Have deaths gradually shifted from younger to older ages and what are the implications for underlying mortality dynamics?

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Abstract

Major mortality improvements shifted from young to old ages. Although this finding has become basic knowledge, several related questions remained open. We aim to answer three of these questions: (I) How have mortality improvements at older ages replaced those at younger ages? (II) When did old-age mortality improvements exceed those at younger ages? (III) Was there a point in time where mortality improvements at older and younger contributed equally? We avoid the use of rigid definitions of "old" and "young" by combining decomposition techniques with the novel concept of the equilibrium point between backward and forward cumulative age-contributions. Preliminary results reveal a sudden change of the equilibrium point. We observe a steep increase of this point between the 1950s and the 1970s for both sexes. The finding indicates a rapid age-shift that occurred within the period of sustained old-age mortality improvements and not, as often believed, prior to this period.

1 Aim of the study

As populations evolved from having low to high life expectancy, the major drivers of increases in life expectancy shifted from young to old ages. Accordingly, the forces that drove progress at the beginning of the life expectancy revolution differ from those

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of the current changes[3,8,10]. This finding is major a cornerstone in numerous demographic studies about mortality and health. Along with the shift in the age-pattern of mortality improvement, further aspects of mortality, such as lifespan variability, changed substantially. This could be seen, for instance, in the replacement of the compression of mortality by shifting of mortality as leading force of life expectancy increase[2].

Although the changing age-pattern of mortality improvement has become basic knowledge among scholars in the respective fields, several crucial questions remain open:

(I) How have mortality improvements at older ages replaced those at younger ages? It is still unclear whether old-age mortality improvements have gradually replaced those at younger ages or if their have been, for instance, sudden changes in the age schedule of mortality change.

(II) When did old-age mortality improvements exceed those at younger ages and how does the point differ by sex and country? Different concepts such as the epidemiological transition[6] or the broader concept of the health transition[9] are describing the forces that drove the shift of mortality improvement. Based on this concept, it is important when the transition took place and how this temporal characteristics are related to the progress that has been achieved in the era of sustained old-age mortality improvements[5].

(III) Was there a point in time where mortality improvements at older and younger contributed equally to the increase of the lifespan? The progression of age-shifts in mortality improvements should might have a reached an equilibrium state such that mortality improvements at older and younger ages are equal. If such a state exists, the mortality trajectory might follow specific characteristics that provide insights into the evolution of lifespan variability and the respective underlying mortality dynamics.

In this article, we aim to answer the aforementioned questions. Moreover, we try to avoid the use of rigid definitions of old- and younger ages by combining life expectancy decomposition techniques with a dynamic perspective using the novel concept of an equilibrium point between backward and forward cumulative age-contributions. We define the equilibrium point as the age where the backward and forward cumulative age-contributions are equal. We expect an increasing equilibrium point over time; however as progress in survival differs across populations, we also expect variations in the timing and pattern over time. Based on our findings, we are discussing the implication for the mortality dynamics that determine lifespan variability.

2 Data and methods

We applied the classical decomposition approach that has been developed originally by Arriaga[1] in the form as presented by Preston et al.[7], S. 64:

$$e_{0,B} - e_{0,A} = \Delta = \frac{l_x^A}{l_0^A} \cdot \left(\frac{{}_nL_x^B}{l_x^B} - \frac{{}_nL_x^A}{l_x^A} \right) + \frac{T_{x+n}^B}{l_0^A} \left(\frac{l_x^A}{l_x^B} - \frac{l_{x+n}^A}{l_{x+n}^B} \right).$$

The decomposition method estimates the age-specific contribution of changes in age-specific mortality to the change in life expectancy. Based on this age-specific contributions, we calculated the cumulative sum of the contribution from two directions: (a) from age 0 onward and (b) from the open-ended age-group (100+) backward (see Figure 1). Based on these two estimates, we searched the point at which the forward and backward cumulative contributions equal each other (black dot in Figure 1). This equilibrium point serves as our basic criteria to measure the change of the age-shift over time.

To provide as much detail as possible, we applied the decomposition to annual changes in life expectancy. The equilibrium points have then been estimated for each decomposition separately. The study is based on age-specific deaths counts and exposure-to-risk provided by the Human Mortality Database[4].

3 Results

Figure 2 shows the trajectories for the equilibrium points for males and females in France (left panel) and Italy (right panel) between 1900 and 2014. In other words, it shows how the age where forward and backward cumulative age-contributions crossed over time by males and females. Females estimates are depicted in red and male estimates are depicted in blue.

The example shows distinct patterns. Italian males and females as well as French males show an almost stable equilibrium point until the 1940s/50s and rapid increase

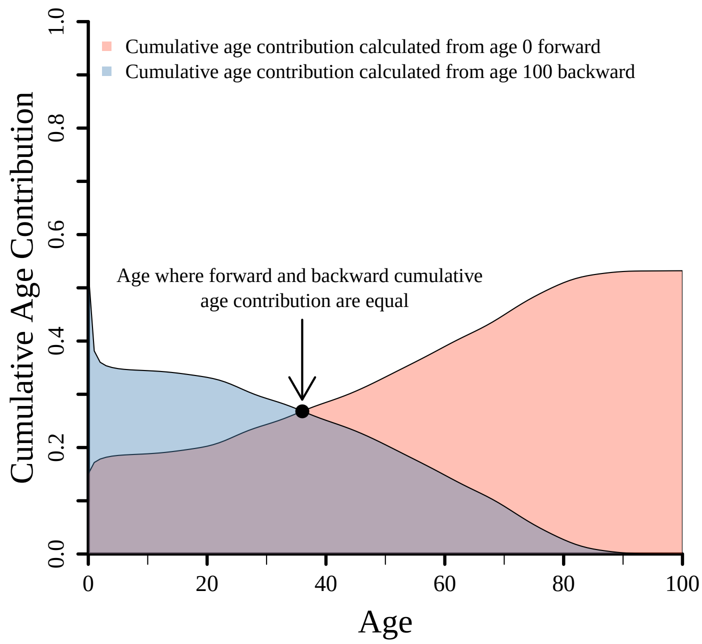

Figure 1: **Scheme of the calculation of the equilibrium point of age-specific ontributions to the change in life expectancy.**

thereafter, whereas the equilibrium point of French females depicts a steady rise at least until the early 1980s. However, all of the four populations show a relatively sudden shift from the age contributions from young to old ages. This is an intriguing result and would suggest that the shift in the age-pattern of mortality improvement has not been a gradual process. For instance, at the beginning of the 1950s age contributions between ages 0 and 10 of Italian females are equal to those at all higher ages together. However, less then 40 years later this equilibrium has changed to an equality between the contributions from ages 0 to 70 and those thereafter.

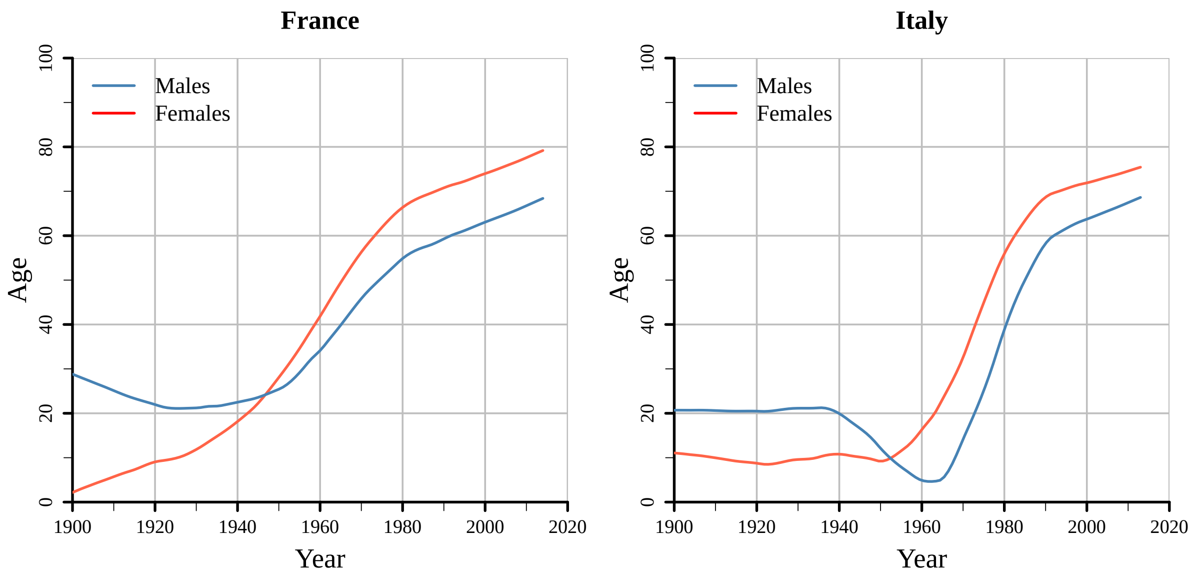

Figure 2: **Equilibrium point, males and females, Italy and France, 1900-2014.** The trend lines are based on a locally weighted smoothing to highlight the patterns only.

4 Discussion and outlook

Using the forward and backward cumulative age-contribution, we revealed that the age where mortality improvements at older ages and at younger ages are equal has been changing over time. Between the 1950s and the 1980s, our results showed a steep increase of this equilibrium point for both sexes, indicating a rapid age-shift during this period.

The equilibrium point serves as basic tool to approach questions (I) to (III), as it provides a dynamic threshold between young- and old-age contributions. However, clear answers to the question require further analysis to relationship between life expectancy and the equilibrium point, and the arising implications for our definition or thoughts about the labels "old" and "young".

In addition to life expectancy, it is important to grasp the relationship between the equilibrium point and lifespan disparity. Compression and shifting of mortality require different different age-schedules of mortality improvement. Compression results from stronger improvement at younger ages, while shifting requires almost similar improvements at all ages. The equilibrium point as such divides the age-range into two parts with equal improvements, and thus, provides a link to the pattern of lifespan disparity.

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