Regression Trees for Estimating Mortality Deceleration and Levelling-off

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Abstract

Mortality deceleration and leveling-off take place for a number of populations, but there are datasets that provide little or no such evidence. As for many contemporary populations, deaths are postponed; we hypothesize that the onset of mortality deceleration is also shifted to higher ages. We use regression trees to estimate the age of mortality deceleration, as well as the onset and level of an eventual mortality plateau for six countries from the Human Mortality Database after 1950. Our preliminary findings show that the onsets of deceleration and leveling-off increase with time, while the level of the plateau is quite stable. For almost all populations after 2000, mortality deceleration starts at age 100 or above, while the plateau is reached at ages above 105.

Introduction

There is a long-standing debate about whether or not human mortality decelerates and, if yes, whether or not it levels off. Analyses based on different datasets have reached diverging conclusions. Most studies point at mortality's slowing down (Kannisto, 1994; Horiuchi and Wilmoth, 1998; Vaupel et al., 1998; Steinsaltz and Wachter, 2006) and eventually levelling off (Vaupel et al., 1998; Gampe, 2010, 2021; Rootzén and Zholud, 2017; Barbi et al., 2018; Belzile et al., 2022). However, Gavrilov and Gavrilova (2011); Gavrilova and Gavrilov (2015); Gavrilov and Gavrilova (2011, 2019b) find no evidence of mortality deceleration in several human and non-human populations, claiming that mortality's slowing down might be an artifact of data errors (Gavrilov and Gavrilova, 2019a). Newman (2018b,a) supports this hypothesis and argues that mortality plateaus result from data inaccuracies, too. In addition, while Barbi et al. (2018) estimate a plateau using high-quality individual data at ages 105+ for Italy, Dang et al. (2023) reject the plateau hypothesis using data of comparable quality for France in the same age range.

We hypothesize that it is not data errors but a shift to higher ages of the onset age of deceleration and leveling-off that prevent their detection. For contemporary populations, these onset ages are above 100, where data are scarce and conventional statistical methods work with low accuracy. We propose applying a machine learning algorithm, regression trees, to overcome this shortcoming. Our preliminary findings show a steadily increasing tendency for both onset ages, with deceleration currently starting after 100 and leveling-off taking place at age 107 or above.

Data and Methods

We use raw death counts $D(x)$ and exposures $E(x)$ for France, Italy, Japan, Sweden, Denmark, England and Wales, the Netherlands, and Spain from HMD (2023) for ages 85 and above, males and females separately from 1950 to the last available year. We assume $D(x) \sim \text{Poisson}(\mu(x)\, E(x))$, where $\mu(x)$ is the gamma-Gompertz force of mortality, i.e.,

$$\mu(x) = \frac{ae^{bx}}{1 + \frac{a\gamma}{b}(e^{bx} - 1)}\,, \tag{1}$$

where a denotes the death rate at the starting age of analysis, b is the rate of individual aging, and γ is the squared coefficient variation of the frailty distribution (Vaupel et al., 1979; Vaupel and Missov, 2014). We estimate the onset age of mortality deceleration $x*$ by

$$x* = \frac{1}{b} \ln \frac{b - a\gamma}{a\gamma}\,, \tag{2}$$

or, alternatively, by

$$x* = M - \ln \gamma\,, \tag{3}$$

where M is the gamma-Gompertz modal age at death. We estimate the gamma-Gompertz model in a Bayesian setting with inverse-gamma priors for the parameters (Patricio and Missov, 2023).

To estimate the onset age and the level of the mortality plateau, we apply a regression tree method (Liaw and Wiener, 2002). This method works by recursively partitioning the data into subsets and fitting a constant value to each subset. The subsets are defined by a set of decision rules based on the features of the data (age, in our case). In the context of mortality deceleration, the onset age of the mortality plateau is given by the last age where there is a partition, and the constant value gives the level of the mortality plateau. Bootstrapping was used to create a bootstrap distribution for the onset age and the level of the mortality plateau. The modes of the distributions were used as point estimates. The bootstrap distribution was also used to create the confidence intervals.

Preliminary Results

The onset ages of mortality deceleration and leveling off increase with time for almost all studied populations, the only exception being deceleration for Spanish females (see Figure 1). After 2000, deceleration takes place at ages above 100 while the mortality plateau is reached at 105 or above.

While for both sexes, deceleration starts approximately at the same age (Figure 2), levelling-off occurs earlier for males than for females (Figure 3)

Discussion and preliminary conclusions

Using regression trees, we are able to estimate with high accuracy the onset ages of mortality deceleration and leveling-off. For current populations, they are in the age range where just a few or no deaths occur. The latter prevents conventional statistical methods from detecting late-life shifts from the linear adult death rate pattern. We plan to extend our analysis to cohorts and compare our findings to the studies that do not find evidence for mortality deceleration.

References

Barbi, E., Lagona, F., Marsili, M., Vaupel, J. W., and Wachter, K. W. (2018). The plateau of human mortality: Demography of longevity pioneers. *Science*, 360(6396):1459–1461.

Belzile, L., Davison, A., Gampe, J., Rootzen, H., and Zholud, D. (2022). Is there a cap on longevity? a statistical review. *Annual Review of Statistics and Its Application*, 9:21–45.

Dang, L., Camarda, C., Ouellette, N., Meslé, F., Robine, J.-M., and Vallin, J. (2023). The question of the human mortality plateau: Contrasting insights by longevity pioneers. *Demographic Research*, 48:321–338.

Gampe, J. (2010). Human mortality beyond age 110. In *Supercentenarians*, pages 219–230. Springer.

Gampe, J. (2021). Mortality of supercentenarians: Estimates from the updated idl. In *Exceptional Lifespans*, pages 29–35. Springer, Cham.

Gavrilov, L. and Gavrilova, N. (2011). Mortality measurement at advanced ages: A study of the social security administration death master file. *North American Actuarial Journal*, 15(3):442–447.

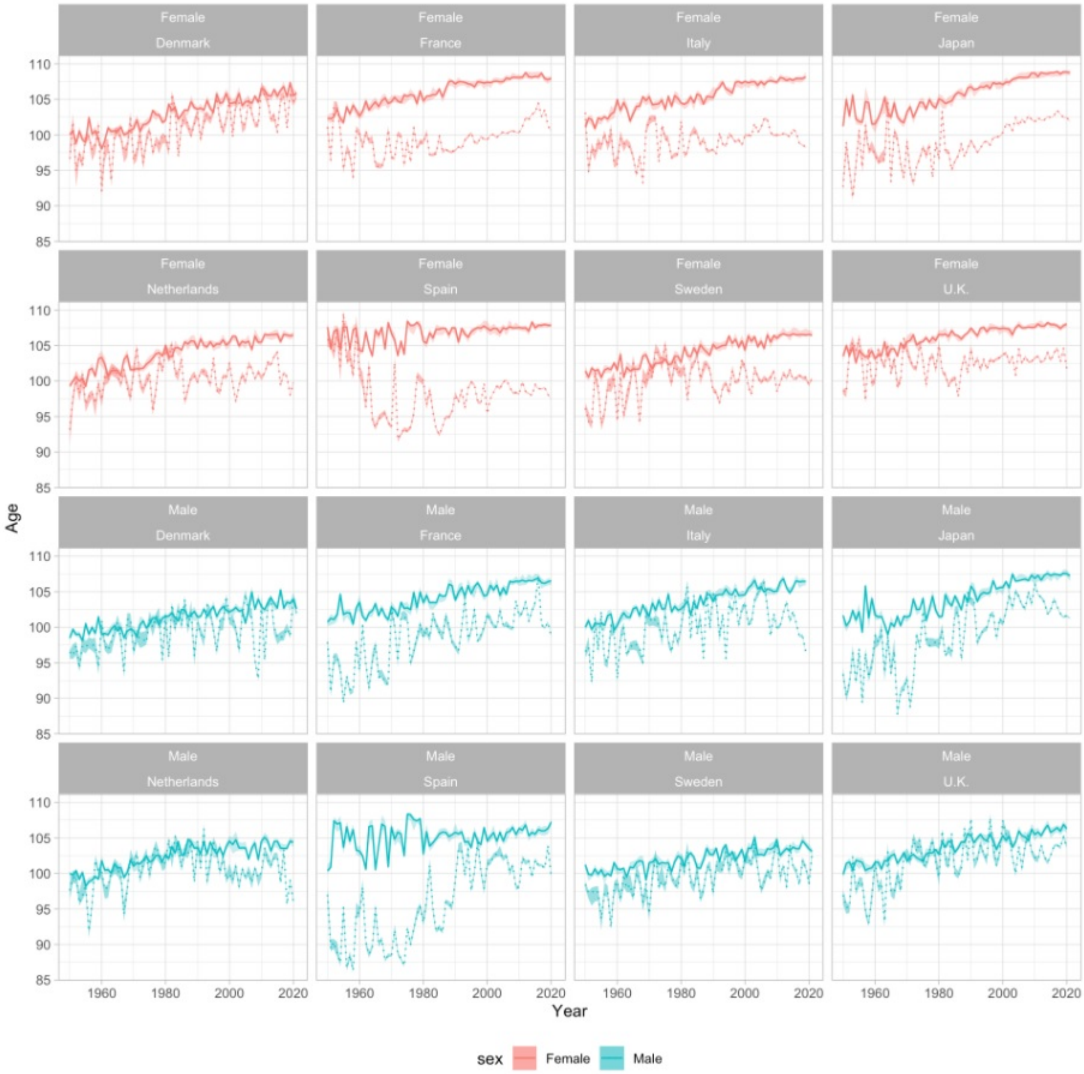

Figure 1: Estimated onset ages of mortality deceleration (dashed line) and leveling-off (solid line) in eight HMD countries from 1950 to the last available year, for males (blue) and females (red) separately.

Gavrilov, L. and Gavrilova, N. (2019a). Late-life mortality is underestimated because of data errors. *PLoS Biology*, 17(2):e3000148.

Gavrilov, L. and Gavrilova, N. (2019b). New trend in old-age mortality: Gompertzialization of mortality trajectory. *Gerontology*, 65(5):451–457.

Gavrilova, N. S. and Gavrilov, L. A. (2015). Biodemography of old-age mortality in humans and rodents. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 70(1):1–9.

HMD (2023). The human mortality database. http://www.mortality.org/.

Horiuchi, S. and Wilmoth, J. (1998). Deceleration in the age pattern of mortality at older ages. *Demography*, 35(4):257–269.

Kannisto, V. (1994). *Development of oldest-old mortality, 1950–1990: evidence from 28 developed countries.* Odense University Press.

Liaw, A. and Wiener, M. (2002). Classification and regression by randomforest. *R News*, 2:18–22.

Newman, S. (2018a). Plane inclinations: A critique of hypothesis and model choice in barbi et al. *PLoS Biology*, 16(12):e3000048.

Newman, S. J. (2018b). Errors as a primary cause of late-life mortality deceleration and plateaus. *PLoS Biology*, 16(12):e2006776.

Figure 2: Estimated onset ages of deceleration in eight HMD countries from 1950 to the last available year, for males (blue) and females (red) separately.

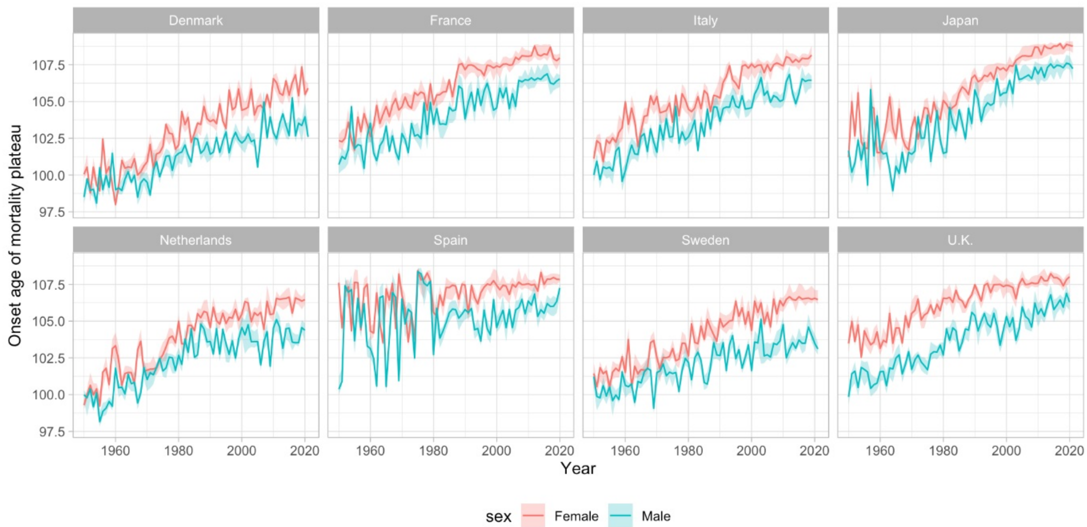

Figure 3: Estimated onset ages of the mortality plateau in eight HMD countries from 1950 to the last available year, for males (blue) and females (red) separately.

Patricio, S. and Missov, T. (2023). Using a penalized likelihood to detect mortality deceleration. *PLoS ONE*, page forthcoming.

Rootzén, H. and Zholud, D. (2017). Human life is unlimited–but short. *Extremes*, 20(4):713–728.

Steinsaltz, D. and Wachter, K. (2006). Understanding mortality rate deceleration and heterogeneity. *Mathematical Population Studies*, 13:19–37.

Vaupel, J. and Missov, T. (2014). Unobserved population heterogeneity: A review of formal relationships. *Demographic Research*, 31(22):659–686.

Vaupel, J. W., Carey, J. R., Christensen, K., Johnson, T. E., Yashin, A. I., Holm, N. V., Iachine, I. A., Kannisto, V., Khazaeli, A. A., and Liedo, P. (1998). Biodemographic trajectories of longevity. *Science*, 280(5365):855–860.

Vaupel, J. W., Manton, K. G., and Stallard, E. (1979). The impact of heterogeneity in individual frailty on the dynamics of mortality. *Demography*, 16(3):439–454.