The Recent Evolution of Mortality Patterns Over Age Across Europe[1]

1. Introduction

Against some expectations that theorized a limit to life expectancy, humans are breaking limits to life expectancy (Oeppen and Vaupel, 2002). Following the authors, if the most part of the gain in life expectancy was due to huge reductions in mortality at younger ages, after this period, in the second half of the century, were the improvements in survival after age 65 that contributed to an extension in the lifespan.

These contributions are result from an *"intricate interplay of advances in income, salubrity, nutrition, education, sanitation, and medicine"*, or to sum up, the result of large improvements in human health, *"with the mix varying over age, period, cohort, place, and disease"* (Riley – 2001, quoted in Oeppen and Vaupel, 2002). Vaupel in 2010 wrote in his Nature paper that *"mortality is by far the most important readily and reliably measured index of health"*, and the truth is that the world's life expectancy rose more than the double in the last centuries due to low levels of mortality observed at all ages.

As it is known, there are many actions that can reduce an organism lifespan, like smoking (Vaupel et al., 2003), reckless behaviour, or even the choice of wrong diets (Mair et al., 2003). These are behaviours that lead to a cumulative imbalance between damage and repair resulting in senescence. Is because of this that progress in reducing damage and in increasing repair are two fundamental causes of health improvement (Vaupel, 2010). Following this point of view, is very important to emphasize that senescence is being delayed not decelerated. Especially because, instead of a stretch in the period of senescence, senescence is being shifted to older ages.

There are two factors that are being pointed out as the main factors in the contribution to the postponement of senescence: prosperity and medicine (Vaupel, 2010). Prosperity is presented mainly because people with high resources have higher opportunities to live a healthier life due to their capability to satisfy the most basic needs (e.g., clothes, house with living conditions, healthy food, etc…). Medicine was pointed mainly because all the improvements associated with health are of major importance to all persons in their senescent process. Nevertheless, is the junction of these two factors that gives the major contribution to increase life expectancy, mostly because prosperity leads to higher education and consequent healthier and longer lives, and allows the population to have more opportunities to access better treatments.

Despite all the improvements that resulted in an increase in life expectancy, are people themselves that need to have proactive behaviours with the goal of achieve older ages in better shape: *"a person has little chance of surviving to very old age if he or she smokes cigarettes, gets little exercise and is grossly obese"*, however, *"even a person who strives to behave in a healthy manner has a probability of only a few percent of living to age 100 under current health conditions"* (Vaupel, 2010).

[1] Filipe Ribeiro (University of Évora/Max Planck Institute for Demographic Research, ribeiro@demogr.mpg.de)
Maria Filomena Mendes (University of Évora, mmendes@uevora.pt)

If all these improvements and resulting increase in life expectancy leaded to a decrease in the variance in age at death on one hand, on the other hand an increase in the average length of live is happening. Studies made about centenarians are also very important to understand mortality behaviours and in 2010, Jutta Gampe discovered that after age 110 the force of mortality presents a constant value of 0.7, implying an annual probability of death constant at a level of 50% per year.

2. Measuring Mortality

2.1. The Life-Table Aging Rate

The usual method to analyse and understand the mortality patterns is plotting the mortality rates in a logarithmic scale against age. In the most part of the cases this relation presents a linear pattern, and as consequence it is assumed that the associated slopes are constant. However, this slopes are not constant, and *"what appears to be an exponential increase in mortality with age may actually be an artefact resulting from forcing a straight line through data whose derivations are minimized due to a logarithmic transformation"* (Carey and Liedo, 1995).

Understanding the rate of aging is one of the most important steps to estimate in an accurate way the force of mortality for a population.

In 1990, Horiuchi and Coale proposed a mortality measure with the intention to give a step ahead in the age pattern analysis of death rates and that is different from the conventional way to examine age variations in mortality (plotting the logarithm of the death rate against age). The measure itself can be called the *age-specific rate of mortality change with age*, or in an easiest way, the *life-table aging rate* (LAR) like it was designated by Carey and Liedo in 1995, Horiuchi and Wilmoth in 1997 and 1998, and is denoted by $k(x)$:

$$k(x) = \frac{1}{\mu_x}\frac{d\mu_x}{dx} = \frac{dln(\mu_x)}{dx}$$

where $k(x)$, as it was explained, measures the rate of mortality change at age x.

According to the authors, this measure provides a better visual interpretation, when it is plotted, about the acceleration and deceleration in the mortality patterns and has at least four advantages. The first one is that this is a good tool to evaluate some of the mathematical mortality models, once that the age patterns of LAR implied by those models are significantly different. Secondly, it is also a plus in the understanding of heterogeneous populations, mainly because the age pattern of the obtained LAR should highlight the differences between subpopulations and their vulnerability to the risk of death. Thirdly, it is also useful in studying physiological aging due to the variations in the risk of death correlated with the pace of aging in LAR. Finally, the fourth advantage is the practical utility in detecting cohort mortality variations.

Horiuchi and Coale (1990), found that all the studied females populations presented a not constant value of $k(x)$, but instead, a *bell-shaped* pattern, where changes are systematic and that rises at younger old ages and after reaching a peak start to decline at older old ages. Males, on the other hand, did not present *bell-shaped* patterns in uniformly way, but fluctuating patterns instead. However, this deviance from the *bell-shaped* pattern is explained by the authors as a consequence of the First World War in some of the countries: *"it seems that those $k(x)$ curves that might be similar to the female curves have been confounded with cohort mortality variations that reflect long-term impacts of World War I upon the health of its survivors"*.

The obtained results, i.e., the *bell-shaped* patterns, and still following the authors can be explained due to a utilization of an estimation model that includes individual frailty, the Gamma-Gompertz-Makeham model. This means that mortality at younger ages is shaped by the chance factor and by selective survival at older ages.

2.2. The Force of Mortality

The instantaneous death rate, the hazard rate, or as usually used, the force of mortality, is a mechanism applied to measure the number of deaths per head of population per unit of time. The creation of a model that be able to explain mortality over age will be a huge step in demography.

Since early years that many efforts were being done trying to create a correct law that result in accurate results and that can be used to do forecast human mortality. Nonetheless, until now it was not possible to reach an agreement.

In the next steps it will be seen either how it can be measured the force of mortality, either how it can be estimated, giving a glance by some of the developed models.

Using the life table, it is possible to compute various probabilities involving mortality (Pollard, 1973). Based on this, and once that l_x is the life table survival function, the probability that an individual will survive from age *x* until age *x* + *t*, is given by l_{x+t}/l_x .

Letting μ_x be the force of mortality at age *x*, the probability of dying between age *x* and age *x* + *dx* is given by $\mu_x . dx$, where μ_x is:

$$\mu_x = -\frac{1}{l_x}\frac{dl_x}{dx} = -\frac{d}{dx}\ln l_x$$

and lx the survival function of a given cohort, and the number of occurrences, i.e., the number of deaths, between age *x* and age *x* + *dx* is – dl_x.

Benjamin Gompertz, in 1825, was one of the pioneers in estimating mortality, creating the first "law of mortality":

$$\mu_x = \alpha e^{\beta x}$$

where the force of mortality at age *x* – $[\mu_x]$, increases with age at a stable exponential rate. α is the mortality level and β the rate of increase in mortality with age, being both parameters positive.

3. Expected Results

From these methodologies, we expected, as Horiuchi and Coale, a *bell-shaped* pattern for both sexes, where an increase in mortality will be shown until old ages to present a decrease after. Once that different chosen countries will be observed, some similarities are expected, mainly among south European countries. However, is expected that all of them, or at least a great part, present a shift in the highest level of mortality to older ages when LAR is observed over the years.

Is also expected that some countries have a “faster” LAR development than others, and for males the highest mortality level be attained faster than for females.

The application of this methodology for different chosen causes of death will also show really interesting behaviours, where despite differences among countries in some chosen causes of death mortality levels, is also expected that in some of the chosen causes the highest values are attained faster when compared to another.

Then, observing the different force of mortality levels by the different countries, and applying some of the methodology to forecast mortality over age (e.g. Gompertz), it will be also possible to distinguish between rate of aging and the life-table aging rate. Here, we expect that the force of mortality be better approximated by the Gompertz law, as many authors saw before, and that besides different levels of mortality between countries, sex, and the chosen causes of death, the behaviours show no converge or divergence at any stage but, in opposition a parallel shape when plotted for older ages.

Bibliography:

Carey, J. R. & **Liedo**, P. (1995): Sex-specific life table aging rates in large medfly cohorts. Experimental Gerontology 30: 315 – 325, USA.

Gampe, J. (2010): Human mortality beyond age 110. In: H. Maier, J.G.B. Jeune, J.M. Robine, and J.W. Vaupel (eds.) Supercentenarians. Heidelberg: Springer: 219 – 230.

Gompertz, B. (1825): On the nature of the function expressive of the law of human mortality. London, UK: Philosophical Transactions Royal Society.

Horiuchi, S. & **Coale**, A. J. (1990): Age patterns of mortality for older women: An analysis using the age-specific rate of mortality change with age. Mathematical Population Studies 2(4): 245 – 267.

Horiuchi, S. & **Wilmoth**, J. R. (1997): Age patterns of the life-table aging rate for major causes of death in Japan, 1951-1990. Journal of Gerontology: Biological Sciences 52 A(1): B67–B77.

Horiuchi, S. & **Wilmoth**, J. R. (1998): Deceleration in the age pattern of mortality at older ages. Demography 35 (4): 391 – 412.

Oeppen, J. & **Vaupel**, J.W. (2002): Broken limits to life expectancy. Science 296, 1029-1031.

Pollard, J.H. (1973): Mathematical models for the growth of human populations. Cambridge University Press.

Vaupel, J. W. (2010): Biodemography of human aging. Nature 464(7288), 536-542.