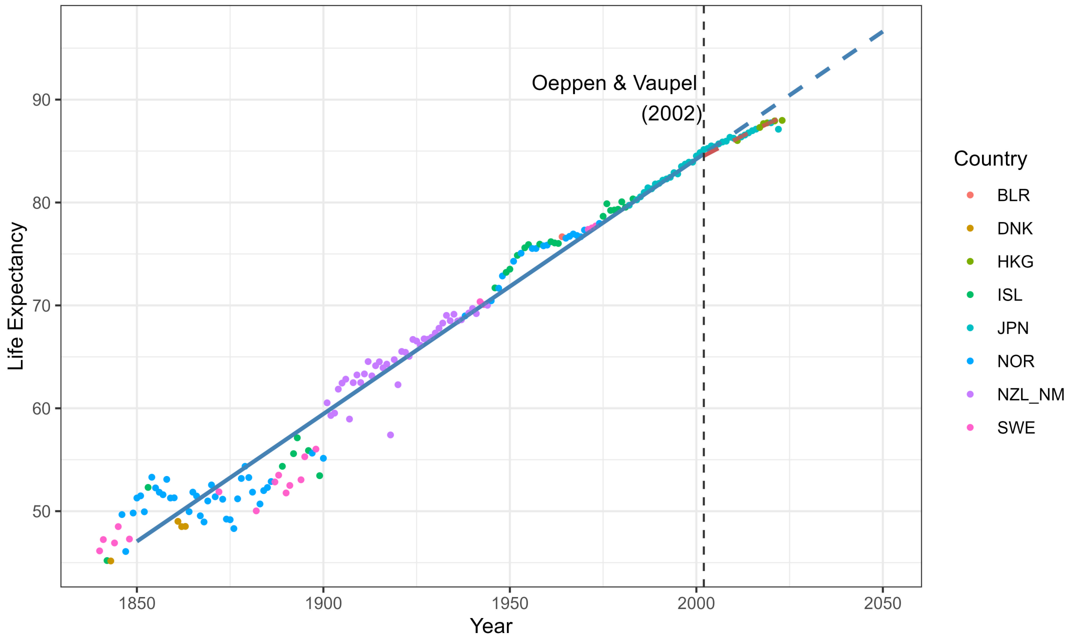

Figure 1: Record female life expectancy from 1840 to the present. The linear-regression trend for 1840–2001 is shown as a bold blue line; the extrapolated trend for 2003–2050 is shown as a dashed blue line. The red dashed line represents a LOESS spline fit to the updated data through 2024.The vertical dashed black line indicates the year of publication of Oeppen and Vaupel (2002).

Data and analytical strategy

We use data from the Human Mortality Database (2024) (HMD), covering all available populations up to 2024. Following Oeppen and Vaupel (2002), best practice life expectancy is defined as the highest national (female) life expectancy at birth in each year. For each record-holding population, we also extract the full distribution of ages at death, treating this as the best-practice mortality profile for that year. We use individual age groups from 0 to 110+, keeping in mind that older ages (100+) are subject to modelling in most countries and years.

To compare trajectories over time, we calculate the distance between each annual record and the best record observed to date (Hong Kong female population in 2023). For life expectancy, this distance is measured in years of life expectancy, reproducing the linear rise documented until 2000 in Oeppen and Vaupel (2002). For the age-at-death distribution, we apply the recently introduced Non-Overlap Index (Shi et al., 2023), which quantifies the degree of difference between two distributions. In both cases, the distance shrinks to zero as the current best record is reached.

Finally, to examine the demographic drivers of these trajectories, we decompose changes by single age group using Horiuchi's stepwise replacement method. This approach attributes improvements in record life expectancy and in the record age-at-death distribution to specific ages, revealing whether progress is concentrated at younger or older ages (Horiuchi et al., 2008; van Raalte and Nepomuceno, 2020).

This combined strategy provides two complementary perspectives: a traditional, summary measure of longevity, and a distributional measure that captures mortality improvements across all ages. Together, they allow us to assess whether the apparent slowdown in record life expectancy reflects a true limit to human longevity or the limits of the indicator itself.

Two frontiers, two speeds

In Figure 2, we contrast two distances to the current longevity frontier (Hong Kong, 2023). The first is the gap between the best-ever life expectancy at birth and the best practice value achieved in each year. The second is the distance between the full age-at-death distribution in the best-ever year and the corresponding distribution in each earlier year. Because we are interested in trends, not magnitudes, both series are normalized to [0, 1], where 1 denotes the largest observed distance and 0 indicates convergence to the 2023 frontier. The life-expectancy series (blue) is a rescaled mirror of Figure 1: a convex trajectory with faster early improvements that gradually decelerate, a pattern that could be mistaken for an approach to a limit. By contrast, the distribution-based series (red) is concave: convergence accelerates, especially from the mid-1970s onward, indicating sustained—and increasingly rapid—alignment of the full mortality profile with the best-ever distribution.

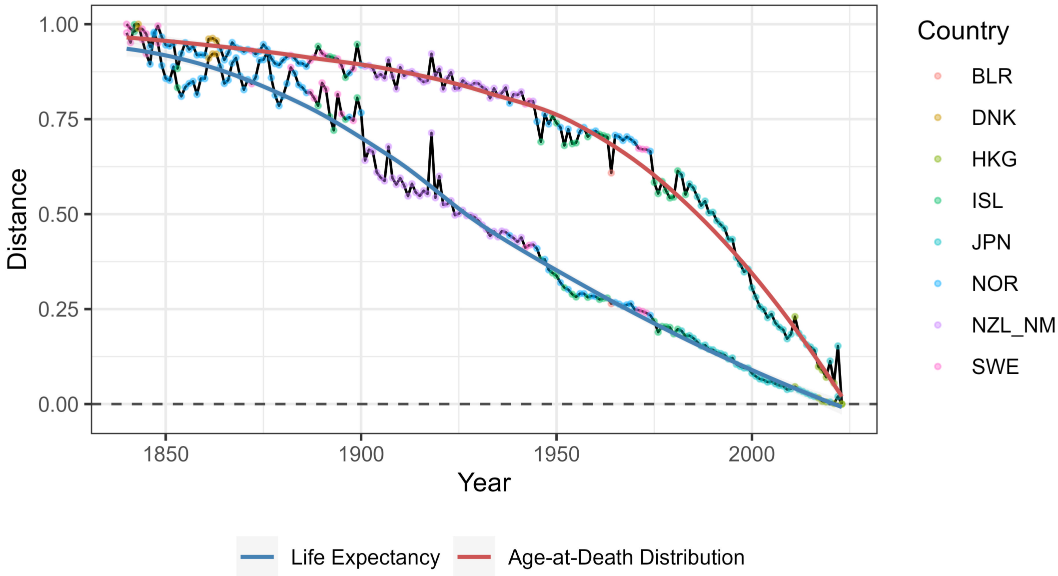

Figure 2: Annual distances between the all-time best life expectancy and each year's best life expectancy (bold blue line) and between the all-time best age-at-death distribution and each year's best distribution (bold red line). Both distances are normalized between 0 and 1. Lines represent LOESS spline interpolation of the calculated annual values.

Thus, although the distance in terms of life expectancy continues to decrease—indicating ongoing gains—its rate of convergence is comparatively modest. By contrast, the age-at-death distribution exhibits much faster convergence, underscoring that improvements in survival are increasingly producing a broad shift of the mortality schedule rather than incremental increases in a single summary indicator.

Figure 3 explains the difference in these two speeds. Using Horiuchi's stepwise replacement decomposition, we allocate changes in each distance to single-year age contributions (shown for selected quinquennial years). For life expectancy, gains are front-loaded at younger ages and diminish over time as improvements there become nearly exhausted in low-mortality settings. For the age-at-death distribution, contributions are concentrated at older ages and intensify in recent decades: ages 80+ provide the largest and growing shares of progress. These age patterns generate a slowing in the life-expectancy gap alongside an acceleration in the distributional gap—evidence that the locus of improvement has shifted upward in age without weakening the overall advance of the mortality frontier.

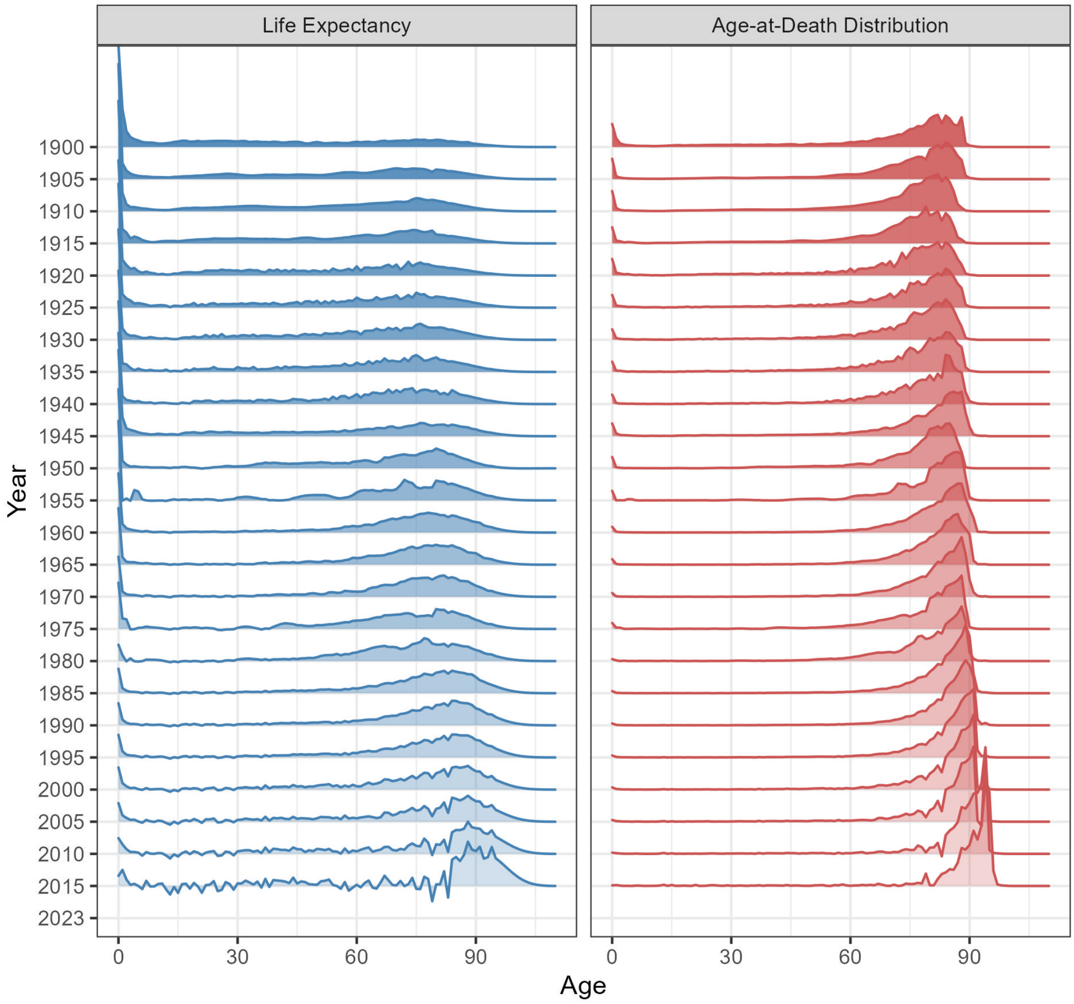

Figure 3: Age-specific contributions to changes in the two distances. Blue gradient (left) shows contributions to the decline in the gap between all-time best life expectancy and each year's best; red gradient (right) shows contributions to the decline in the gap between all-time best age-at-death distribution and each year's best. Shown for every 5th year from 1900 to 2015, plus 2023. Higher values indicate larger relative contributions at that age.

Slower growth, stronger progress

The deceleration of record life expectancy does not, on its own, imply proximity to a biological limit. Our results indicate a change in where progress comes from, not whether it exists. As gains at young ages have become nearly exhausted in low-mortality settings, additional increases in life expectancy naturally slow. The decomposition analysis makes this mechanism explicit: the age profile of contributions has shifted upward, with diminishing additions from childhood and early adulthood and growing additions at older ages. Consistently, the distributional perspective—measured by the Non-Overlap Index—shows continued, and since the mid-1970s accelerating, convergence of the age-at-death distribution toward the best-ever profile (see Figure 2). By design, our normalization emphasizes trajectories rather than magnitudes; the divergence between the two curves is therefore about the shape of progress, not its absolute size.

Taken together, these patterns support a cautious inference. If improvements at advanced ages persist, best-practice life expectancy should continue to rise, albeit more slowly than the linear trend described by Oeppen and Vaupel. The distributional evidence provides a stronger reason to expect ongoing gains than life expectancy alone would suggest, because it captures the broadening and postponement of mortality across the age range rather than relying on a single summary statistic increasingly dominated by ages with little remaining scope for improvement. At the same time, this is not a claim of inevitability: should gains at older ages stall—because of biological, medical, or societal constraints—a plateau could emerge. Our contribution is to show that, for now, the underlying mortality profile continues to improve and does not display the slowdown that would presage a hard ceiling.

The practical implication is straightforward: projections and policies should account for slower top-line growth in life expectancy and for continued advances concentrated at older ages. Focusing solely on life expectancy risks mistaking a change in tempo for an end to progress. The tempo has changed; the direction has not.

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