

# Molding the Rate of Aging

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## Abstract

One of the most widely accepted regularities in mortality analysis is that the risk of dying increases at a constant rate from age 40 onward. This regularity was formalized by the Gompertz model 200 years ago. However, recent empirical evidence suggests that, at the population level, the rate of aging, i.e. the relative change in mortality rate over age, is not constant and has undergone significant changes in recent years. We find that the rate of aging follows a piecewise pattern: it remains relatively stable up to age 65, then increases up to age 85, and subsequently decreases. To support these empirical findings, we propose a theoretical framework to explain this emerging mortality age structure. Our model demonstrates that this new rate of aging pattern can be explained by faster mortality reductions around ages 70–80 than at younger and older ages. This suggests that the rate of aging can be molded by varying progress in reducing mortality across different age groups.

## Introduction

The shape of the age-specific mortality curve is one of the most accepted regularities in mortality analysis. Specifically, mortality risk has been shown to increase log-linearly with age after approximately age 40 (or even 30). This pattern is described by the Gompertz model (Gompertz 1825), which assumes that the rate of aging, or the rate of relative mortality change with age, is constant across adult ages. Published 200 years ago, Gompertz's groundbreaking model remains one of the most widely used frameworks for describing human mortality patterns at adult ages.

However, the Gompertz model may not optimally capture population-level adult mortality age patterns. Already in 1990, Horiuchi and Coale (1990) found that the population-level rate of aging is not constant over age but instead follows a bell-shaped curve. The authors investigated whether this bell-shaped pattern resulted from cohort effects, methodological artifacts, or reporting issues at the oldest ages, finding no evidence for any of these explanations. Instead, they concluded that the bell-shaped curve of the age-specific rate of aging reflects an underlying age-structure of mortality.

We have found that the bell-shaped age-specific rate of aging is undergoing significant modifications and increasingly resembles a segmented function, as illustrated in Figure 1. In this paper, we present empirical findings on how population-level rates of aging have changed over time and provide a theoretical framework to explain these changes.

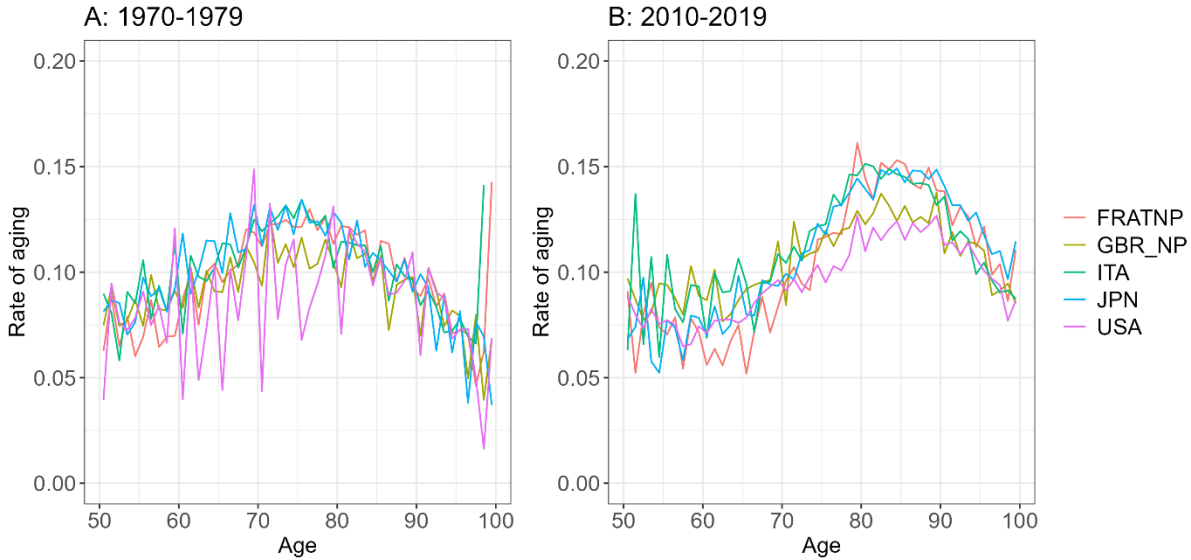
## Empirical findings

We calculate the period life table rate of aging (LAR) for five countries in the Human Mortality Database (HMD 2025) with populations of 50 million or more, to limit random fluctuations in our calculations. These countries are France (FRTNP), Great Britain (GBR\_NP), Italy (ITA), Japan (JPN) and the United States (USA). We use the non-smoothed age-specific death rates provided in the HMD. Figure 1 shows the average LAR over 10-year periods at ages 50 to 100 for the five countries in the 1970s and 2010s. The figure demonstrates that the LAR was bell-shaped in the 1970s, as documented by Horiuchi and Coale (1990), with increasing LAR up to age 75 in all countries, followed by a decline. However, this pattern has changed considerably in recent years: the LAR now remains constant or decreases slightly between ages 50 and 65, then increases up to approximately age 85, followed by a decline.

Table 1 presents the breakpoints in the LAR for the five countries, estimated using the Muggeo (2020) model. The old-age breakpoint (B2) has been observed across all decades and has shifted toward older ages, except in Great Britain and the United States. However, a new breakpoint (B1) emerged at younger ages in the 2000s in France and Japan, and in the 2010s in the other three countries.

The deceleration in mortality increase observed at the oldest ages has been extensively studied, and various models have been proposed to account for it, including the Kannisto, Gamma-Gompertz, and Beard models. This deceleration has been theorized to result from mortality selection (Vaupel, Manton, and Stallard 1979): frailer individuals tend to die at earlier ages, leaving more robust individuals in the population. However, the reasons for the newly observed leveling off in the rate of aging at younger ages remain unknown. We propose a new model to explain this emerging mortality age-structure.

**Figure 1.** Mean life table rate of aging over a 10-year period in France (FRATNP), Great Britain (GBR\_NP), Italy (ITA), Japan (JPN), and the United States (USA), 1970-1979 and 2010-2019.



**Table 1.** Breakpoint estimated in the mean LAR per decade in France, Great Britain, Italy, Japan and the United States.

	France		Great Britain		Italy		Japan		United States	
	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
1970s	-	76.1	-	78.7	-	75.8	-	76.2	-	85.1
1980s	-	78.7	-	83.5	-	80.3	-	79.3	-	91.5
1990s	-	83.2	-	88.6	-	82.4	-	82.2	-	91.4
2000s	59.8	83.1	-	83.3	-	84.4	56.1	83.3	-	88.8
2010s	65.1	83.8	63.5	84.9	66.5	83.1	62.7	85.0	58.0	88.2

### Theoretical framework

We theorize that the levelling-off in the rate of aging at younger ages is due to uneven mortality progress over ages. For example, let's assume that the force of mortality follows a Gompertz curve, but mortality is changing over time by a positive factor ( $r_t$ ), common to all ages:

$$\mu_{x,t} = \alpha e^{\beta x} r_t. \quad (1)$$

As mortality is falling,  $0 < r_t < 1$ . Under this scenario, the rate of aging,  $\rho$ , being the relative derivative of  $\mu_{x,t}$  with respect to age, will remain unchanged over time and equal to:

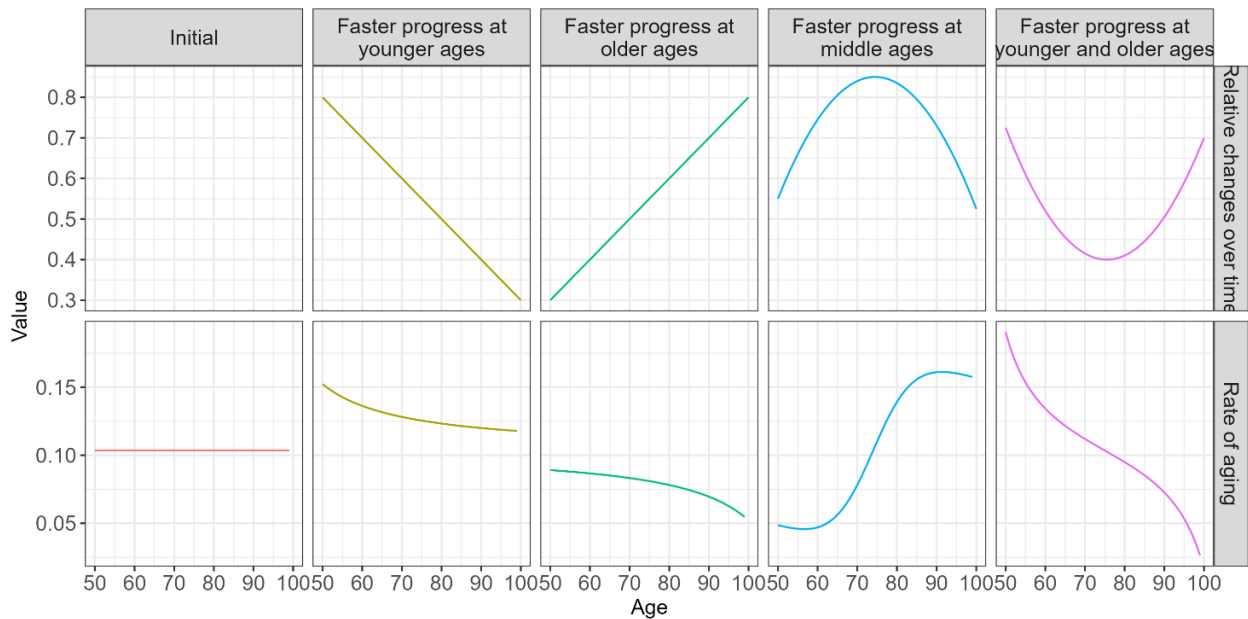
$$\rho = \beta. \quad (2)$$

Now, let's assume that mortality is changing over time, but by a positive factor that varies across ages ( $r_{x,t}$ ), such that  $\mu_{x,t} = \alpha e^{\beta x} r_{x,t}$ . The rate of aging will then become equal to:

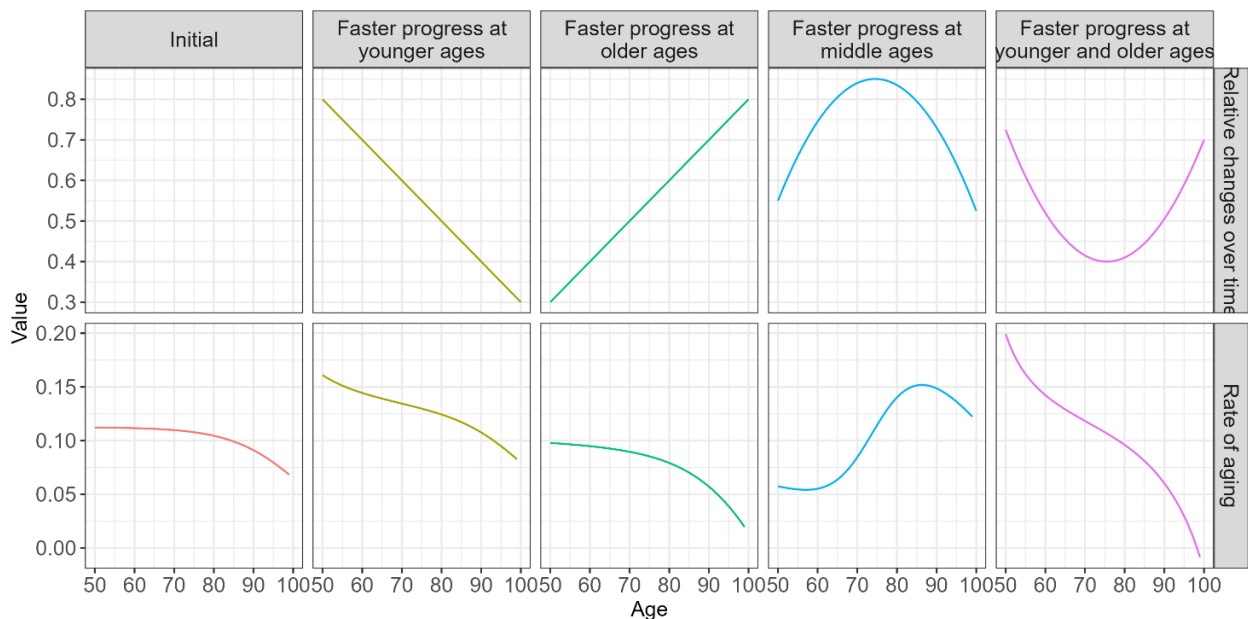
$$\rho = \beta + \frac{\dot{r}_{x,t}}{r_{x,t}} \quad (3)$$

where the dot on the top of the variable represents its derivative with respect to age. If mortality reduction varies across ages, the initial rate of aging  $\beta$  will then be modified. Figure 2 shows different scenarios of  $\frac{\dot{r}_{x,t}}{r_{x,t}}$  and their effect on the rate of aging, assuming an initial mortality profile following a Gompertz model. The only scenario that could explain the leveling off in  $\rho$  at younger ages is if the mortality reduction was faster at “mid-ages” (70-80 years) compared to progress made at earlier and older ages. This assumption about mortality changes also produces a levelling off in  $\rho$  at older ages, partly explaining the second break points shown in Figure 1. Figure 3 shows the same conclusion when assuming an initial mortality curve with the Gamma-Gompertz model, but with a stronger decline in  $\rho$  at the oldest ages.

**Figure 2.** Scenarios showing how various age-specific mortality changes over time (here shown as  $1 - \frac{\dot{r}_{x,t}}{r_{x,t}}$ ) affect the rate of aging, using a Gompertz model as the initial mortality level.



**Figure 3.** Scenarios showing how various age-specific mortality changes over time (here shown as  $1 - \frac{\dot{r}_{x,t}}{r_{x,t}}$ ) affect the rate of aging, using a Gamma-Gompertz model as the initial mortality level.



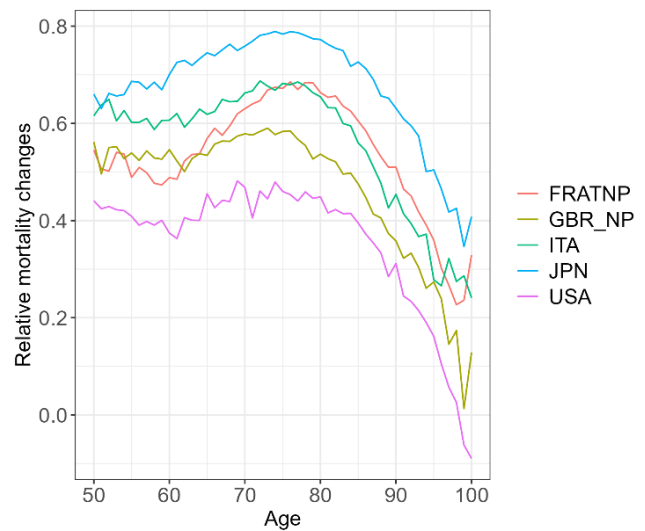
Empirical evidence shows (Figure 4) that, indeed, mortality has declined faster between ages 70 and 80 than at ages 50-70 and 80+ in all countries.

### Conclusion and next steps

The empirical and theoretical evidence show that the rate of aging can be modified over time. In particular, faster mortality progress around ages 70-80 compared to younger and older ages, produced a levelling off in the rate of aging at younger and older ages. This model cannot, however, fully explain the decrease in the rate of aging at the oldest ages and selection might also play a role in this decrease (e.g., in the Gamma-Gompertz model).

The findings suggest that the shape of the human mortality curve might not be as regular over time as we thought and can be modified depending on how mortality decreases has been uneven across ages. This project is still ongoing and more analyses are planned, such as including more countries in the analysis, analyzing whether the same patterns are observed for cohorts, and improving the selection of the breakpoints in the rate of aging.

**Figure 4.** Age-specific relative mortality changes between 1970 and 2019 in five countries



### References

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