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# Authors' response to 'Limitless longevity': The contribution of rectangularization to the secular increase in life expectancy: an empirical study

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We thank our colleagues Modig *et al.*[1] for their interest in our paper 'The contribution of rectangularization to the secular increase of life expectancy: an empirical study',[2] and for raising substantial issues related to mortality among the oldest old persons.

The authors are correct in pointing out that the maximum age at death depends partly on the size of the population at risk of dying, in that a larger number of people reaching old age will increase the probability of there being one single person with a very high age at death. It was for this very reason of buffering the effect of population size on extreme values that our paper used the 90th quantile as an indicator of longevity, rather than using the maximum age at death. One should note that from a theoretical point of view, the maximum age at death is an ambiguous dimension. According to the Gompertz model or the logistic one, the maximal age at death is in fact infinite, and one may ask whether it is relevant to use it at all.[3]

Further to this point is that empirical evidence in our study shows that rectangularization of a survival curve does not automatically increase our indicator of longevity. From a theoretical perspective, we illustrated, in an earlier paper (top panel of Figure 2),[4] a situation combining a rectangularization of the survival curve with the lack of an increase in longevity (which incidentally corresponds to the paradigm developed by Fries on the future of longevity).[5] In our study we also noted that the pace of increase in longevity was not strictly related to the pace of rectangularization. There were in fact substantial differences between the two processes, as summarized in Figure 4 (panels a and b).[2]

Even when an increase is observed in both rectangularity and longevity as indicators of mortality, the effect of each process on the number of years gained in life expectancy does vary. Whereas we found that the extension of longevity was responsible for more gained years than was rectangularization in most of the countries in our study from 1922 to 2006, the opposite is true during some periods and/or in some countries. Consider, for example, the analysis by Gavrilov *et al.* of Swedish male mortality.[6] There, a Gompertz–Makeham model was fitted, in which the mortality rate at age $x$ is given by the equation $a{*}exp(b{*}x)+g$. In the period from 1901–1910, the parameters of the model were estimated to be $a=0.0000356$, $b=0.1005$, and $g=0.00557$, whereas in the period from 1966–1970 these parameters were estimated to be $a=0.0000244$, $b=0.1048$, and $g=0.00068$, as seen in Table 1 in Gavrilov *et al.*'s paper.[6] Between the two periods, the gain in (trimmed) life expectancy at 50 years was 2.5 years. Applying our indicators to this example, we found that rectangularization was responsible for a gain of 1.8 years, whereas the longevity extension contributed only 0.7 years, showing that rectangularization of the survival curve was responsible for 72% of the increase in life expectancy. There are thus situations in which rectangularization is more important than the extension of longevity in terms of years gained, suggesting that our indicators are able to capture different patterns of evolution of mortality.

Lastly, we should mention that our two indicators cannot be used to infer a possible leveling of mortality among the oldest old. Because our approach uses the 90th quantile of the distribution of age at death to measure longevity, the resulting indicators are not sensitive to the mortality of the oldest old. As pointed out by the authors, whether mortality does or does not level off at advanced ages is widely debated. Much more data are needed to reliably analyze the pattern of mortality at very old age, pointing to the specific requirement of having survival curves based on a much larger number of persons living beyond 90, 100, or 110 years.

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