# Statistical Analysis and Forecasting of Cause of Death Data: Novel Approaches and Insights

*Filipe Ribeiro*

Tese apresentada à Universidade de Évora
para obtenção do Grau de Doutor em Sociologia

ORIENTADORA : *Professora Doutora Maria Filomena Mendes*

INSTITUTO DE INVESTIGAÇÃO E FORMAÇÃO AVANÇADA

**To the memory of my grandfather, António**

# Acknowledgement

This thesis project was funded by the Fundação para a Ciência e Tecnologia (FCT) (SFRH/BD/71174/2010) and was developed in collaboration between CIDHEUS.UE, as national host institution, and the Max Planck Institute for Demographic Research (MPIDR), as the international host institution. I thank to all three for the opportunity and full support on the undergoing of this project.

During this process, many were the people that presented me with their support and that I want to show my gratitude. First of all, I particularly want to thank to my supervisor, Maria Filomena Mendes, for all the support (personal and scientific) and to make me believe that is possible to achieve our own dreams. I also want to thank to James Vaupel, for giving me the opportunity of working surrounded of the most incredible scientists and for all the thoughtful suggestions about my topic. It was an honor to be under his supervision while at the MPIDR. To Trifon Missov besides showing my entirely gratitude about his fully support, helpful and essential discussions, I want to respectfully say: "you're the MAN". Thanks for everything.

To the love of my life, my wife Lídia, companion in all adventures, I also would like to show my entire gratitude. Without her support and understanding, I'd never be able to be successful. Thanks for being a part of me.

To my family, despite don't understanding well what is and why I'm following this path, I want to thanks for being always there and for being a support even without realizing. Mom, in the end, the choice of Évora for academic studies was not so bad, hein? To my brother, just thanks for being the best brother in the world. Keep in the right track!

Across this process, that also includes a participation in the European Doctoral School of Demography to which I am glad to be a former student, many other precious persons were showing up in the way, being an important part of it and revealing to be good friends. Robert, Julia, Andy, Angelo, Joana, Elena, Bartek, Fred and Jordi, were the ice on the cake that comes from this adventure. My many thanks to all of you. Robert, it was amazing to share an office with a friend like you. Without your help and essential discussions this wouldn't be so funny.

To all my friends at “home”, Ivo, Carlos, both Ana’s, both João Pedro’s, and many others, thanks for not letting physical distance to vanish our friendship. Love you all.

During these last months of work, my psychological sanity was almost kept intact mainly due to Strauss, Sushi, Jack and the pet’s friendly gang, remembering me always to breath and to keep calm.

Last, but not the least, I also would like to express my special gratitude to Maria da Graça Morais, Graça Magalhães, José G. Dias, Frans Willekens, Thomas Sobotka and Isabel T. Oliveira for all the important support to accomplish this goal successfully.

**Resume**

Substantial improvements in public health resulted in exceptional increases in life expectancy. Nevertheless, mortality related processes have been change differentially at distinctive stages and accordingly with different related processes. To understand and analyze properly the mortality phenomena under a demographic point of view, it is indispensable to study populations as a heterogeneous mixture of individuals. Within this heterogeneous mixture, individuals are frailer than others and there are diverse risks of death competing with each other to be successful. Under this assumption, it is possible to differentiate between the individual pace of mortality increase with age, i.e., the individual rate of aging and the population rate of aging. If the first proves to be a biological constant invariant across humans and over time, besides a great demographic and biological finding, many research disciplines and policymakers may take advantage of previous knowledge and validated information. Insurance companies, e.g., could make use of this previous knowledge to elaborate a more precise and complete evaluation of risks. Thus, coherent and accurate mortality forecasts could be also performed. But if this hypothesis proves to be wrong, recent coherent compositional approaches are available and need to be tested to fulfill the need for detailed forecast discriminated by cause-specific probabilities. Nevertheless, in order to let doubts aside, a distinction between population and individual rate of aging needs to be realized in a clear end complete perspective.

Briefly, in this piece of research we develop a consistent contemporary exploration of mortality patterns, under a heterogeneous perspective, and make use of obtained information to provide not only an interesting demographic and social perspective, but also a tool for decision-makers to evaluate and identify possible points of intervention in what concerns to public health.

# Análise Estatística e Métodos de Previsão de Diferentes Causas de Morte: Uma Nova Abordagem


## Resumo

De uma forma geral, apesar da evolução extremamente positiva dos comportamentos de mortalidade se traduzir em indicadores-resumo como é o caso da esperança de vida à nascença, ao longo dos anos, as melhorias registadas na saúde pública, encontram-se relacionada com diversos processos distintos. A elaboração de uma análise completa e detalhada do fenómeno da mortalidade sob uma perspectiva demográfica, torna-se assim, unicamente possível se esta análise tiver em conta a composição heterogenia da população. Por entre esta heterogeneidade populacional, existem indivíduos considerados mais frágeis do que outros, onde diversos riscos associados à probabilidade de morte, competem entre si para conseguirem levar a melhor sobre o indivíduo. Deste modo, tendo em conta esta conjetura, torna-se possível diferenciar entre o ritmo de aumento nos níveis de mortalidade por idade, i.e., a velocidade de envelhecimento, tanto associada ao próprio indivíduo, como à população em si. Caso a teoria de que o primeiro indicador será uma constante biológica invariável entre indivíduos e por todo o seu tempo de vida se verificar verdadeira, apesar de ser uma importante descoberta ao nível biológico e demográfico, resultará em informação relevante tanto para diversas áreas de investigação, como para decisores políticos. Companhias de seguros, por exemplo, poderiam utilizar este conhecimento prévio e elaborar uma avaliação de riscos muito mais precisa. Consequentemente, a elaboração de previsões de mortalidade mais precisas e coerentes seria uma realidade. No entanto, se esta teoria não for validada, os resultados obtidos não deixam de ser importantes, pois contribuirão sempre para trabalho futuro, e novas abordagens metodológicas consideradas coerentes para a previsão dos padrões de mortalidade continuam a emergir e a necessitar de serem testadas.

Resumidamente, com este estudo desenvolveu-se uma análise rigorosa e contemporânea dos padrões de mortalidade tendo em conta a heterogeneidade populacional, fazendo uso da informação obtida para elaborar não só uma análise interessante do ponto de vista demográfico, mas também proporcionar informação indispensável para a sociedade e para os decisores políticos.

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# CHAPTER 1

# INTRODUCTION

## 1.1. Mortality trajectories and related processes

"How long do we will live?" is one of the most important questions that every individual, as human being, would like to have an answer for. Oeppen and Vaupel (2002) did not answer to this question, but demonstrated that life expectancy is breaking old theorized limits and with time every human can expect to live longer and with improved health.

It is well known that the increase in human longevity occurs due to significant improvements in health and consequent reductions in mortality rates. This improvement can be explained by two main phases, firstly, were massive reductions that occurred in mortality at younger ages, secondly, were the reductions in mortality rates associated to old-age on the second half of the last century, especially after age 65 (see e.g., Oeppen and Vaupel, 2002). Today, the high levels of mortality of the past are being experienced later in life. Nevertheless, observed mortality reductions are not following the same rhythm of decrease across different causes-of-death (from which *circulatory system diseases* and *neoplasms* are assuming the most important role), countries, ages, or even, between sexes (see e.g., Meslé, 2006). Mortality improvements increased, consequently, human longevity and originated considerable negative consequences in what concerns population aging. Nevertheless, individuals are reaching older ages in better physiological conditions (see e.g., Vaupel, 2010).

As acknowledged, mortality rates present different evolutionary patterns across populations, sexes and causes of death. However, it's not sure whether all individuals share the same rate of aging, i.e., the same chance of death across age. Vaupel's hypothesis (2010) suggests that the rate of aging, defined as the relative derivative of the baseline risk of dying, might be a biological constant for every species. Previous studies (Gampe, 2010) found evidence for a leveling-off of human mortality at ages 110-114, speaking in favor of a relative-risk model (Missov and Vaupel, 2015) with a Gompertz-Makeham baseline hazard (Gompertz, 1825;

Makeham, 1860). Unobserved heterogeneity (frailty) can be captured by a gamma distribution with a unit mean and $\gamma$ variance at the starting age (Vaupel et al., 1979; Missov and Finkelstein, 2011; Missov and Vaupel, 2015). This leads to the gamma-Gompertz-Makeham frailty model (Vaupel et al., 1979) as the model basis to obtain accurate estimates in what concerns the individual rate of aging.

Nevertheless, in opposition with the rate at which age-specific death rates increase, known as the life-table aging rate (LAR) (Horiuchi and Coale, 1990), the individual rate of aging is defined as the relative derivative of the baseline hazard of death if the aging process is captured by a Gompertz curve. If the first is constant across age, the second presents a well-defined and characteristic bell-shaped pattern, widely studied since Gompertz (1825), and consequently finding evidence for a mortality deceleration at older ages. The force of mortality for an entire population is described by the associated age-specific death rates, resulting from a "contribution" of different subpopulations under diverse specific mortality conditions (Beard 1959; Vaupel et al., 1979).

Summarizing, mortality research necessarily requests to analyze population as a heterogeneous group composed by different subpopulations where the individuals are exposed to the hazard of death in very different and random ways, and as a whole, population present distinctive behaviors from the individuals. Thus, every individual in overall population or across different subpopulations is continuously exposed to different risks of death. *"Because death is not a repetitive event and is usually attributed to a single cause, these risks compete with one another for the life of a person. Competing risks must be considered in any cause-specific mortality analysis"* (Chiang, 1991).

A proper evaluation of those risks contributes to a complete and accurate evaluation of probabilities of death, which are important to extrapolate to the future and contribute to decision and policymakers evaluate where to intervene. In this way, accurate forecasts discriminating mortality by cause of death are indispensable. Nevertheless, in a theoretical perspective many authors support that breaking down mortality forecasts by cause results in higher accuracy but practice also proves the opposite (Booth and Tickle, 2008). Studies like the one from Wilmoth (1995) found that decomposing mortality forecasts result not-rarely in higher mortality forecasts. Oeppen (2008) makes use from one of the most known statistical models to forecast

mortality trends over time, the Lee-Carter model (Lee and Carter, 1992), and expressed in a Compositional Data Analysis (CoDa) its equivalent definition, avoiding those issues. In the CoDa equivalent model, the constraint imposed by the sum to the unit of each of the compositional vector, ensures that *"changes in the density by age and cause have to be compensated by changes in other ages and causes"* (Oeppen, 2008).

## 1.2. Motivation and aim of the study

The main motivation of this study comes from the interest in evaluating Vaupel's hypothesis about the rate of individual aging. If the findings prove the hypothesis to be correct, its results are not only an important major finding for demography but also for biology. Demographic specific areas as, e.g., mortality forecasts may take advantage of more important and previously known information to elaborate more accurate forecasts. Nevertheless, to explore properly this subject, it is fundamental to understand mortality as a whole, analyzing its evolutionary patterns as an outcome of a heterogeneous mixture of individuals. At the same time, it is indispensable to differentiate between individual and population rate of aging. The knowledge resultant from this research is an indispensable tool to consolidate precise information for decision and policymakers.

Consequently, the overall aim of this study is to contribute to mortality research with important knowledge that comes from investigating mortality trends and its related processes. In this study, we focus essentially on the detailed evaluation of mortality trends discriminating between who and what is contributing the most for the observed increases in human longevity, and which are the leading causes of death across different countries. We also identify how Japan becomes the leading country in what concerns to life expectancy. We do not only focus on longevity measures, as life expectancy, but also on alternative measures of longevity as the median and modal age at death, to give a complete evolutionary perspective. Across entire research, discriminating the analysis by cause of death was a constant.

In the end, we shed light into mortality research by answering questions as: (1) how mortality trends developed across time; (2) what were the registered paces of increase in longevity; (3) are neoplasms consolidating as the cause of death with major impact in mortality, or can we identify one other that needs special attention;

(4) is the reduction in mortality at older ages the most important source of life expectancy increase; (5) is that really true that all individuals age at the same rate; (6) how and why the rate of individual aging is different from the one for individuals; (7) can we identify any relation between the age where the rate of aging for the entire population reaches its maximum with changes in the slope of life expectancy increase; (8) its is really possible to elaborate coherent forecasts of mortality trends when discriminating mortality by different causes of death; (9) if different causes of death present dissimilar rates of aging for individuals, is it still possible to aggregate them based on similar trends; and lastly, (10) which causes of death will play a major role in a near future.

## 1.3. Outline of the study

Including the present Introduction, this study consists in six different but complementary chapters. In *Chapter 2*, is provided an empirical overview about the evolution of mortality trends and its impact on overall longevity. The study relies on three different measures of longevity (life expectancy at birth, median and modal age at death) in order to evaluate how and why possible positive evolutions in mortality rates contributed to the increasing lifespan registered across time. Here it is also our intention to explore the female/male gap and understand why Japan is a standard model in the last years. To better understand this evolution, the analysis cannot be simply restricted to overall mortality, and we not only discriminate the contribution that the observed reductions in mortality by age had to life expectancy at birth improvement, but also complement those improvements adding information by cause of death. The analysis on the duality between early and old age mortality is a constant explored across the chapter.

In *Chapter 3*, our analysis focused entirely on the most important agent in demography, i.e., in the individual itself. Vaupel (2010) hypothesizes that *"except for individuals with accelerated aging disorders, all other humans have a similar and perhaps, essentially the same, rate of increase in mortality with age"*, i.e., the same rate of aging, which might be a biological constant invariant across humans and over time. Thus, we test Vaupel's hypothesis by studying major groups of cause of death under a gamma-Gompertz-Makeham framework, seeking evidence to confirm or

refute the stated hypothesis by estimating the individual rate of aging by taking each cause as a subpopulation.

The analysis accomplished in *Chapter 4*, is elaborated once again under a gamma-Gompertz-Makeham framework, refers now to the population rate of aging, or as it is widely known, to the life table aging rate. The analysis explored in this chapter can be summarized in three stages: (1) first, we fit the model to the countries selected based on the qualitatively different evolutionary patterns of life expectancy at birth over time; (2) elaborate on the possible relationship between the population rate of aging and the rate of life expectancy increase in the selected countries, evaluating simultaneously how estimated patterns reflect the age patterns of mortality deceleration for overall and cause-specific mortality; and lastly, (3) we test the "heterogeneity hypothesis" by Horiuchi and Wilmoth (1998), which states that for the characteristic measure's bell-shaped pattern a) deceleration occurs for the most major CODs, being less pronounced for the ones with lower death rates, and b) mortality deceleration should occur at later ages due to selection effects. The age at which the maximum value for life table aging rate is obtained is called here the age of mortality deceleration, and is used as a new measure of longevity that is used to evaluate how it reacts to changes in life expectancy dynamics.

In *Chapter 5*, we elaborate cause-specific mortality forecasts in order to provide not only an interesting demographic analysis, but also to decision-makers a tool to evaluate and identify possible points of intervention in what concerns to public health. In order to avoid overestimating mortality rates for overall mortality after summing up the obtained results, we make use of Oeppen's (2008) suggestion of expressing the original Lee-Carter method to forecast mortality trends in compositional form. We elaborate thus, coherent medium-term (30 years horizon) forecasts distinguishable by cause of death for distinctive countries with different cultural backgrounds and characteristic mortality patterns.

Finally, *Chapter 6* concludes, based on a brief, but complete summary, of the most important findings achieved throughout previous chapters. An introspective discussion about the work done and insights resulting from the study is included, as well as the limitations that constrained the approach are identified. Additionally, an outlook for future challenges is also provided.

# CHAPTER 2

# THE RAISING OF LIFE EXPECTANCY IN EUROPE AND THE BEST-PRACTICE COUNTRY: A CROSS-SECTIONAL COMPARISON

## 2.1. Introduction

It is well known that, across the years, mortality improvement originated an increase on the average length of live, and consequently, the variance in age at death has decreased. This improvement occurred in two phases, being the first one connected with reductions in the mortality rates at younger ages, and the second one due to improvements in survival after age 65. Therefore, human life expectancy is rising to values thought to be not attainable and is breaking old theorized limits (Oeppen and Vaupel, 2002). The high levels of mortality of the past are now experienced at older ages, suggesting that senescence is being delayed and not stretched (Vaupel, 2010). This brings up the discussion about the concepts of aging and senescence, and if aging is an intrinsic characteristic of life course, senescence becomes more likely as life proceeds (Hamilton, 1966) but is not an inevitable condition (Baudisch, 2008). Nevertheless, if aging can be also connected with some good variation in human condition, as becoming wiser for example, senescence can be described as the decline in physiological functioning with age (Comfort, 1964; Finch, 1990).

In this chapter, we evaluate how and why the registered evolutions in mortality rates contributed positively to life expectancy increase, discriminating different patterns and trying to understand the observed gap between males and females and why Japan is on the leading. Thus, we elaborate single and multiple-decrement life-tables, with the intention to discriminate the impact that each cause of death (COD) has in life expectancy; and applied two distinct decomposition methodologies that allow to evaluate the gains in life expectancy at birth accordingly to different contributes across ages (Arriaga, 1984) and discriminate those contributions also by cause (Shkolnikov et al., 2001).

## 2.2. The epidemiologic transition and the evolution of mortality rates

Together with the decline in mortality rates, the high rates of mortality are shifting to older ages worldwide. If we brake down mortality rates accordingly to different CODs, we can conclude that distinctive patterns of evolution can be identified and the different causes present dissimilar patterns across distinct nations. If in the past were the infectious diseases that strongly affected entire populations, nowadays, neoplasms are leading in almost all of the developed countries. In this way, the elimination of any preventable cause will result in an increasing lifespan, having impact not only in the overall mortality, but as well, in age-specific mortality rates.

All these developments suggest that mortality advances are closely related to health improvements, mainly due to population prosperity and medicine development. Preventive medicine diffusion among medical doctors played a major important role in medicine development, together with the identification of the microbiological agents from infectious diseases (Morais, 2002). If prosperity represents better opportunities to live a healthier life due to better chances in satisfying some basic needs (at least in most developed countries), advances in medicine provide a better approach to compete with most severe diseases and allows the population to have more opportunities to access better treatments. Nevertheless, measuring health is not an easy task due to its subjectivity, so, "*mortality is by far the most important readily and reliably measured index of health*" (Vaupel, 2010), also agreed by Santana (2005).

The theory of epidemiological transition presented by Omran in 1971, was the first relating the nature of the connection between the observed CODs with the age patterns of mortality for one population, pointing out that mortality declines were related with the reductions observed in the deaths caused by infectious diseases and continuous shift of degenerative diseases to older ages. In this situation, children and young women were the ones with more benefits with increases in life expectancy (Omran, 1971). The theory of epidemiologic transition try to combine the different factors that play an important role in the past mortality trends (Meslé and Vallin, 2006), presenting three main stages, or like it was called by Omran, three epidemiologic ages. The first age, is denominated as the age of pestilence and famine,

which was characterized by high rates of mortality and low life expectancy (around 30 years of average life), marked by the predominance of infectious diseases, endemics, epidemics and famine. The second stage, or age, is documented as the age of receding pandemics, where a strong rise in life expectancy was observed, mainly due to the lower frequency of epidemics and fewer registered cases of endemic infectious diseases. Finally, during the third age, the age of degenerative and man-made diseases, a continuous decline and consequent stabilization of mortality at very low rates was presented. In this last stage, the pace of increase in life expectancy starts to decelerate and seems to reach a threshold.

Nonetheless, the mortality progress is being continuous and the epidemiological transition theory proposed by Omran is now considered, as discussed by Meslé and Vallin in 2006, as becoming outdated, despite that the three-presented ages reflected accurately the reality until the end of the 1960s. Following the authors, a massive decline in cardiovascular diseases in the western countries resulted in a new acceleration in the pace of increase of life expectancy in the early 1970s. Still, Meslé and Vallin, find it preferable to adopt the concept of health transition, once that it is a wider concept and if in a first phase includes the gains in life expectancy related with the reductions in the levels of mortality due to infectious diseases, a second phase is advanced, marked by the decline in cardiovascular diseases. The concept of health transition also opens space for the possibility of future changes originated by reductions in mortality rates due to different causes, like the example of cancer, or due to delays in senescence, already expressed by Vaupel in 2010.

As expected, the presented stages that characterize the mortality progress did not occur at the same precise time across different countries, presenting major disparities when mortality is focused on COD patterns. Even within the same country, it is possible to identify diverse evolutionary stages at the regional level possibly closely related to the socioeconomic development stage of a region. Oliveira et al. in 1994, found a clear and distinctive level of socioeconomic development between the interior north and the south coast of Portugal. In this study, the authors also identified a strong evidence of deaths caused by malignant neoplasms, ischaemic heart diseases and tuberculosis. On late 20$^{th}$ century, infectious and parasitic diseases and diseases of the circulatory system declined and circulatory system diseases were negatively influencing health of males above age 45 (Morais, 2002). Oliveira and Mendes (2010)

also found in their study, that in Portugal, the life expectancy gap between sexes was increasing till middle 1990s, only declining afterwards.

Comparing Portugal and Spain, Canudas-Romo et al. (2008), concluded that the first was ahead in what concerns to positive life expectancy improvements, diminishing the registered gap between both countries, however, is still behind its south European neighbors (Fernandes, 2007).

Following the COD statistics published by the EUROSTAT (2014), we can realize that in a general way, between 2004 and 2010 cancer related death rates diminished 8.4 % and 4.8 % from females and males, respectively, across the European Union countries. Deaths caused by ischaemic heart diseases and transport accidents registered were reduced in more than 20 %. These results correspond to a very positive evolution, but neoplasms (principal cause) and diseases of the circulatory system are still the leading CODs. The most common causes related to the circulatory system diseases are the ischaemic heart diseases, affecting mainly, e.g., countries like Slovakia, Hungary and Estonia. Portugal, France and Spain are among the countries with lower death rates related to ischaemic heart diseases. Identified as the third most common cause across the European Union, respiratory system diseases presented the highest death rates in the United Kingdom, Denmark, Ireland and Portugal. In Japan, the results presented in the Japan Statistical Yearbook of 2014, showed a very identical pattern, once that neoplasms, circulatory and respiratory system diseases are the most recorded.

## 2.3. Methods

### 2.3.1. Measuring longevity: life expectancy, median and mode

Population longevity is often measured in terms of life expectancy. However, other measures can provide different insights about longevity trends and better understanding about possible differences observed across countries. This is why we choose to include in this analysis, the median and modal ages at death.

If life expectancy can be calculated as the mean age at death, taking the single decrement life-table methodology we have:

$$e(x,t) = \frac{T(x,t)}{l(x,t)} \tag{2.1}$$

where, *e(x, t)* is the life expectancy at age *x* and time *t*, *l(x, t)* is the proportion of people alive at age *x*, and *T(x, t)* the person-years lived above age *x*.

The median age at death (*Md, t*) is the age by which half of the population at time *t* is dead, i.e., when the survival function equals 0.5: *l*(*Md, t*)=0.5. So, letting *x* and *x*+1 be the ages of the interval in which *l*(*Md, t*)=0.5 is located, the median age at death is given by:

$$Md(t) = x + \frac{[0.5 - l(x,t)]}{[l(x+1,t) - l(x,t)]} \tag{2.2}$$

Lastly, the modal age at death is the age when most of the deaths occur: *M*(*t*) = {*x* | max[*d*(*x*, *t*)]}. Here, *d*(*x*, *t*) is the life-table density function for the distribution of deaths. Nevertheless, and taking into account the age distribution of deaths, two modes should be distinguished (Canudas-Romo, 2010): one at age 0, where people die soon after birth, and a late mode found at older ages. In this essay, our focus is in the second one, i.e., the late modal age at death, and for this only deaths occurred after age 5 are considered:

$$M(t) = \{x \mid max[d(x,t)] \text{ for } x > 5\} \tag{2.3}$$

To obtain a precise result, Kannisto (2001) proposed an approach that allows obtaining a modal age at death with decimal precision. In this way, taking *x* as the age with the highest number of deaths in life the table at time *t*, we have:

$$M(t) = x + \frac{[d(x,t) - d(x-1,t)]}{[d(x,t) - d(x-1,t)] + [d(x,t) - d(x+1,t)]} \tag{2.4}$$

### 2.3.2. Multiple decrement life-tables

If the conventional construction of a life-table is described as a singular decrement process in which individuals have only one mode of exit from a defined state,

multiple decrement processes, like the name suggests, are the ones in which the individuals have more than one mode to exit. These processes can be used in a set of different approaches, e.g., in the analysis of fertility, migration or nuptiality. Nevertheless, and if one of our main goals is to interpret the impact that each COD group has in population life expectancy, multiple decrement life-tables, period based, will be constructed. Here, the intention is to estimate which would be the expected life expectancy in the absence of a certain cause. However, many critics are raised against this approach because there are significant competing risks to which all individuals of a population are exposed, and if an individual doesn't die from a certain COD, it is possible that another cause attempts to be successful.

In this way, if the conventional life expectancy is given by equation (2.1), the life expectancy that a population can expect in the absence of a certain disease id given by:

$$e^{-i}(x,t) = \frac{T^{-i}(x,t)}{l^{-i}(x,t)} \tag{2.5}$$

where -*i* represents the absence of a certain cause.

### 2.3.3. Decomposing differences in life expectancies

The simple measure of changes in life expectancy at birth between two different periods, populations or CODs, is very useful to calculate the rate of increase in life expectancy across time or countries, or even simply to quantify the increase itself. However, it is also very useful to estimate how mortality differences in a specific age group can contribute to the total difference in life expectancy. In this chapter, one of our goals is also to define the importance of older ages in life expectancy increment. To reach our goal, two different methodologies were chosen: firstly, the one developed by Arriaga in 1984 (and explained by Preston et. al. in 2001, for example), for the decomposition of total increases in life expectancy; and, secondly, the methodology developed by Shkolnikov et. al. in 2001, that will also allow to quantify the contribution of different age groups, but, identifying at the same time, the contributions of different CODs.

Starting by the discrete approach proposed by Arriaga (1984), we have that the total effect, ${}_n\Delta_x$, of a difference in mortality rates between ages $x$ and $x + n$, is given by:

$$ {}_n\Delta_x = \frac{l_x^1}{l_0^1}\left(\frac{{}_nL_x^2}{l_x^2} - \frac{{}_nL_x^1}{l_x^1}\right) + \frac{T_{x+n}^2}{l_0^1}\left(\frac{l_x^1}{l_x^2} - \frac{l_{x+n}^1}{l_{x+n}^2}\right) \tag{2.6} $$

where:

$$ e_0^2 - e_0^1 = \sum_0^\infty {}_n\Delta_x \tag{2.7} $$

If the first term of equation (2.6) corresponds to the direct effect of a change in mortality rates, the second term, corresponds to the sum of the indirect and interaction effects, i.e., the contribution of the exposition to new mortality conditions. For the open-ended age interval, there will be only a direct effect, resulting in the following equation:

$$ {}_\infty\Delta_x = \frac{l_x^1}{l_0^1}\left(\frac{T_x^2}{l_x^2} - \frac{T_x^1}{l_x^1}\right) \tag{2.8} $$

Nevertheless, in presence of cause-specific mortality data, this approach can take a supplementary step and a further decomposition according different CODs can be performed. That was the intention of Shkolnikov et. al. in 2001, with the presentation of a new method that allows to decompose the differences between life expectancy by age and CODs. Here, the difference between the observed life expectancy for two populations between ages $x$ and $x + n$ and CODs $j$, is given by:

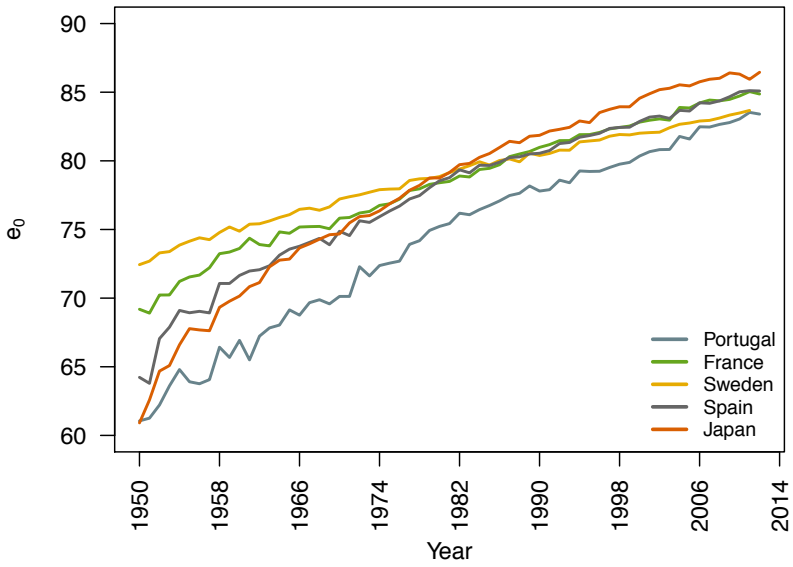
$$ {}_ne_{x,j} = \frac{{}_nM_{x,j}^1 - {}_nM_{x,j}^2}{{}_nM_x^1 - {}_nM_x^2}\Delta_x \tag{2.9} $$

where, ${}_nM_{x,j}^1$ and ${}_nM_{x,j}^2$ are the central death rates for two different populations between ages $x$ and $x + n$ and cause $j$. Additionally, ${}_nM_x^1$ and ${}_nM_x^2$ also correspond to the central death rates for the same two populations, but now, for all causes combined.

## 2.4. Data

Country selection was based on the qualitatively different patterns of life expectancy evolution over time, where France and Sweden, registering a high life expectancy at birth already in the 1950s, experienced a drop in the life expectancy rate of increase in the following decades; Spain, Portugal and Japan experienced a low life expectancy at birth in the 1950s, but the rates of increase surpassed the life expectancy leaders at the time, and the three countries caught up and the values of life expectancy in Spain even surpassed the ones registered in Sweden. Japan, registers today the highest life expectancy in the world (Figure 2.1).

**Figure 2.1:** Female life expectancy for selected countries, 1950-2012




**Source:** HMD 2014, own elaboration

Data on *overall death counts* $D(x, y)$ and *exposures* $E(x, y)$ derived from the *Human Mortality Database* (HMD 2014: www.mortality.org) and *deaths by cause* $D_i(x, y)$ from the *World Health Organization Mortality Database* (WHOMD 2014).

WHOMD COD data are only available by five-year age groups and once that we extract death counts according to the 10th International Classification of Diseases (ICD), our timeline in what concerns to COD is restricted essentially to the last decade (depending on the country data availability). Data codification corresponds to the ICD 10 detailed 3rd and 4th character list classification and was rearranged in 8 main COD groups: 1) Neoplasms, 2) Ischaemic Heart Diseases; 3) Cerebrovascular

Diseases; 4) Remaining Diseases of the Circulatory System; 5) Diseases of the Respiratory System; 6) Diseases of the Digestive System; 7) External Causes of Death; and 8) Remaining Causes of Death. Following the WHO recommendation (1977) to avoid uncertainty that comes from changes and updates in the classification system, we base our research on the *underlying cause-of-death*, *i.e.*, the disease or injury, which initiated the series of events that lead to death.

## 2.5. Results

### 2.5.1. Life expectancy patterns and the best-practice country

As discussed before, life expectancy is increasing with time due to general improvements in public health. Nevertheless, different countries present different evolutionary patterns and rates of increase in life expectancy.

Table 2.1 not only presents information about life expectancy values observed in 1950 and 2012 (due to data availability, 2011 for Sweden) for males and females, but also ranks the countries from higher to lower values. In the slightly more than 60 years of analysis, we can realize that major increases in life expectancy values were verified. In 1950, Japan, independently of the sex, was on the bottom, with lower life expectancy at birth. Sweden, was at the time, leading, with a life expectancy at birth of 72.44 and 69.83, for females and males, respectively. Thus, between those two countries existed a gap of 11.53 years for females and 14.04 years for males.

Recently, for the latest available year, Japan is on the "*pole position*": a Japanese female newborn in the year 2012 could expect to live on average 86.45 years and a newborn male 79.96. If in the female case, Sweden is now presenting very similar values to the Portuguese case (Sweden: 83.67, Portugal: 83.41), expecting to live on average almost 3 years less (2.78) than a Japanese one, males are ranked on the second position with a gap lower than one year (0.16).

Despite the changes on the life expectancy ranking for the selected countries, we can denote a higher proximity between the presented values in more recent periods. For the most recent available year, the registered gap between countries for both sexes separately, is roughly 3. Nevertheless, the gap between males and females life expectancy at birth is still high. For the observed countries, the average difference between sexes in the year of 1950 was 4.37 and in 2012 increases to 5.73. Further,

breaking down the values of life expectancy by decade will give a better understanding about why the average difference between sexes increased.

**Table 2.1:** Ranking Countries by Life Expectancy

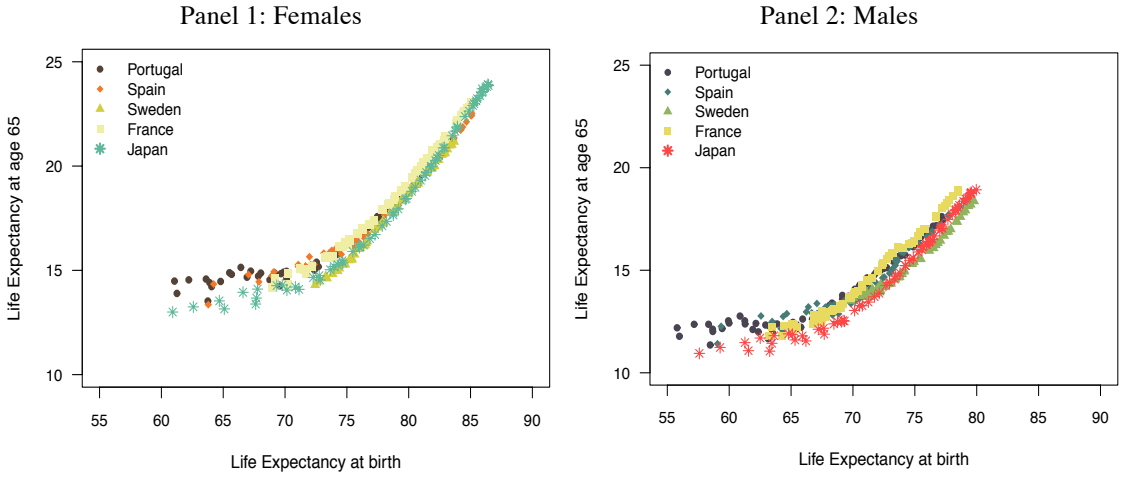
| L. E. Ranking | Females | | | | Males | | | |
|---|---|---|---|---|---|---|---|---|
| | 1950 | | 2012 | | 1950 | | 2012 | |
| | Country | $e_0$ | Country | $e_0$ | Country | $e_0$ | Country | $e_0$ |
| 1 | **Sweden** | 72.44 | **Japan** | 86.45 | **Sweden** | 69.83 | **Japan** | 79.96 |
| 2 | **France** | 69.19 | **Spain** | 85.09 | **France** | 63.43 | **Sweden*** | 79.80 |
| 3 | **Spain** | 64.23 | **France** | 84.87 | **Spain** | 59.35 | **Spain** | 79.33 |
| 4 | **Portugal** | 61.06 | **Sweden*** | 83.67 | **Japan** | 57.59 | **France** | 78.51 |
| 5 | **Japan** | 60.91 | **Portugal** | 83.41 | **Portugal** | 55.79 | **Portugal** | 77.26 |

* Due to data availability refers to 2011

**Source:** HMD 2014, own elaboration

Figure 2.2 represents both, life expectancy at birth and at age 65, for males and females from 1950 to the last available year, registered on the five selected countries. As expected, the recorded values present a clear and positive evolution of both longevity indicators, but if we imagine a two-break segmented regression line over the dots, a distinctive difference in the slope of life expectancy increase can be recognized. Plus, it was only when life expectancy at birth reached values around 75 for females and 70 for males, that life expectancy at age 65 started to increase significantly.

**Figure 2.2:** The evolution of Life Expectancy between 1950 and 2011/12




**Source:** HMD 2014, own elaboration

Breaking down the values of life expectancy at birth increase by decade (Table 2.2[1]) demonstrates that for all countries and both sexes, but Swedish males, were the 1950s that recorded the highest increase of the analysis. On the other hand, after the year 2000, Portugal was the country that recorded the highest increase in opposition with Japan and Swedish females.

Generally, it can be also said that in the last 3 decades, Japan is the country that presents lower life expectancy increase and Swedish males are the ones that, in the same timeline, present higher improvements when compared with the first 3 previous decades. Males, when compared with females, present higher improvements in the last 3 decades, and the Portuguese ones recorded the highest observed improvement between the year 2000 and 2012. Thus, we can conclude, that despite the average gap between sexes have increased between 1950 and 2012, in the last decades, males are catching up and becoming nearer to female values of life expectancy.

**Table 2.2:** Quantifying the increase of life expectancy at birth by decade

| Period | Portugal | | France | | Sweden* | | Spain | | Japan | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| **1950 - 1960** | 5.49 | 5.87 | 3.60 | 4.43 | 1.41 | 2.44 | 7.32 | 7.42 | 7.73 | 9.24 |
| **1960 - 1970** | 2.60 | 3.20 | 1.35 | 2.21 | 1.01 | 2.34 | 2.65 | 3.22 | 4.00 | 4.53 |
| **1970 - 1980** | 4.22 | 5.10 | 1.78 | 2.58 | 0.54 | 1.63 | 3.07 | 3.68 | 4.06 | 4.08 |
| **1980 - 1990** | 2.66 | 2.57 | 2.57 | 2.58 | 2.03 | 1.54 | 1.03 | 2.00 | 2.55 | 3.11 |
| **1990 - 2000** | 2.49 | 2.55 | 2.52 | 1.84 | 2.57 | 1.62 | 2.57 | 2.32 | 1.75 | 2.70 |
| **2000 - 2012** | 4.00 | 3.06 | 3.26 | 2.05 | 2.42 | 1.66 | 3.36 | 2.22 | 2.29 | 1.89 |

* Due to data availability last year is 2011

**Source:** HMD 2014, own elaboration

Notwithstanding life expectancy as the most common used measure to evaluate human longevity, it is important, not only to policymakers specifically, but also for decision-makers in general, to identify when is half of the population of a country dying or when are occurring most observations.

Tables 2.3 and 2.4 present two alternative measures of longevity to life expectancy: the median and the modal age at death. Starting with the analysis of Table 2.3, one can realize that, normally, 50 % of the deceases occur later than the

[1] Whenever tables are presented with color graduation, it means that red colors recognize higher values

average (life expectancy), and the age where the highest number of deaths is recorded, is even later. In the year of 1950, for the five countries, 50 % of females deceased, approximately around age 74 (on average) and on last decade the value increased to about 88 years. From an average modal age at death of 80.50 in 1950, the female modal age at death in 2012 increased to an average of 90.24.

**Table 2.3:** Life Expectancy at birth, Median and Modal age at death for Females

| | Year | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2012 | Tot. Inc. | Inc. Rate[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| | $e_0$ | 61.06 | 66.92 | 70.12 | 75.22 | 77.80 | 80.35 | 83.41 | **22.35** | **4.26** |
| **Portugal** | **Median** | 72.59 | 75.80 | 76.79 | 79.34 | 81.24 | 83.35 | 86.04 | **13.44** | **2.56** |
| | **Mode** | 80.47 | 78.49 | 78.55 | 82.87 | 83.86 | 85.82 | 89.17 | **8.70** | **1.66** |
| | $e_0$ | 69.19 | 73.62 | 75.82 | 78.41 | 80.98 | 82.82 | 84.87 | **15.68** | **2.99** |
| **France** | **Median** | 75.65 | 78.21 | 79.90 | 82.08 | 84.42 | 86.09 | 88.05 | **12.40** | **2.36** |
| | **Mode** | 80.63 | 81.86 | 82.77 | 85.12 | 86.92 | 88.64 | 90.55 | **9.91** | **1.89** |
| | $e_0$ | 72.44 | 74.88 | 77.22 | 78.85 | 80.39 | 82.01 | 83.67 | **11.23** | **2.17** |
| **Sweden[2]** | **Median** | 76.51 | 78.30 | 80.45 | 81.87 | 83.35 | 84.70 | 86.36 | **9.85** | **1.91** |
| | **Mode** | 80.45 | 81.75 | 82.15 | 85.22 | 86.48 | 88.35 | 89.36 | **8.90** | **1.72** |
| | $e_0$ | 64.23 | 71.65 | 74.87 | 78.55 | 80.55 | 82.87 | 85.09 | **20.86** | **3.97** |
| **Spain** | **Median** | 73.43 | 77.20 | 79.05 | 81.78 | 83.68 | 85.60 | 87.65 | **14.22** | **2.71** |
| | **Mode** | 80.47 | 80.36 | 82.75 | 84.63 | 86.59 | 88.11 | 89.95 | **9.48** | **1.80** |
| | $e_0$ | 60.91 | 70.15 | 74.68 | 78.75 | 81.86 | 84.56 | 86.45 | **25.54** | **4.86** |
| **Japan** | **Median** | 69.76 | 75.45 | 78.25 | 81.78 | 84.70 | 87.42 | 89.26 | **19.50** | **3.71** |
| | **Mode** | 80.54 | 79.20 | 82.25 | 84.65 | 87.45 | 91.05 | 92.18 | **11.65** | **2.22** |

[1] Rate of increase per year in months; [2]due to data availability last year is 2011
**Source:** HMD 2014, own calculation

Compared with females, and as expected, 50 % of male's deaths (Table 2.4) are recorded earlier, occurring on average at age 69 in 1950 and 82.23 in 2012. Similar situation can be observed for the modal age at death, even presenting higher values than life expectancy at birth and median age at death, is still lower in average than for females (1950: 76.38; 2012: 86.20).

Nevertheless, from Tables 2.3 and 2.4, we also can access information about the total life expectancy at birth increase and the increase rate per year in months. Japan, as the best-practice country in what concerns to life expectancy at birth, present the maximum observed increase since 1950 being closely followed by Portugal, the country with lower life expectancy at birth in the analysis. Both

countries were even the only two recording an average monthly increase in life expectancy at birth of more than 4 months.

**Table 2.4:** Life Expectancy at birth, Median and Modal age at death for Males

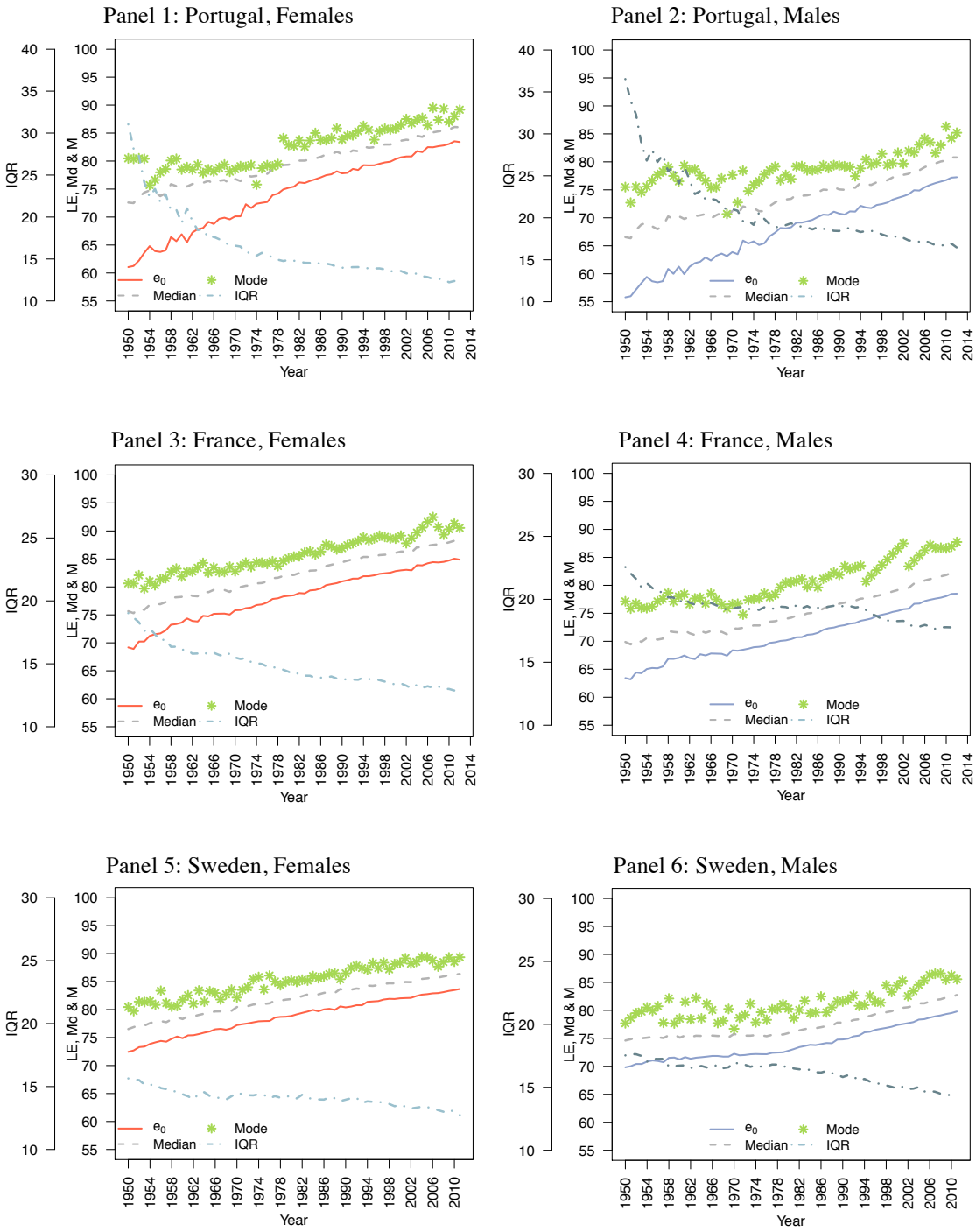
| | Year | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2012 | Tot. Inc. | Inc. Rate[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| | $e_0$ | 55.79 | 61.28 | 63.88 | 68.11 | 70.76 | 73.26 | 77.26 | **21.47** | **4.09** |
| **Portugal** | **Median** | 66.55 | 70.29 | 71.22 | 73.28 | 75.07 | 77.21 | 80.78 | **14.23** | **2.71** |
| | **Mode** | 75.49 | 76.51 | 77.65 | 77.65 | 79.34 | 79.75 | 85.20 | **9.71** | **1.85** |
| | $e_0$ | 63.43 | 67.03 | 68.38 | 70.16 | 72.73 | 75.25 | 78.51 | **15.08** | **2.87** |
| **France** | **Median** | 69.88 | 71.58 | 72.32 | 74.02 | 76.71 | 78.90 | 82.31 | **12.43** | **2.37** |
| | **Mode** | 77.14 | 78.01 | 76.63 | 80.48 | 81.85 | 85.58 | 87.74 | **10.60** | **2.02** |
| | $e_0$ | 69.83 | 71.23 | 72.24 | 72.78 | 74.80 | 77.37 | 79.80 | **9.97** | **1.93** |
| **Sweden[2]** | **Median** | 74.61 | 75.11 | 75.79 | 75.93 | 77.81 | 80.22 | 82.74 | **8.13** | **1.57** |
| | **Mode** | 77.69 | 78.52 | 76.69 | 80.30 | 81.57 | 84.43 | 85.56 | **7.87** | **1.52** |
| | $e_0$ | 59.35 | 66.66 | 69.32 | 72.39 | 73.42 | 75.97 | 79.33 | **19.98** | **3.81** |
| **Spain** | **Median** | 68.19 | 72.71 | 74.03 | 76.07 | 77.20 | 79.25 | 82.34 | **14.15** | **2.70** |
| | **Mode** | 78.31 | 78.45 | 78.54 | 80.67 | 82.29 | 82.75 | 85.69 | **7.38** | **1.41** |
| | $e_0$ | 57.59 | 65.32 | 69.32 | 73.38 | 75.93 | 77.68 | 79.96 | **22.37** | **4.26** |
| **Japan** | **Median** | 65.79 | 70.71 | 73.13 | 76.75 | 79.14 | 80.72 | 82.97 | **17.18** | **3.27** |
| | **Mode** | 73.28 | 75.54 | 77.42 | 80.42 | 83.28 | 84.41 | 86.80 | **13.52** | **2.58** |

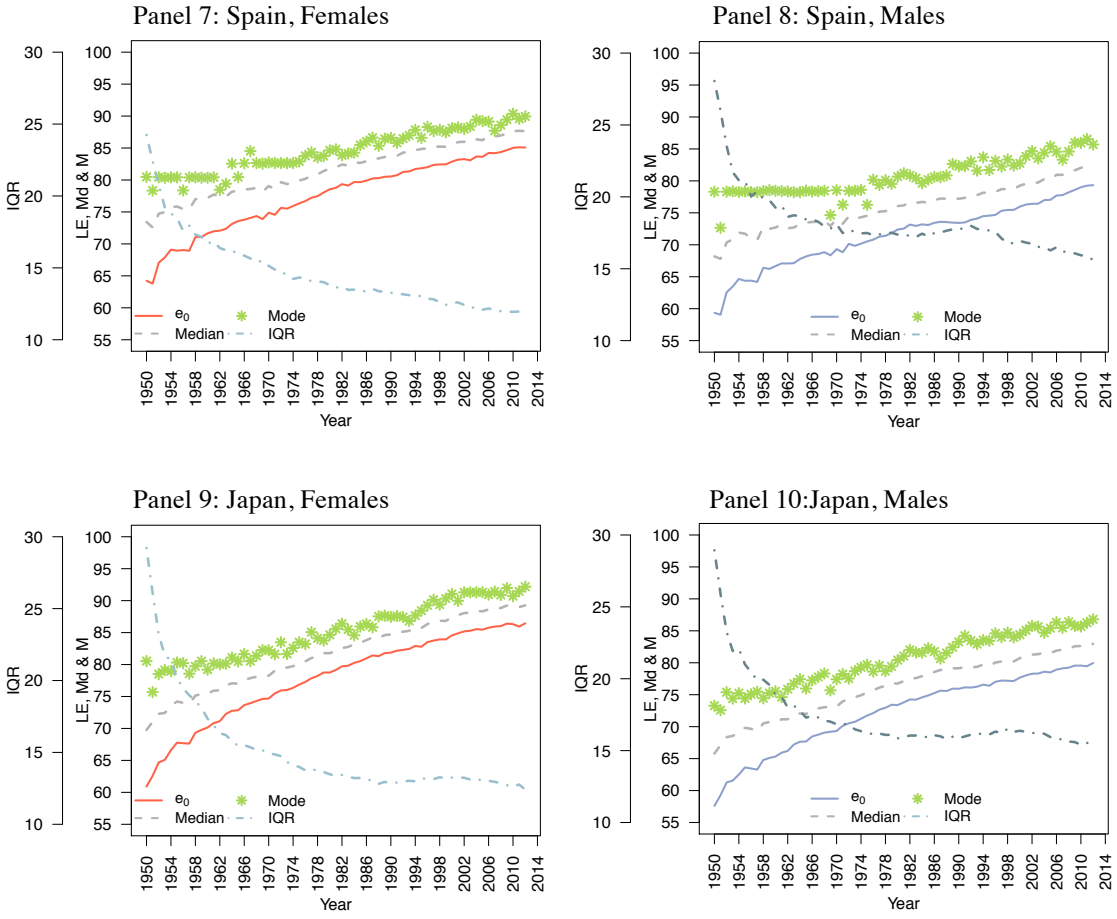
[1] Rate of increase per year in months; [2]due to data availability last year is 2011

**Source:** HMD 2014, own calculation

Representing graphically information presented in Tables 2.3 and 2.4 (Figure 2.3), and adding the information about the interquartile range, one has a better idea about what was previously explained. We can also realize that besides the differences between the 3 present measures, always with positive patterns evolution, the interquartile range is diminishing. As a result, it indicates that high rates of mortality are becoming concentrated in a shorter age range, more specifically it can be concluded that the concentration of deaths occurs at older ages.

**Figure 2.3:** Life expectancy at birth, median and modal age at death



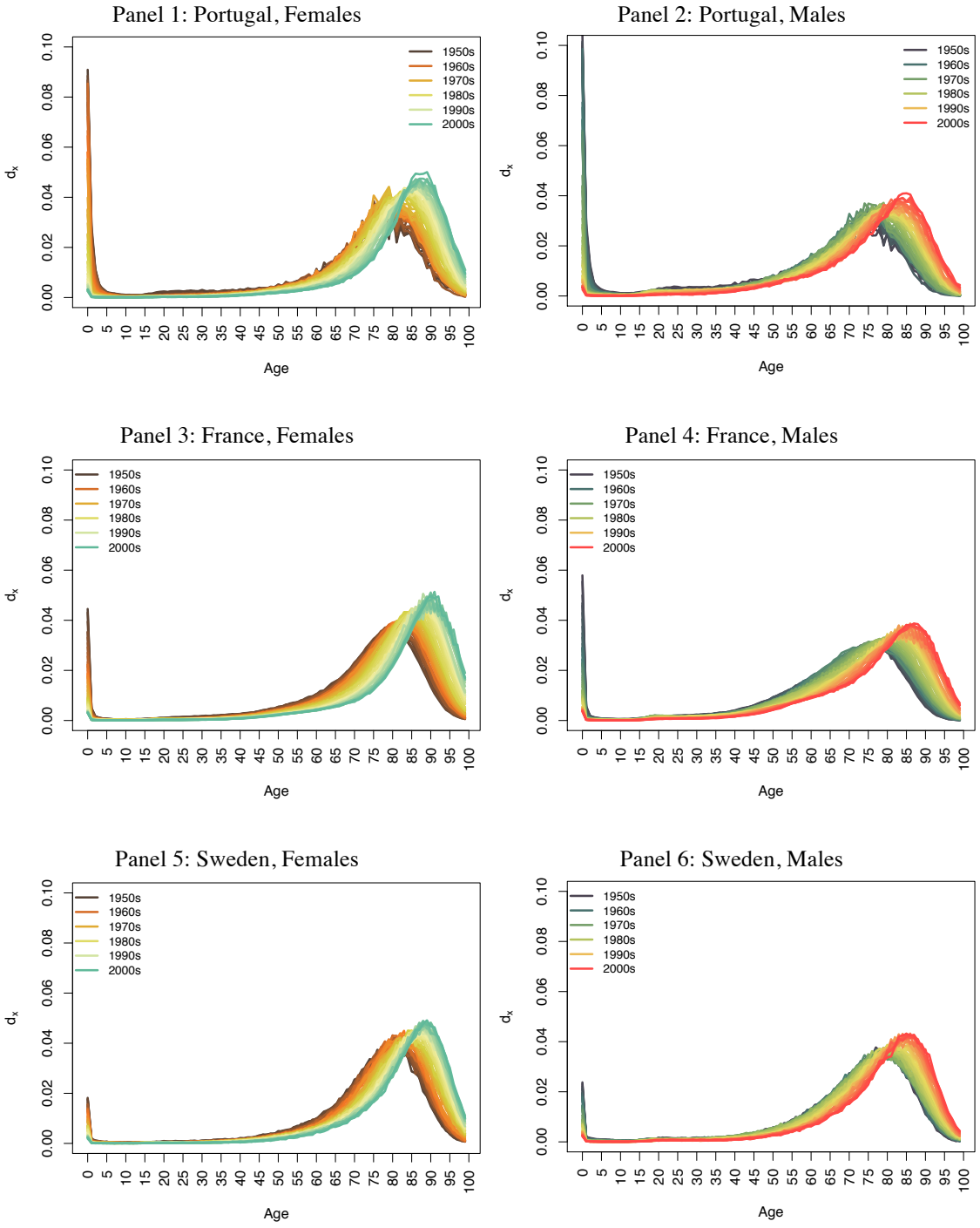



**Source:** HMD 2014, own elaboration

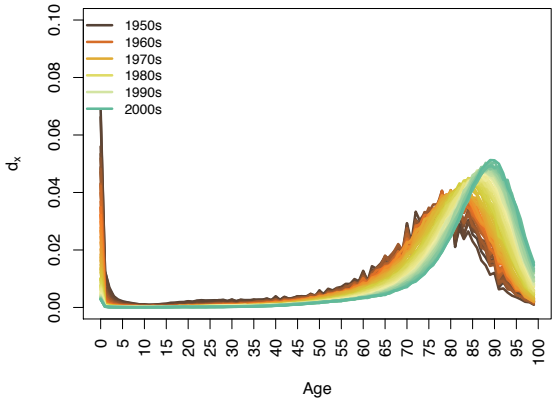
Figure 2.4 clearly confirms our previous deduction with graphical representation of the life-table age distribution of deaths $d_x$, for all five countries and both sexes. The colored patterns consent the identification of the different evolutions by decades, and as time proceeds, less and less deaths are being recorded at early ages, independently of country and sex, and most deaths are being recorded later in life. Despite the clear observed shift in deaths to older ages, the peak is becoming more and more pronounced, especially in the female case. As a result, it results in a rectangularization of the life-table survival curve, already widely studied.

Concluding, as expected, the observed life-table age distribution of deaths $d_x$, reflect unquestionably, the evolutionary patterns observed before for life expectancy at birth, median and modal ages at death.

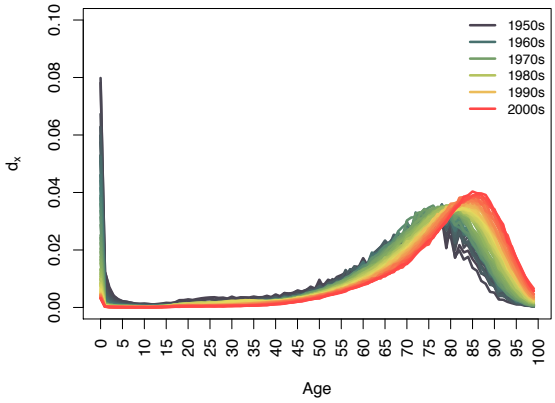
**Figure 2.4:** Life-table age distribution of deaths $d_x$



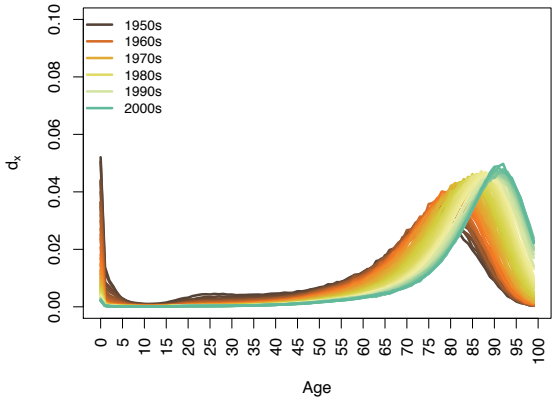
Panel 7: Spain, Females



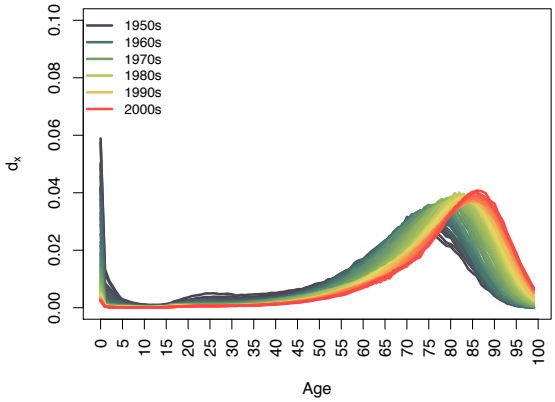

Panel 8: Spain, Males




Panel 9: Japan, Females




Panel 10:Japan, Males




**Source:** HMD 2014, own elaboration

### 2.5.2. Decomposing life expectancy improvements

Previous findings explained in the introductory part of this chapter, distinguished two main phases that contributed to the increase of life expectancy at birth: 1) massive reductions in mortality rates at younger ages, and 2) decrease in mortality rates beyond age 65. Taking advantage of this information, we re-calculated life expectancy at birth assuming that mortality rates after age 65 were maintained unchanged since 1950. Table 2.5 presents the obtained results and demonstrates that the consolidation of Japan as best-practice country was only possible due to improvements registered after age 65. If mortality rates for those ages become unchanged since 1950, Japan would be at the bottom of the "classification" in 2012 with 76.26 years of life expectancy at birth for females and 72.96 for males (nearby France and Portugal).

Excluding Japan, in the female case, life expectancy at birth would be around 77 years and for males would present higher disparity between registered values besides (Sweden: 75.49; Spain: 73.95).

**Table 2.5:** Life expectancy at birth if mortality rates kept constant after age 65 since 1950

| L. E. Ranking | Females 2012 | | | | Males 2012 | | | |
|---|---|---|---|---|---|---|---|---|
| | Country | $e_0$ | $e_0^*$ | Diff. | Country | $e_0$ | $e_0^*$ | Diff. |
| **1** | **Japan** | 86.45 | 76.26 | 10.19 | **Japan** | 79.96 | 72.96 | 7.00 |
| **2** | **Spain** | 85.09 | 77.52 | 7.57 | **Sweden*** | 79.80 | 75.49 | 4.31 |
| **3** | **France** | 84.87 | 77.31 | 7.56 | **Spain** | 79.33 | 73.95 | 5.38 |
| **4** | **Sweden*** | 83.67 | 77.30 | 6.37 | **France** | 78.51 | 72.98 | 5.53 |
| **5** | **Portugal** | 83.41 | 77.29 | 6.12 | **Portugal** | 77.26 | 72.88 | 4.38 |

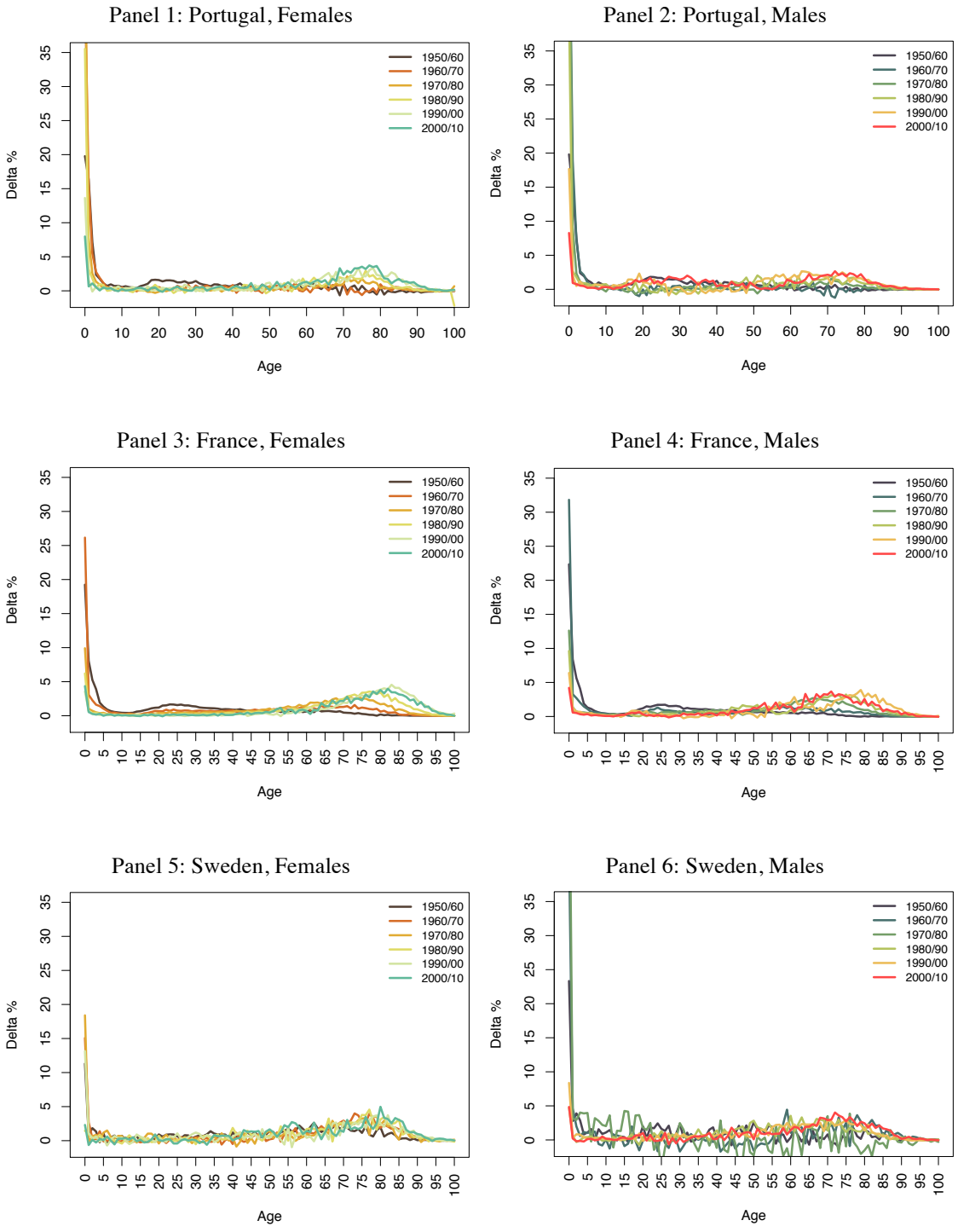
* Due to data availability last year is 2011

**Source:** HMD 2014, own elaboration

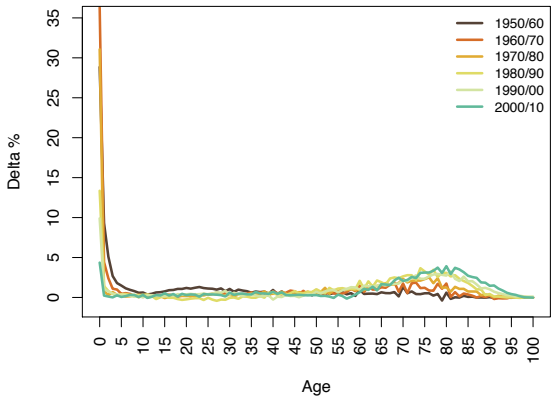
Complementary information can be extracted by the methodology developed by Arriaga (1984), once that allows identifying contributes by age (the obtained results are presented in Figure 2.5).

Generally, we can confirm that in the beginning of the period were the improvements at younger ages that contribute the most to life expectancy improvement. However, the positive contributions observed here are highly connected with older ages. If for females we can expect that for the future, improvements may be especially connected with older ages, in the male case, there is still a larger flexibility to improve at younger ages, essentially between age 15 and 35. As a result of previous studies, we can assume that contributes associated with those ages are mainly connected with behavioral decisions, i.e., external causes-of-death (essentially transport accidents in the Portuguese case, for example).

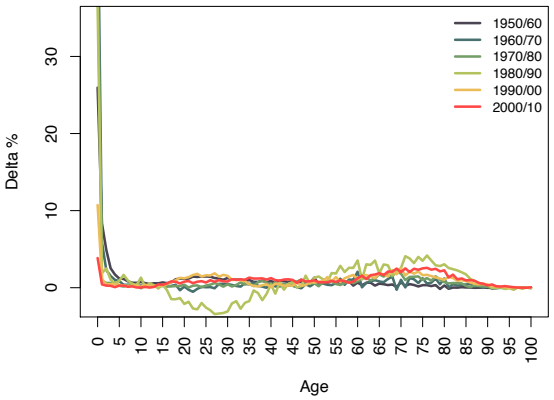
**Figure 2.5:** Contributions, in percentage, for $e_0$ increase



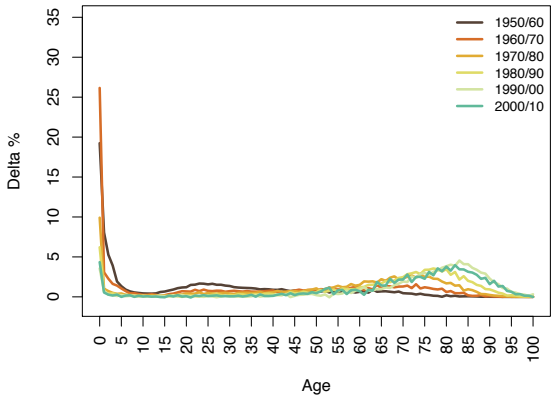
Panel 7: Spain, Females



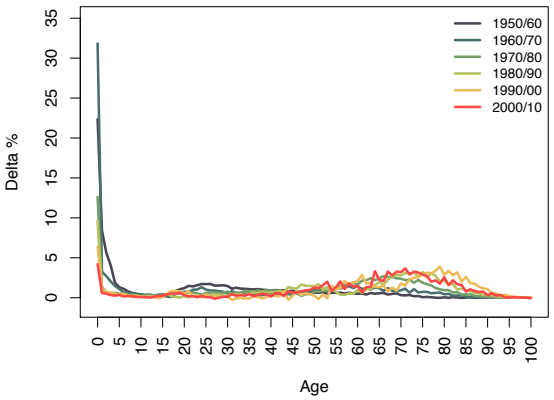

Panel 8: Spain, Males




Panel 9: Japan, Females




Panel 10:Japan, Males



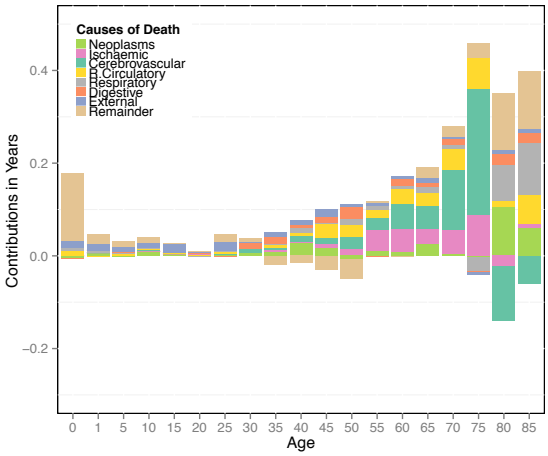

**Source:** HMD 2014, own elaboration

Despite the possible identification of positive or negative contributions to the increase of life expectancy applying the decomposition methodology developed by Arriaga (1984), the computation of the decomposition approach developed by Shkolnikov et al. (2001) allows to break down this contributions by COD.

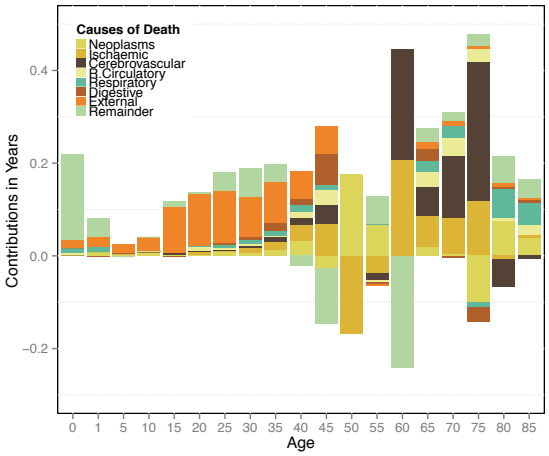
Intending to focus on recent years, Figure 2.6 presents the obtained results for the last decade and we can already identify what was said before. Nonetheless, for this last decade, in the male case, some important contributions were given by young adult ages, especially related to deaths originated by external causes of death. Besides external causes for males, in a broad perspective, were the positive impacts of neoplasms, ischaemic, cerebrovascular and other circulatory system diseases that most "affected" life expectancy at birth. Lastly, especially at older ages, diseases of the respiratory system can also be identified as important.

**Figure 2.6:** Contributions, in years, for $e_0$ increase by COD (2000 and 2010)

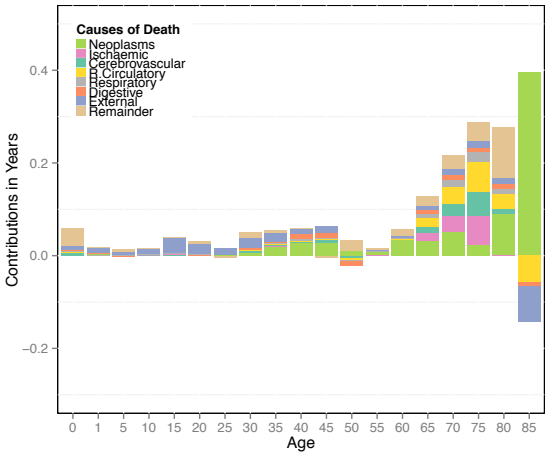
Panel 1: Portugal*, Females



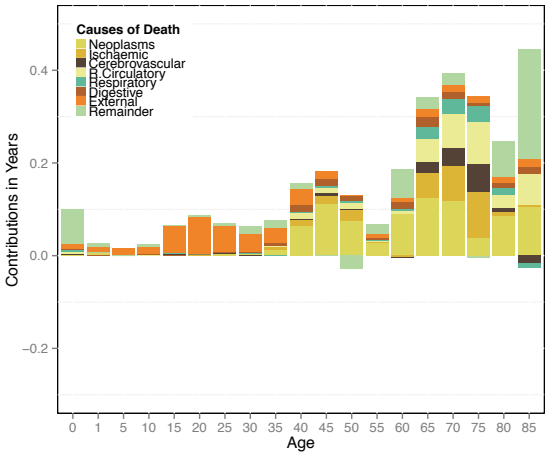

Panel 2: Portugal*, Males



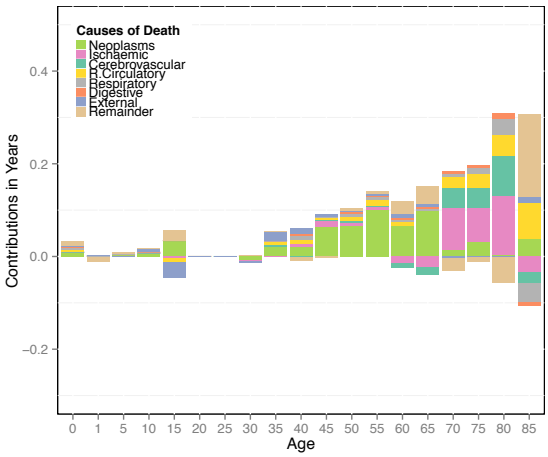

Panel 3: France, Females



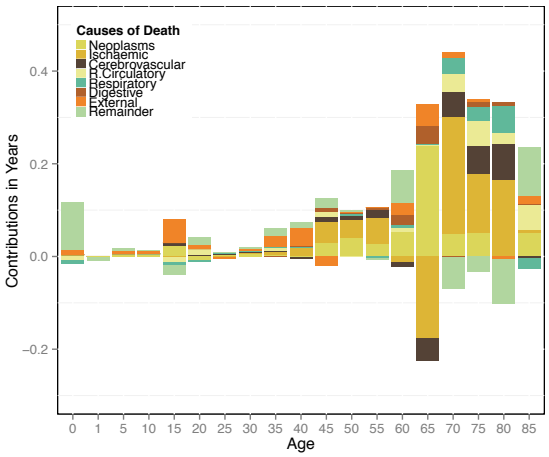

Panel 4: France, Males



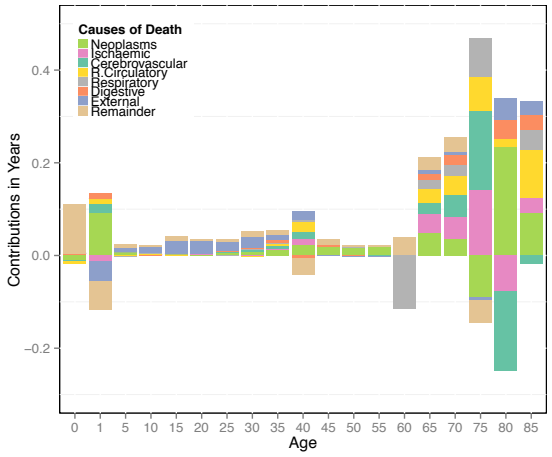

Panel 5: Sweden, Females



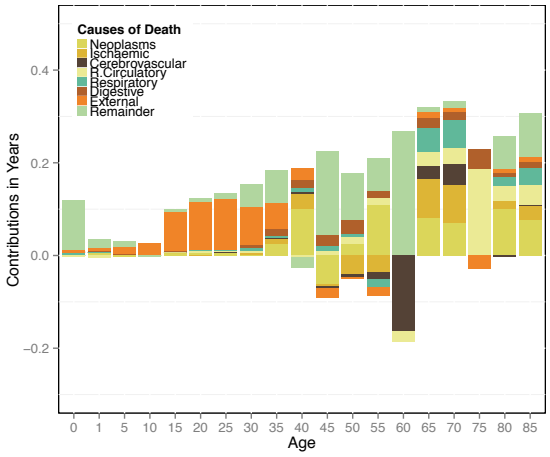

Panel 6: Sweden, Males



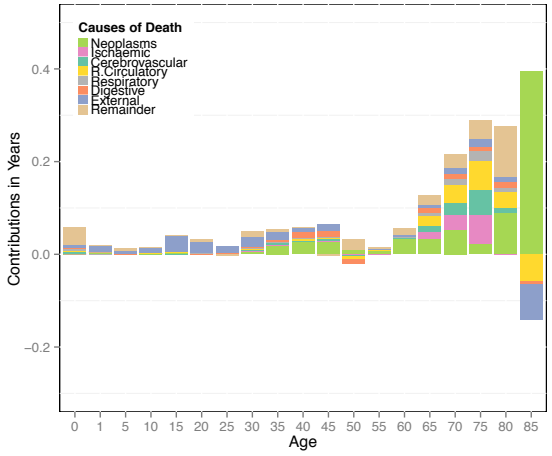
Panel 7: Spain, Females



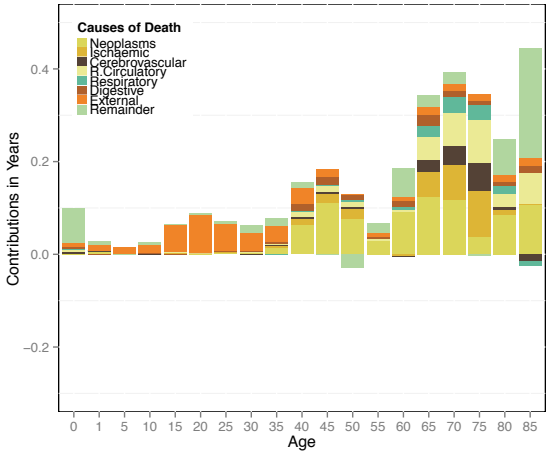

Panel 8: Spain, Males




Panel 9: Japan, Females




Panel 10:Japan, Males




* Due to data availability first year is 2003

**Source:** HMD 2014, own elaboration

With the previous analysis elaborated in this chapter, we can conclude that are (still in this decade) mainly the positive contributes given by older ages and reductions in mortality rates connected with neoplasms and diseases of the circulatory system in general, and external causes predominantly for males, that contribute the most for the registered life expectancy at birth in 2012. Nonetheless, if we calculate the associated single decrement life-table for other than a specific COD, we would be able to evaluate how much is the impact of a certain cause in overall life expectancy.

Thus, based on that approach, we calculated correspondent life expectancy at birth in the absence of each considered COD. Due to competing risks theory, which theorizes that if an individual doesn't die from a certain and specific COD, there are many different ones to which he is exposed, competing to contribute to his dead. We

need thus, to be aware that the real impact of the absence of a certain COD in life expectancy would be slightly lower than the obtained by this approach.

Our intention is simply to identify which COD influences the most, negatively, life expectancy at birth, and the obtained results for the year 2000 presented in Table 2.6 show that are the death related with neoplasms that had higher negative influence across all countries and sexes. In Sweden, again for both sexes, it can also be identified a negative influence caused by ischaemic heart diseases. Generally, as expected, were the diseases related with the circulatory system, together with neoplasms, the ones presenting a major negative impact. On the other side, were the deaths caused by digestive system diseases that less influence negatively life expectancy at birth.

The group that includes all the remaining CODs also records significant values to be neglected, however, this shows that there are still an important group of all other CODs not specified here that need intervention. It is not our intention in this monograph, but the identification of the different CODs correspondent to that last group, will certainly produce important information for the health public system

**Table 2.6:** Life expectancy at birth in the absence of a certain COD, 2000

| COD | Portugal* | | France | | Sweden | | Spain | | Japan | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| **Neoplasms** | 3.44 | 2.67 | 4.89 | 3.48 | 3.25 | 3.44 | 4.47 | 2.96 | 4.74 | 3.88 |
| **Ischaemic** | 1.23 | 0.93 | 1.17 | 0.86 | 2.86 | 2.16 | 1.51 | 1.09 | 0.93 | 0.98 |
| **Cerebrovascular** | 1.74 | 2.54 | 0.71 | 0.98 | 0.97 | 1.31 | 0.94 | 1.42 | 1.56 | 2.31 |
| **R. Circulatory** | 1.06 | 1.52 | 1.54 | 2.03 | 1.34 | 1.61 | 1.27 | 2.13 | 1.12 | 1.72 |
| **Respiratory** | 1.11 | 0.89 | 0.80 | 0.75 | 0.76 | 0.79 | 1.53 | 1.11 | 2.01 | 2.04 |
| **Digestive** | 0.81 | 0.51 | 0.70 | 0.58 | 0.44 | 0.42 | 0.76 | 0.61 | 0.60 | 0.53 |
| **External** | 1.88 | 0.66 | 1.88 | 1.06 | 1.32 | 0.65 | 1.47 | 0.57 | 1.71 | 0.94 |
| **Remaining** | 3.24 | 3.36 | 2.98 | 3.77 | 1.91 | 2.27 | 2.26 | 3.03 | 1.52 | 2.30 |

* Due to data availability, corresponds to year 2003
**Source:** HMD 2014, own elaboration

Likewise as shown for the year 2000, in 2010 are still neoplasms that influence the most overall life expectancy at birth and diseases of the digestive system the least. Respiratory system diseases also present a significant impact when compared with the obtained values in the year 2000. Nevertheless, in these 10 years of observation the group of CODs that includes all than the specified here, is

increasing its negative impact. This situation reinforces the need to identify "emerging" diseases that may influence negatively overall life expectancy.

**Table 2.7:** Life expectancy at birth in the absence of a certain COD, 2010

| COD | Portugal | | France | | Sweden | | Spain | | Japan | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| **Neoplasms** | 3.98 | 2.83 | 5.13 | 3.85 | 3.39 | 3.43 | 4.82 | 3.23 | 4.59 | 3.90 |
| **Ischaemic** | 0.91 | 0.75 | 1.00 | 0.72 | 2.16 | 1.61 | 1.30 | 0.96 | 0.87 | 0.79 |
| **Cerebrovascular** | 1.28 | 1.79 | 0.63 | 0.86 | 0.77 | 1.01 | 0.78 | 1.11 | 1.19 | 1.53 |
| **R. Circulatory** | 1.01 | 1.52 | 1.59 | 2.16 | 1.45 | 1.77 | 1.37 | 2.23 | 1.23 | 2.05 |
| **Respiratory** | 1.28 | 1.19 | 0.82 | 0.76 | 0.66 | 0.64 | 1.45 | 1.09 | 2.19 | 2.09 |
| **Digestive** | 0.74 | 0.50 | 0.69 | 0.57 | 0.45 | 0.38 | 0.72 | 0.60 | 0.56 | 0.52 |
| **External** | 1.20 | 0.55 | 1.65 | 0.91 | 1.31 | 0.66 | 0.93 | 0.45 | 1.56 | 0.91 |
| **Remaining** | 3.44 | 3.73 | 3.55 | 4.88 | 2.53 | 3.25 | 2.61 | 3.85 | 1.76 | 3.03 |

**Source:** HMD 2014, own elaboration

## 2.6. Discussion

As a result, obtained results in this chapter confirm what has been concluded in many other previous studies: neoplasms, diseases of the circulatory and respiratory system are the principal CODs and the ones that influence the most, negatively, life expectancy for populations. However, in this chapter, with the calculation of alternative measures of longevity and presentation of different points of view, we perspective that if the rate of increase in life expectancy at birth keeps recent evolutionary patterns, it is possible that the male/female gap keep diminishing and all analyzed countries can aim for Japanese values.

Usually, less attention is given to causes that are less expressive in overall mortality, however, in our study we identify that this group as being one of the most important in influencing negatively life expectancy.

Likewise Oliveira and Mendes acknowledged (2010) the emergent importance associated with this wide-ranging group of CODs might be intimately related with shift of high rates of mortality to older ages.

## 2.7. Conclusions

Together with the shift of higher rates of mortality to older ages with time, changes in the CODs that are influencing those deaths are also being registered. Decision makers should not neglect less representative CODs and be prepared to, not new, but emergent CODs that were not related with mortality rates registered at younger ages.

Nonetheless, it is also very important to identify how different CODs may influence overall slopes of mortality, either for individuals and populations, evaluating how those can be differentiated and if they contribute to each other. That will be done on the next two chapters.

# CHAPTER 3

# THE INDIVIDUAL RATE OF AGING BY CAUSES OF DEATH: TESTING VAUPEL'S HYPOTHESIS

## 3.1. Introduction

Population's longevity is being affected, across history, by changes in the curve of age-specific mortality. Changes in the slope are often designated by *rate of aging* (e.g.: Vaupel, 2010; Zarulli, 2012) or *rate of senescence* (e.g.: Comfort, 1964; Rozing and Westendorp, 2008). In both, the general concept is rather similar. In this research, the term *rate of aging* is the choice over rate of senescence.

Vaupel (2010) hypothesizes that *"except for individuals with accelerated aging disorders, all other humans have a similar and perhaps, essentially the same, rate of increase in mortality with age"*, i.e., the same rate of aging, which might be a biological constant invariant across humans and over time.

In opposition with the rate at which age-specific death rates increase, known as the life-table aging rate (LAR) (Horiuchi and Coale, 1990), the individual rate of aging is defined as the relative derivative of the baseline hazard of death if the aging process is captured by a Gompertz curve. If the first is constant across age, the second presents a well-defined and characteristic bell-shaped pattern, widely studied since Gompertz (1825), and consequently finding evidence for a mortality deceleration at older ages. The force of mortality for an entire population is described by the associated age-specific death rates, resulting from a "contribution" of different subpopulations under diverse specific mortality conditions (Beard, 1959; Vaupel et al., 1979). Like it was suggested by Vaupel and Yashin in 1985, and well illustrated by the gamma-distributed frailty model with exponentially increasing individual mortality, i.e., the widely known gamma-Gompertz or gamma-Gompertz-Makeham model, individual and population mortality patterns might be qualitatively distinct. In their study, Vaupel and Yashin (1985) explored in a variety ways, that the pattern of attrition for the population as a whole can differ from the patterns for subpopulations or individuals, and in 2006, the same authors, pointed out 3 key reasons to justify the application of frailty models: (1) Cox regression yields coefficient estimations that

tend to be biased towards zero; (2) frailty models permit the estimation of underlying (baseline) hazards (i.e., the hazards that control the trajectory of risks at the individual level); and, (3) the possibility of using supplementary vital statistics in the analysis. Within this framework, individual mortality is characterized by different starting levels, which combined, result in a S-shaped logistic mortality curve for the population (Beard, 1959).

If Vaupel's hypothesis is confirmed, the individual force of mortality, from senescent causes, is characterized by 1) a constant and essentially identical rate of aging across individuals that share the same subpopulation, in a given cohort; and 2) for all subpopulations combined across different cohorts.

Testing this hypothesis is not easy, though. Data for complete cohorts becomes only available when all the individuals that share the same birth cohort leave the population by death. Still, data available for complete cohorts correspond to beginning of the 20$^{th}$ century, while for more ancient cohorts data quality is questionable (HMD, 2014; Wilmoth et al., 2007). Besides the issues about data convenience and quality, constant reductions in the age-specific mortality rates across time for countries considered to provide high-quality data, mainly after World War II (Tuljapurkar et al., 2000; Rau et al., 2008), subject individuals born in different cohorts with age $x$ in year $y$ to lower mortality rates than other individuals that attained the same age on previous years. This results in the underestimation of the rate of individual aging due to the rate of mortality improvements, making challenging to test point 2). Salinari and Santis (2014), based on Human Mortality Database data (HMD, 2014), find no evidence of a common rate of individual aging, but the direct association of mortality improvements and the rate of individual aging might be an explanation.

If in modeling non-human organisms there are several examples of scientific experiments where analyses of the effects of environmental and genetic experiments are conducted, in the case of humans this is rather difficult and profoundly censured. To avoid this, a way to analyze the validity of Vaupel's hypothesis is to analyze "natural" mortality shocks (occurred in different subpopulations) to achieve a better understanding about the changes in human mortality curves (Zarulli, 2012). Till now, the only piece of research addressed to this context comes from Zarulli (2012). The author took advantage of "natural mortality experiments" and achieved the same

mortality shifts in the age mortality trajectories of humans, finding that among Australian prisoners-of-war (in Java, during WWII) obtained estimates speak in favor of a constant rate of individual aging, but not in the case of Ukrainian famine. Nevertheless, in some cases, the conduction of experimental analyses with diverse non-organisms resulted in changes in the slope of the mortality trajectory (de Magalhães et al., 2005; Johnson, 1990) and others have found a parallel shift in the age of mortality trajectories when compared with the control group (Lin et al., 1998; Flurkey et al., 2001; Mair et al., 2003).

In this chapter, Vaupel's hypothesis is tested by studying major groups of cause of death (COD), addressed here as subpopulations. Data aggregation in major groups of CODs provides subpopulation sizes large enough to produce a significant statistical analysis. Period data, distinguishable by country and age is used to estimate the individual rate of aging, by fitting a gamma-Gompertz-Makeham [ΓGM] model, and seeking evidence to confirm or refute the existence of a constant rate of individual aging over time, and if, the obtained estimates accordingly each subpopulation, i.e., COD group, presents essentially the same rate of individual aging.

## 3.2. Methods

### 3.2.1. The gamma-Gompertz-Makeham frailty model

Generally, demographers view populations as a heterogeneous mixture of individuals, sharing, at adult ages, the same baseline hazard of death. This means that each population is composed by different subpopulations where, despite sharing the same hazard of death, all individuals are susceptible to in a different and random way. To estimate cause-specific individual rates of aging we fit a gamma-Gompertz-Makeham (ΓGM) frailty model, where the baseline hazard of death $\mu(x)$ at age $x$, is assumed to follow a Gompertz-Makeham mortality pattern (Gompertz, 1825; Makeham, 1860):

$$\mu(x) = ae^{bx} + c \tag{3.1}$$

where the aging process is captured by $b$, obtained by the relative derivative of $ae^{bx}$, i.e., the Gompertz part of the equation, $a$ refers to the starting level of mortality for a

given adult age (where $x = 0$) and $c$ corresponds to non-senescent mortality. Previous research revealed that individual susceptibility could be reflected in both parameters of the model presented in (3.1) at the same time; only on the mortality level at the starting age given by parameter $a$, applying relative-risk models; or on the individual rate of mortality increase, here given by $b$, applying accelerated-life models. Nevertheless, Gampe (2010), in her research, found evidence for a human mortality plateau at older age mortality when realized that mortality rates are leveling off beyond age 110, being favorable to the relative risks (Missov and Vaupel, 2015), while that accelerated-life mortality models would result in an eventual vanishing hazard of death (Finkelstein and Esaulova, 2006).

So, letting a random variable *frailty* capture individual susceptibility to death, in a relative-risk model framework with Gompertz-Makeham baseline mortality, the force of mortality $\mu(x \mid z)$ for individuals with frailty $z$ is given by:

$$\mu(x \mid z) = z\, ae^{bx} + c. \tag{3.2}$$

If we assume frailty as being gamma-distributed with a unit mean and $\gamma$ variance at the starting age of analysis, which is an additional standard (Beard, 1959; Vaupel et al., 1979) already proved theoretically (Steinsaltz and Wachter, 2006; Missov and Finkelstein, 2011), we end-up with a *gamma-Gompertz-Makeham* (ΓGM) *frailty model*. Thus, within a ΓGM theoretical framework, the hazard for the population is given by (Vaupel et al., 1979; Vaupel, 2002; Vaupel and Missov, 2014):

$$\bar{\mu}(x) = ae^{bx}[\bar{s}(x)]^{\gamma} + c. \tag{3.3}$$

where, $a$, $b$ and $c$ maintain the same meaning explained before, $\bar{s}$ corresponds to the population survivorship at age $x$ and $\gamma$ is the frailty variance at the initial age of analysis. The inclusion of the Makeham term $c$ is fundamental to obtain non-biased estimates since it is statistically significant and its exclusion of (3.3) may interfere negatively with the obtained estimates for the other parameters in the model (Missov and Nemeth, 2014).

Like it was stated before, considering the model in (3.3), the individual rate of aging is captured by the relative derivative of the Gompertz part $ae^{bx}$, but in

opposition, the relative derivative of $\bar{\mu}(x)$ results in the obtainment of the population rate of aging. If the first is constant across age, corresponding to $b$ in (3.3), the second, proposed by Horiuchi and Coale in 1990 and addressed later as the *life-table aging rate* (LAR), varies age-wise presenting a characteristic bell-shaped pattern (Horiuchi and Coale, 1990; Horiuchi and Wilmoth, 1997, 1998; Vaupel and Zhang, 2010). However, $b$ is only well captured under this theoretical framework, if and only if the baseline hazard $\mu(x)$ follows a Gompertz pattern. In opposition to the individual's rate of aging, LAR has been widely studied, either for human populations (e.g., Horiuchi and Wilmoth, 1997, 1998) or non-human (e.g., Carey and Liedo, 1998), which might have caused some misperception about the relationship between both measures. In 2010, Vaupel and Zhang, explored an explicit relationship between the individual rate of mortality increase and the population rate of aging, proving that, not only $b$ differs from LAR, but also contributes to the estimation of the second.

### 3.2.2. Model fitting

Despite model (3.3) is proposed for cohorts, in this chapter, we use data collected for different CODs by single years $y$. Consequently, due to data availability, to capture overall mortality (Vaupel, 2002; Vaupel and Missov, 2014) we apply:

$$\bar{\mu}(x,y) = a(y)e^{b(y)x}\left[\bar{s}^{(c)}(x)\right]^{\gamma(y)} + c(y) \tag{3.4}$$

where $a(y)$, $b(y)$ and $c(y)$ correspond to estimates at the period level and $\bar{s}^{(c)}$ to survivorship for the subpopulation born in year $y$ - $x$.

Every individual in overall population or across different subpopulations is continuously exposed to different risks of death. *"Because death is not a repetitive event and is usually attributed to a single cause, these risks compete with one another for the life of a person. Competing risks must be considered in any cause-specific mortality analysis"* (Chiang, 1991). In our approach, we incorporate this statement, assuming that the individuals exposed to the risk of death by COD are the same that are exposed to overall mortality: $E_i(x,y) = E(x,y)$. Model (3.4), when applied to different $\mathrm{COD}_i$ is characterized by a unique starting level of mortality $a_i(y)$, $b_i(y)$,

$\gamma_i(y)$, $c_i(y)$ and a common survivorship by cause $\bar{s}_i{}^{(c)}(x)$ and cohort, however, due to data availability, period survival $\bar{s}_i(x,y)$ is used instead:

$$\bar{\mu}_i(x,y) = a_i(y)e^{b_i(y)x}[\bar{s}_i(x,y)]^{\gamma_i(y)} + c_i(y) \tag{3.5}$$

Looking at each $\mathrm{COD}_i$ separately may influence obtained results, mainly due to the competing risks to which individuals are exposed. Thus, if we discriminate cohort survivorship by $\mathrm{COD}_i$, it may still exclude competing risks from our analysis. However, assuming that $\bar{s}_i{}^{(c)}(x) = \bar{s}^{(c)}(x)$, additionally to common exposures and a single frailty term with variance $\gamma(y)$ at the starting age of analysis, we can incorporate again the competing risks into the model:

$$\bar{\mu}_i(x,y) = a_i(y)e^{b_i(y)x}\left[\bar{s}^{(c)}(x)\right]^{\gamma(y)} + c_i(y). \tag{3.6}$$

Applying model in (3.5) to our data results in the estimation of 4 parameters at a time by period $y$. In opposition, the outcome from the model presented in (3.6) results in 25 parameters at a time $y$, leading to a very unstable optimization procedure highly manipulated by chosen starting values. As a result, and due to very complete information about cohort survival concerning overall mortality available at HMD, a model with differentiated $\gamma_i$ is also fitted:

$$\bar{\mu}_i(x,y) = a_i(y)e^{b_i(y)x}\left[\bar{s}^{(c)}(x)\right]^{\gamma_i(y)} + c_i(y). \tag{3.7}$$

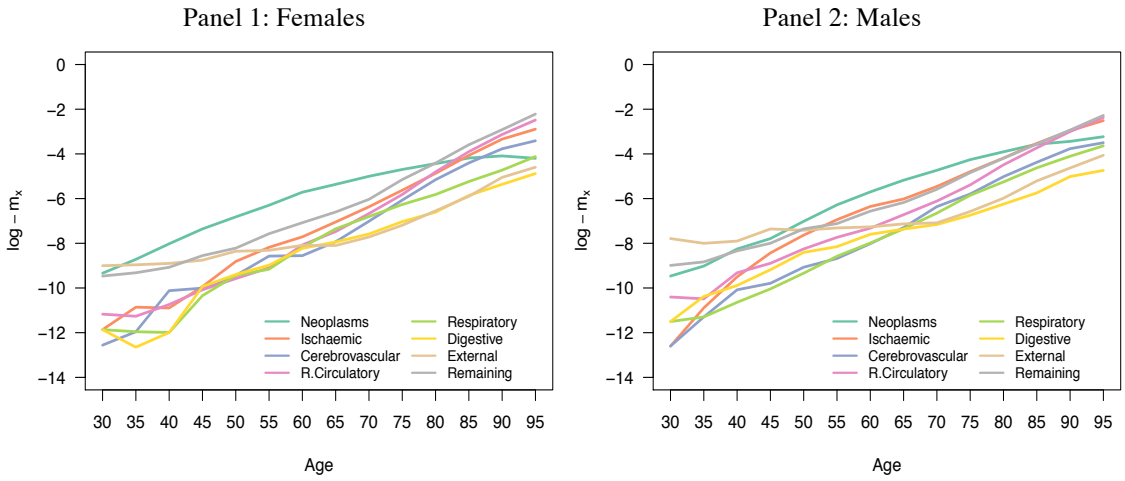
Comparing obtained results in (3.5) with the obtained in (3.7) leads to almost identical parameter estimates, thus, as a results, only the estimates from (3.7) will be seen in the *results* section when the obtained estimates for rate of individual aging are presented.

Introduced the model framework, fitting procedure holds on the assumption that $D_i(x,y) \sim Poisson\left(E(x,y) * \bar{\mu}_i(x,y)\right)$ (Brillinger, 1986), where $D_i(x,y)$ denote the cause-specific death counts $i$, and $E(x,y)$ denote the age specific exposures, both in year $y$. Thus, for each $\mathrm{COD}_i$ separately in year $y$ we maximize a Poisson log-likelihood:

$$\ln L\big(a_i(y), b_i(y), \gamma_i(y), c_i(y)\big) = \sum_x [D_i(x,y) * \ln \bar{\mu}_i(x,y) - E(x,y) * \bar{\mu}_i(x,y)] \qquad (3.8)$$

The same procedure is adopted to estimate the parameters for all causes combined (when $i = \emptyset$, we refer to (3.4)). Analyzing Figure 3.3, where are presented the observed age-specific mortality rates for Sweden (2010) by $\mathrm{COD}_i$, we can conclude that its after age 65, i.e., after age group 65-69, that mortality patterns associated with different major CODs register an approximated exponential increase, followed, in some cases, by an eventual deceleration pattern. Thus, all mentioned models are fitted starting at age group 65-69, because fitting a ΓGM model at earlier ages will result in meaningless $b_i(y)$-estimates for CODs that do not seem to follow a ΓGM curve. Nevertheless, for some specific causes, like e.g. neoplasms, the fitting procedure might need to start earlier once that major incidence for cancer is concentrated at younger ages, being reflected in the age-specific mortality pattern after age 65. However, that strategy needs to be well defined because each cause is singular, so, in this chapter, and for comparison proposes, all estimates are performed starting at age 65.

**Figure 3.3:** Observed age-specific mortality rates after age 30 in Sweden, 2010




**Source:** WHOMD and HMD 2014, own elaboration

## 3.3. Data

### 3.3.1. Source, classification and concepts of cause of death data

The *International Classification of Diseases* (ICD) regulates the classification of COD data, which is revised periodically to allow the inclusion of new diseases and/or the refinement in the identification of diseases and promotes the international comparability of COD statistics. However, new classifications that result from ICD revisions are inevitably followed by the impossibility (for less aggregated groups of causes, e.g., *lung cancer* or *poisoning*) of making comparisons over time and across countries since different countries may adopt the new classifications at different times. Still, more refined the classification becomes, the greater the need for expert clinical diagnosis of cause of death.

National mortality data derives essentially from death certificates, from which diverse information can be used. In death certificates it can be found information about the *underlying cause of death*, i.e., the disease or injury that initiated the train of events leading directly to death, or the circumstances of the accident or violence which produced the fatal injury (WHO, 1977). Death certificates also provide information that gives the possibility to elaborate a more profound and complete analysis, containing information about other contributing causes or identifying what was the *immediate cause of death*, which is the final disease or condition that results in death. This means that an underlying COD can trigger a different disease and only after, death, being this last disease the immediate cause. Exemplifying, imagine a deceased that died from a coronary occlusion. Despite the immediate COD be the coronary occlusion, the underlying COD can be different, like diabetes.

Regardless to the underlying or immediate causes of death, it is also important to define the *external cause of death* category, where the recorded cause is the external cause that resulted in death, not the nature of the injury or the antecedent condition of the deceased. Death is frequently produced by more than one cause and it is also possible, for a restrict number of countries, to have access to statistics on *multiple causes of death*, presenting more detailed information recorded in the death certificates, that can be seen as a recognition about the involvement of combinations of diseases and conditions in many deaths.

### 3.3.2. Validity and viability of data

COD data is very often facing reliability problems, produced mainly by 1) the lack of accuracy in death certificates, or 2) by changes in the classification system (Meslé, 2006), and to avoid this uncertainty, the World Health Organization (WHO) recommends to base COD statistics on the *underlying* cause of death category.

Some studies were conducted with the intention of comparing death certificates and *post-mortem* diagnosis and the most part of the results showed that exists a significant disagreement between them (Modelmog et. al., 1992). This situation can occur, for example, when physicians or other medical professionals are unfamiliar with the true cause of death (Lilienfeld et. al., 1994). Some interrelated illness can be also the explanation for this uncertainty, such as diabetes together with coronary disease, which are two diseases feasible to be fatal. On the other hand, some diseases can be only the contributing COD, what can difficult to identify the real cause. From the combination of all these difficulties can result an impossibility to identify the COD of a deceased and the best option is to consider autopsy results combined with clinical data (Kircher et. al., 1985), however not every deceased is autopsied.

In what concerns to cancer more precisely, different studies where information from death certificates was crossed with autopsy information, presented really positive results when this disease is the underlying COD. It was shown that the sensitivity of death certificates varies between 87 % and 93 % and the predictive capacity between 85 % and 96 % (Kircher et. al., 1985; Engel et. al., 1980; Schottenfeld et. al., 1982).

German et. al. (2011) evaluated the accuracy of cancer statistics in the U.S.A., based on the ICD 9 and ICD 10 classifications, and with a 95 % confidence interval, they achieved a confirmation rate that varies between 80.4 % and 81.6 % for the number of deaths classified under the 10$^{th}$ International Classification of Diseases. The confirmation rate for the deaths recorded under the 9$^{th}$ International Classification of Diseases was even a little higher, varying between 84.8 % and 85.2 %.

Nevertheless, once that is difficult to have access to *microdata* like the *post-mortem* diagnosis for each individual, one option that is often used in this kind of analysis is the calculation of the proportion of death coded in the *ill-defined and unspecified* causes of death category (Meslé, 2006) in order to evaluate the data.

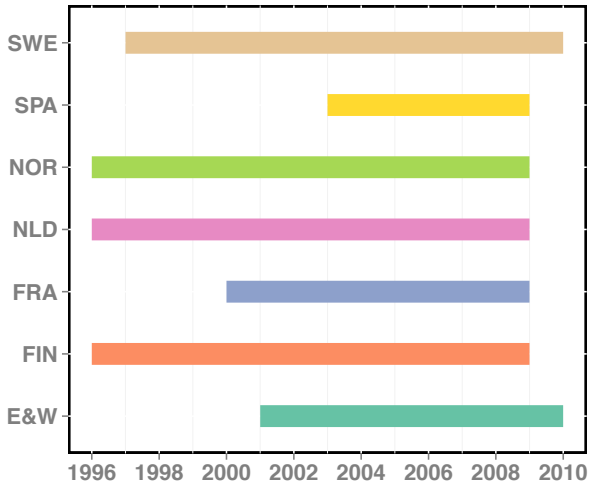
### 3.3.3. Data selection and availability

As already exposed, data collection can face many problems that could influence their validity and viability, however, and besides some of the enumerated problems that COD classification may originate, data availability is also a concerning issue. In some countries, the distribution of data categorized by COD can be considered an ethical problem, and only major causes of death are available. Besides that, it is also almost impossible to find data disaggregated by single-year age groups, so it is very common to deal with data aggregated in five-year age groups, in which the highest open age group starts mainly at age 85. Sometimes, though, it can be also possible to find data where the open age interval starts at age 95 or 100.

Likewise it was done on Chapter 2, data on *overall death counts* $D(x, y)$ and *exposures* $E(x, y)$ derived from the *Human Mortality Database* (HMD, 2014: www.mortality.org) and *deaths by COD* $D_i(x, y)$ from the *World Health Organization Mortality Database* (WHOMD, 2014).

Again, WHOMD cause of death (COD) data are only available by five-year age groups and once that we extract death counts according to ICD10, our timeline in what concerns to COD is restricted essentially to the last available decade (depending on the country; see Figure 3.1). Data codification corresponds to the ICD 10 detailed 3rd and 4th character list classification and was rearranged in 8 main COD groups: 1) Neoplasms, 2) Ischaemic Heart Diseases; 3) Cerebrovascular Diseases; 4) Remaining Diseases of the Circulatory System; 5) Diseases of the Respiratory System; 6) Diseases of the Digestive System; 7) External Causes of death; and 8) Remaining Causes of death. Following the WHO recommendation (1977) to avoid uncertainty that comes from changes and updates in the classification system, we base our research on the *underlying cause of death*, *i.e.*, the disease or injury, which initiated the series of events that lead to death. It also should be said that, for all selected countries, the ill-defined COD group corresponds to less than 3.5 % of all deaths after age 65 and across the study period. Following Meslé (2006), this is an indicator of good overall data quality.

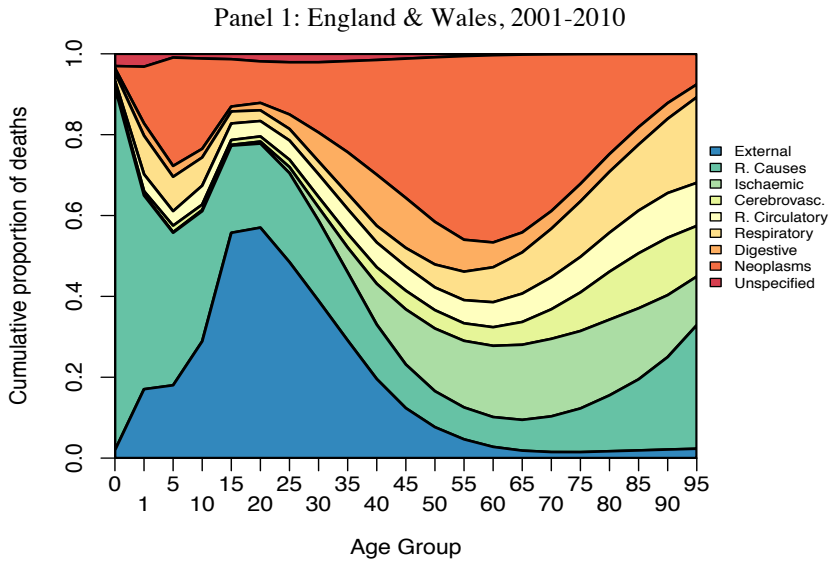
**Figure 3.1:** List of countries and years available for ICD10 cause of death classification

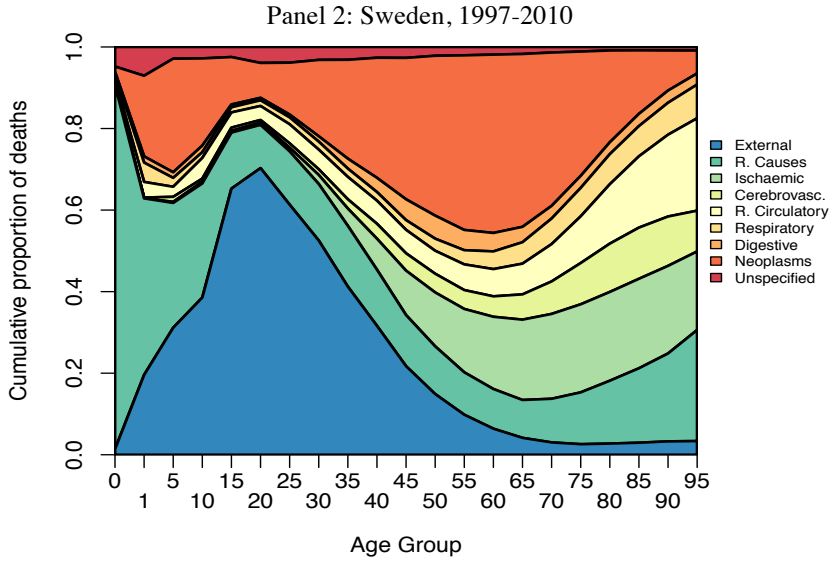



**Source:** WHOMD 2014

Figure 3.2, exemplifies the typical distribution of age-specific deaths by COD, from which we can realize that external causes of death, as well as diseases of the digestive system contribute the least beyond age 65. This situation results in relatively small corresponding $D_i(x, y)$, especially for Sweden, Finland, Norway and the Netherlands.

**Figure 3.2:** Proportion of age-specific deaths by cause






**Source:** WHOMD 2014, own elaboration

### 3.3.4. Data limitations

When we decide to look to CODs as subpopulations and estimate the rate of individual aging, two major difficulties emerge. First of all, COD information desegregated by cohort is not available, restricting our analysis by period. However, previous research found evidence that the actual mortality experience of a preceding cohort is well corresponded by period mortality, as it was discussed, e.g., in Bongaarts and Feeney (2003) or in Rodriguez (2006). This means that with our approach we are also estimating the rate of individual aging for some earlier cohorts.

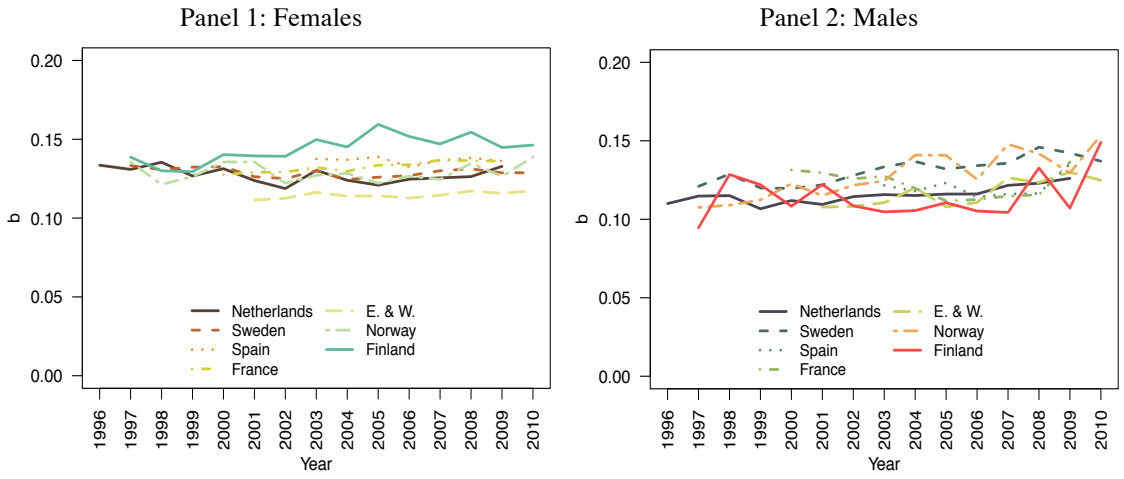
Secondly, changes in the ICD classification system and the necessity of cohort survivorship reconstructed by a given year results in the analysis of a shorter period of time. Nevertheless, when longer periods become available under the same classification, the adopted methodological approach can be still extended.

## 3.4. Results

The rate of individual aging, following what was explained in previous sections, was estimated for all the seven selected countries (Sweden, Spain, France, Norway, Netherlands, Finland and England and Wales), males and females separately, in each

available year (Figure 3.1), by fitting a ΓGM model starting at the age group 65-69. The obtained results corresponding to the overall mortality $b(y)$ are presented in Figure 3.4, and, as it can be seen, especially in the female case, estimates seem relatively stable across the different analyed countries.

**Figure 3.4:** Estimated $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ by country and gender for major CODs group




**Source:** WHOMD and HMD 2014, own elaboration

A closer look, given by Table 3.1, where the obtained results for England and Wales are presented, clearly exemplifies what was just been said. Obtained estimates show that in ten singular years of observation, $\hat{b}(y)$ only increased 0.006 (between 2001 and 2010) in the female case and 0.017 for males, being the associated standard errors smaller in the female case than for males. However, despite the observed differences, a narrow gap for confidence intervals is obtained, and that might be explained by the fact that England and Wales provide a larger subpopulation of analysis. Still, the known fact that females live longer than males, can also affect the subpopulation size and correspondent estimates.

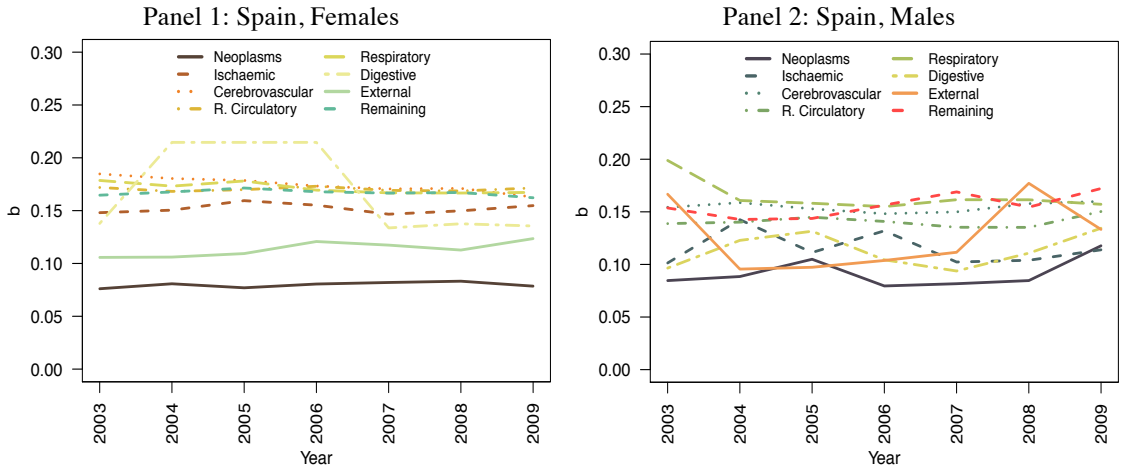
**Table 3.1:** Estimates of $\widehat{b}(y)$ for overall mortality for England and Wales with associated standard errors

| Year | Females | | Males | |
|---|---|---|---|---|
| | $\widehat{b}(y)$ | s.e.$\widehat{b}(y)$ | $\widehat{b}(y)$ | s.e.$\widehat{b}(y)$ |
| **2001** | 0.111 | 0.0019 | 0.108 | 0.0033 |
| **2002** | 0.113 | 0.0018 | 0.108 | 0.0035 |
| **2003** | 0.116 | 0.0018 | 0.111 | 0.0038 |
| **2004** | 0.114 | 0.0018 | 0.120 | 0.0040 |
| **2005** | 0.114 | 0.0017 | 0.108 | 0.0041 |
| **2006** | 0.113 | 0.0016 | 0.111 | 0.0036 |
| **2007** | 0.115 | 0.0016 | 0.126 | 0.0034 |
| **2008** | 0.117 | 0.0015 | 0.123 | 0.0034 |
| **2009** | 0.116 | 0.0015 | 0.130 | 0.0033 |
| **2010** | 0.117 | 0.0014 | 0.125 | 0.0034 |

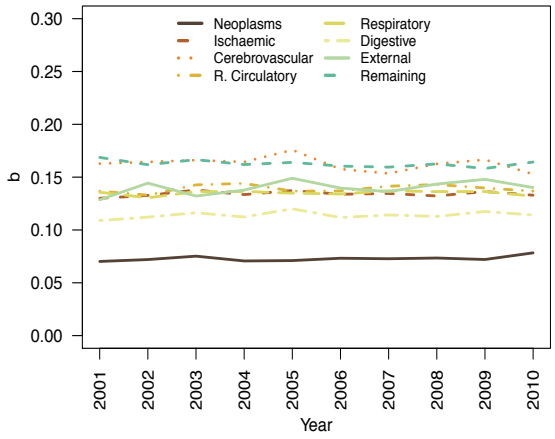
**Source:** WHOMD and HMD 2014, own elaboration

Figure 3.5, reveals that the $\widehat{b}_i(y)$ estimates for the rate of individual aging differentiated by $\text{COD}_i$ follow a similar pattern across time, with exception for some cases with lower subpopulation size, like the *digestive system diseases* in Spain for females, or in the overall male case. Here we already can realize that, despite the existence between the obtained results, of dissimilar estimates, they seem to be reasonably constant over time.

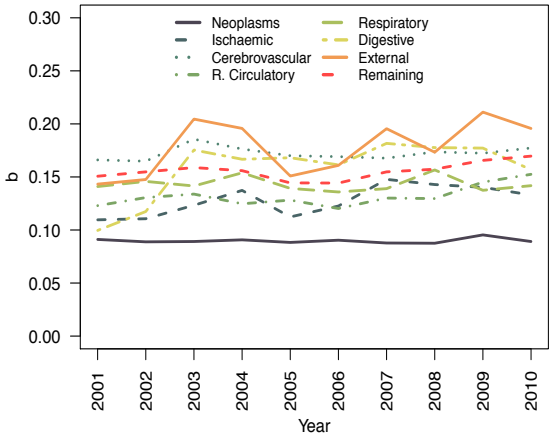
**Figure 3.5:** Estimated $\widehat{b}_i(y)$ by $\text{COD}_i$ for Spain and England and Wales



Panel 3: England and Wales, Females




Panel 4: England and Wales, Males




**Source:** WHOMD and HMD 2014, own elaboration

Despite Figure 3.5 displays a very similar level across the presented estimates, in Table 3.2, we can realize that the gender differences calculated based on the average rates of individual aging over the country-specific available periods seem to be negligible in some cases (countries and CODs). In some other situations, the difference is at least 0.01, what at this magnitude, is considered to be significant.

Generally, the obtained estimates vary from an average of 0.115, registered in Finland and Netherlands, to the Swedish 0.131, for males; while for females varies from the same 0.115, registered in England and Wales, to 0.144 from Finland. From these results, can be also recognized that $\hat{b}(y)$ is constantly overestimated for females in comparison with males, but a possible explanation can be advanced by the gender-gap in the associated mortality rates for both sexes, that result, inevitably, in different estimates for the other corresponding parameters $\hat{a}(y)$, $\hat{c}(y)$ and $\hat{\gamma}(y)$.

**Table 3.2:** Average country-specific individual rate of aging

| | Sex | All | Neo. | Isc. | Cer. | R.Cir. | Resp. | Dig. | Ext. | Rem. |
|---|---|---|---|---|---|---|---|---|---|---|
| **SWE** | **F** | 0.129 | 0.069 | 0.148 | 0.174 | 0.179 | 0.131 | 0.132 | 0.152 | 0.162 |
| | **M** | 0.130 | 0.095 | 0.137 | 0.171 | 0.182 | 0.156 | 0.172 | 0.223 | 0.168 |
| **SPA** | **F** | 0.137 | 0.080 | 0.152 | 0.175 | 0.170 | 0.171 | 0.170 | 0.114 | 0.167 |
| | **M** | 0.121 | 0.092 | 0.115 | 0.155 | 0.141 | 0.165 | 0.113 | 0.126 | 0.156 |
| **FRA** | **F** | 0.132 | 0.067 | 0.147 | 0.150 | 0.161 | 0.156 | 0.125 | 0.145 | 0.152 |
| | **M** | 0.123 | 0.069 | 0.131 | 0.156 | 0.155 | 0.140 | 0.136 | 0.152 | 0.165 |
| **NED** | **F** | 0.128 | 0.065 | 0.136 | 0.175 | 0.156 | 0.146 | 0.149 | 0.162 | 0.162 |
| | **M** | 0.115 | 0.091 | 0.123 | 0.167 | 0.133 | 0.179 | 0.152 | 0.196 | 0.155 |
| **FIN** | **F** | 0.144 | 0.080 | 0.178 | 0.179 | 0.169 | 0.160 | 0.161 | 0.175 | 0.170 |
| | **M** | 0.115 | 0.093 | 0.128 | 0.156 | 0.136 | 0.147 | 0.207 | 0.254 | 0.177 |
| **NOR** | **F** | 0.129 | 0.065 | 0.157 | 0.184 | 0.178 | 0.154 | 0.147 | 0.171 | 0.152 |
| | **M** | 0.128 | 0.095 | 0.145 | 0.180 | 0.169 | 0.163 | 0.150 | 0.191 | 0.156 |
| **E & W** | **F** | 0.115 | 0.073 | 0.134 | 0.163 | 0.139 | 0.135 | 0.114 | 0.140 | 0.163 |
| | **M** | 0.117 | 0.090 | 0.124 | 0.172 | 0.132 | 0.143 | 0.158 | 0.178 | 0.156 |

**Source:** WHOMD and HMD 2014, own calculation

What has just been exposed is clearly exemplified in Table 3.3, where the Spanish example for overall mortality is presented.

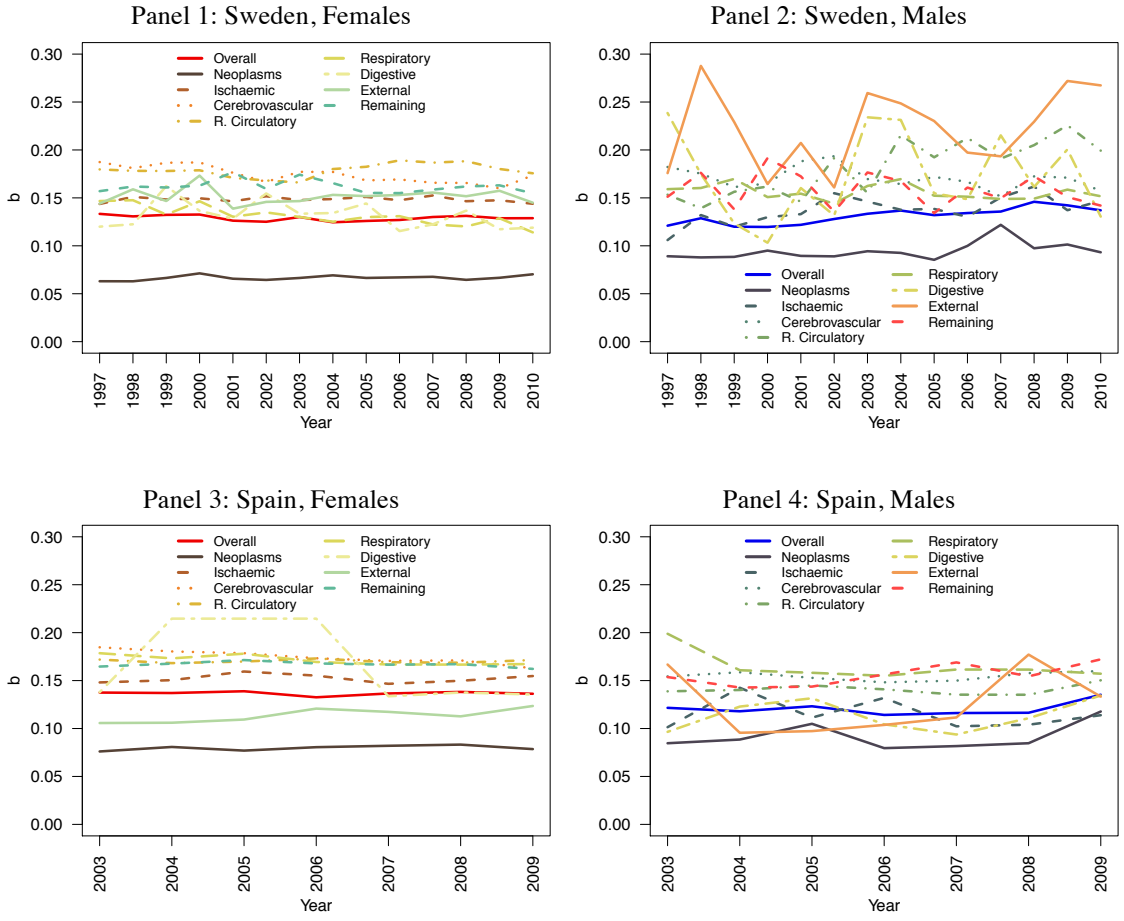
**Table 3.3:** Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in Spain

| **Females** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0.00757 | 0.00021 | 0.137 | 0.0021 | 0.132 | 0.0231 | 0.00000012 | 0.00050474 |
| **2004** | 0.00714 | 0.00020 | 0.137 | 0.0021 | 0.147 | 0.0235 | 0.00000021 | 0.00037330 |
| **2005** | 0.00707 | 0.00019 | 0.139 | 0.0020 | 0.141 | 0.0225 | 0.00000000 | 0.00263809 |
| **2006** | 0.00687 | 0.00018 | 0.133 | 0.0019 | 0.047 | 0.0214 | 0.00000001 | 0.00167468 |
| **2007** | 0.00664 | 0.00016 | 0.137 | 0.0017 | 0.096 | 0.0208 | 0.00000006 | 0.00055173 |
| **2008** | 0.00636 | 0.00015 | 0.138 | 0.0016 | 0.102 | 0.0206 | 0.00000007 | 0.00048874 |
| **2009** | 0.00623 | 0.00014 | 0.136 | 0.0015 | 0.064 | 0.0192 | 0.00000003 | 0.00073094 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0.01492 | 0.00077 | 0.122 | 0.0040 | 0.140 | 0.0291 | 0.00469955 | 0.00084663 |
| **2004** | 0.01500 | 0.00078 | 0.118 | 0.0040 | 0.130 | 0.0289 | 0.00338730 | 0.00084960 |
| **2005** | 0.01427 | 0.00071 | 0.123 | 0.0038 | 0.165 | 0.0283 | 0.00415971 | 0.00078600 |
| **2006** | 0.01448 | 0.00083 | 0.114 | 0.0042 | 0.088 | 0.0311 | 0.00285396 | 0.00089437 |
| **2007** | 0.01478 | 0.00065 | 0.116 | 0.0033 | 0.123 | 0.0254 | 0.00215482 | 0.00070332 |
| **2008** | 0.01419 | 0.00063 | 0.116 | 0.0033 | 0.117 | 0.0261 | 0.00190371 | 0.00068821 |
| **2009** | 0.01080 | 0.00053 | 0.135 | 0.0038 | 0.269 | 0.0314 | 0.00557874 | 0.00059131 |

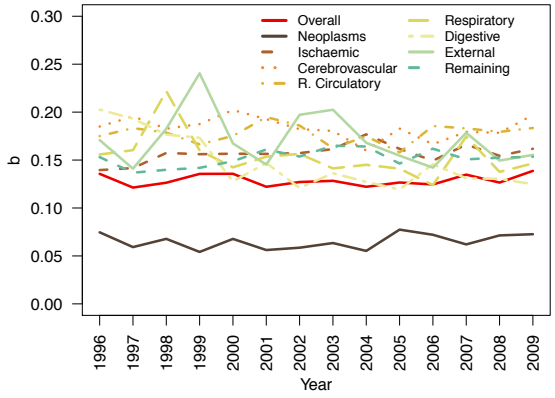
**Source:** WHOMD and HMD 2014, own elaboration

Focusing now again on the estimated rates of individual aging by COD (Figure 3.6), we can distinguish three main patterns, 1) the obtained estimates for neoplasms $\hat{b}_i(y)$ seem to be always lower than the registered for overall mortality $\hat{b}(y)$; 2) the estimates for overall mortality are in agreement with the ones obtained for ischaemic heart diseases, being very similar; and lastly, 3) all other CODs show an associated $\hat{b}_i(y)$-estimate higher than $\hat{b}(y)$. Thus, we can conclude that neoplasms influence "negatively" the rate of individual aging estimated for overall mortality, once that the still observed high mortality rates at age 65 contributes to a lower overall $\hat{b}(y)$.

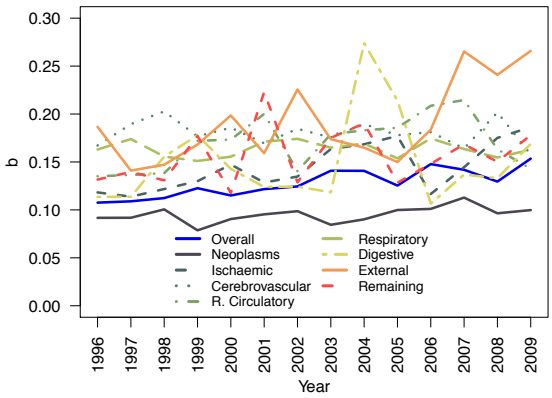
**Figure 3.6:** Estimated $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ and $\widehat{\boldsymbol{b}}_{\boldsymbol{i}}(\boldsymbol{y})$ by $\mathbf{COD}_{\boldsymbol{i}}$ for all selected countries



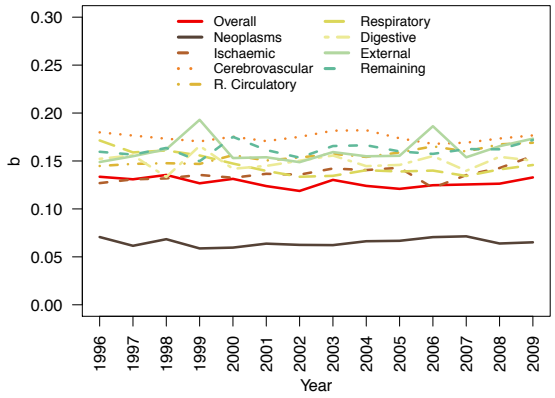
Panel 5: Norway, Females



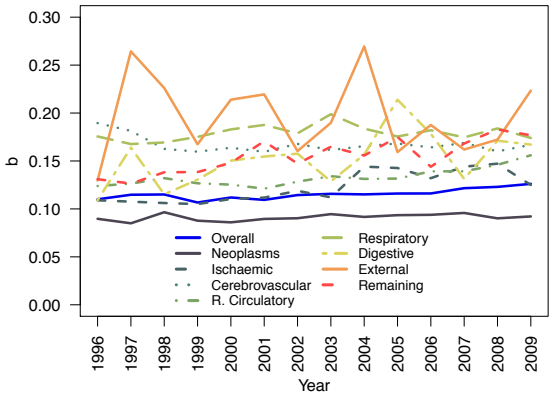

Panel 6: Norway, Males



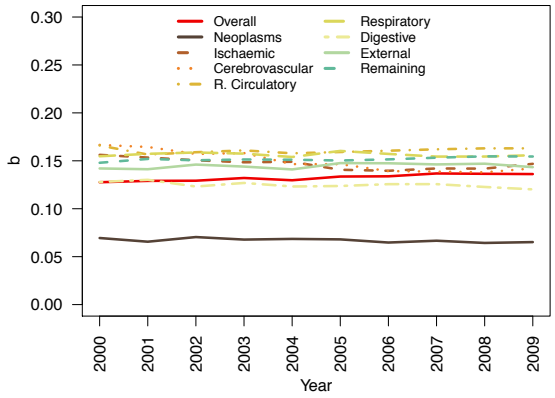

Panel 7: Netherlands, Females



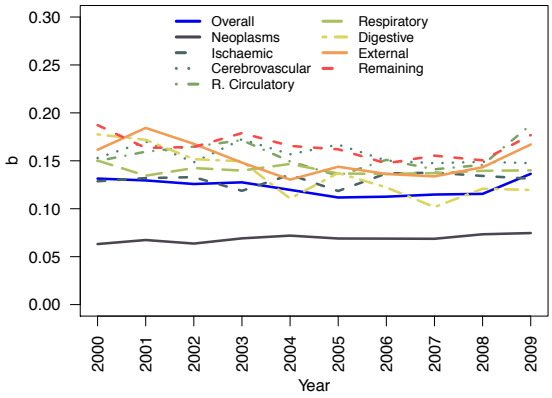

Panel 8: Netherlands, Males



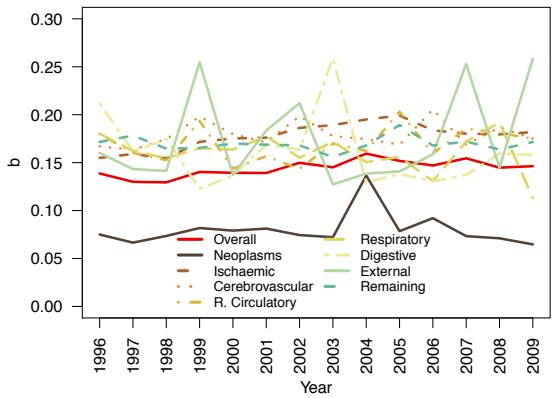

Panel 9: France, Females



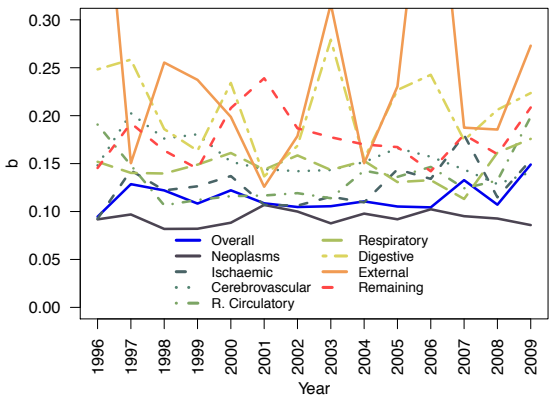

Panel 10: France, Males



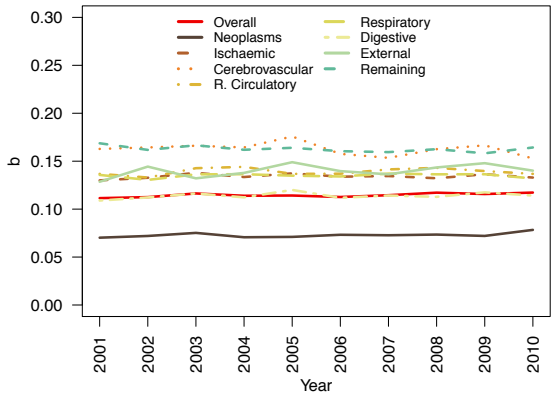

Panel 11: Finland, Females



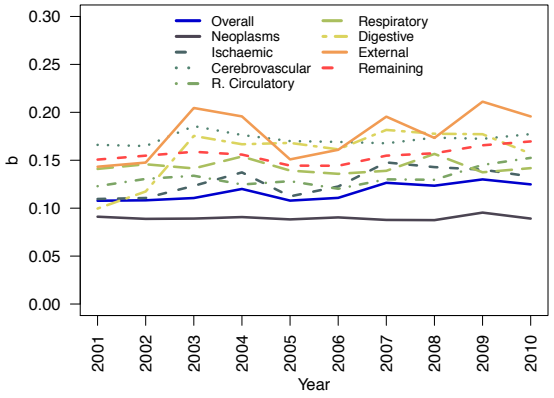

Panel 12: Finland, Males



Panel 13: E. & W., Females




Panel 14: E. & W., Males




**Source:** WHOMD and HMD 2014, own elaboration

From the obtained results, we can observe that the COD that has most distinctive estimates for the rate of individual aging $\hat{b}_i(y)$ is neoplasms, to which is connected the lowest estimates. Nevertheless, some explanations might be advanced: 1) the incidence rate associated to neoplasms achieves its higher values before age 65, where mortality rates seem to decline around age 50/55; 2) following WHO (2014), around 30 % of all deaths related to neoplasms *"are due to five leading behavioral and dietary risks: high body mass index, low fruit and vegetable intake, lack of physical activity, tobacco use, alcohol use"*, and bring some uncertainty to cancer-related mortality patterns; 3) the stage of the diagnosis, that influences directly age-specific mortality rates, once that earlier diagnosis increases survival chances; and 4) a wide-ranging cause of death group, once that all types of neoplasms are concentrated in only one large group, and the overall observed pattern may not reflect directly all distinct neoplasms (for further discussion see Ukraintseva and Yashin, 2003).

Estimates obtained for causes with lower number of deaths, originating lower study subpopulations, present higher fluctuation patterns. Digestive system diseases and external causes of death are two good examples, but specifically the second, due to its strict connection with transport-accident. Country size and sex revealed also to be important, once that exists a higher number of females alive after age 65 and countries like Norway (5.1 M), Finland (5.4 M), Sweden (9.5 M) and Netherlands (16.8 M) have lower population size when compared with France (66 M), Spain (47.3 M) or England and Wales (57.9 M).

## 3.5. Discussion

Despite some criticism about focusing on the slope of age-specific mortality, in log-scale, to measure the rate of aging (Rozing and Westendorp, 2008) and some expositions about the *pros* and *contras* of this measure (de Gray, 2005), we believe that this approach is highly sustainable. Thus, and seeking to test Vaupel's hypothesis the individual rate of mortality increase was estimated under a $\Gamma GM$ framework differentiating each COD as a subpopulation. Under this framework, we can also obtain the estimates for the population rate of aging, which in opposition to the individual's rate of aging, has been widely studied, either for human populations (e.g., Horiuchi and Wilmoth, 1997, 1998) or non-human (e.g., Carey and Liedo, 1998). These two measures not only are completely different, but also present very distinctive patterns, being the individual rate of aging constant across time, i.e., indicating how fast individuals in a population if the initial level of mortality stays unchanged and with no external influences (considered here with Makeham's *c*); and LAR varying age-wise, creating a bell-shaped pattern. Still, not only *b* differs from LAR, but also contributes to its estimation (Vaupel and Zhang, 2010).

Generally, the estimated rates of individual aging across different CODs, sexes and selected countries, perform a fairly stable evolution. Nevertheless, we cannot fully support Vaupel's hypothesis due the discrepancy between the obtained estimates by COD, but a major contribution for this topic is achieved. Our estimates also revealed that, with the exception of neoplasms, the estimates obtained for overall mortality are always lower when compared with different $\hat{b}_i(y)$. In this way, it seems that the different $\hat{b}_i(y)$ associated to different CODs appears to contribute to the "average" rate of individual aging, i.e., to the obtained estimates for overall mortality. Accordingly with Brody and Schneider (1986), our results present lower rates of aging for causes considered close to non-senescent processes, like neoplasms or external causes of death, and higher values for the ones in opposite direction, i.e., for example the case of the deaths caused by diseases of the circulatory system. The case of cancer strikes out as the cause that has the lowest rate of aging of all, factor that can be explained by the fact that *"in the human species, the population that reaches advanced age and has a decreased incidence of cancer, could be less prone to develop cancer and hence more fit to reach the maximum lifespan"* (Macieira-Coelho, 1986). Another explanation can be directly related with the origin of cancer, which is

connected with the unregulated growth of new cells, being a multistage process that starts with a pre-cancerous lesion and ends up with a malignant tumor. Nevertheless, at older ages the proliferation of cells is declining and possibly increases the time between cancer development stages (Ukrainsteva and Yashin, 2003).

As a result, many factors may have interfered with the obtained results: 1) model estimation employing aggregated data (5-year age groups); 2) data validity and viability; 3) the existence of competing risks to which each individual is exposed; and 4) the existence of a close relationship between behavior and some CODs as, e.g., neoplasms and external causes. Consequently, once that the obtained results cannot fulfill Vaupel's hypothesis (it only speaks in favor of a constant evolution across time), a possible complementary way is testing by the estimate of the individual rate of individual aging accordingly to groups of individuals that share the same behavioral pattern, e.g., smokers and non-smokers; athletes and non-athletes; or, alcohol consumption and non-consumption.

Summarizing, obtained estimates present more stable and less variation across time for countries with larger population sizes (Spain, France, and England and Wales), CODs with higher proportion of deaths beyond age 65, and in general for females, as consequence of a larger number of alive females on the analyzed age range.

## 3.6. Conclusions

Even with the obtained results showing that to each considered subpopulation it is obtained a different rate of individual aging, we cannot *completely* refute Vaupel's hypothesis. Nevertheless, we strongly believe that a major contribution in this direction was achieved. The constant rate of aging across all individuals, if proved, *"would fundamentally contribute to our understanding of how and why we age"* (Vaupel, 2010), and our findings are contributing, at least partially, on this direction. It seems that each cause of death contributes for the rate of aging for the overall population. In this way, we understand that, due to the different contributing risks to which all individuals are exposed (Chiang, 1991), it is more correct to test for example a group of individuals that died from one specific cause but that was exposed

to all the causes of death, e.g., smokers versus non-smokers, or people living with cancer versus people without this disease.

Still, the finding of an almost constant rate of aging across time for the causes less prone to human behavior suggests that besides different CODs are characterized by different rates of aging, it is possible that they share the same rate of aging within a subpopulation exposed to all competing risks. One example of a population exposed to all competing risks, that speaks in favor of a constant rate of individual aging is given by Zarulli (2012), where the author finds clear favorable evidences among the Australian prisoners in Java during WWII.

# CHAPTER 4

# REVISITING MORTALITY DECELERATION PATTERNS UNDER A GAMMA-GOMPERTZ-MAKEAHM FRAMEWORK

## 4.1. Introduction

Horiuchi and Coale (1990) proposed a mortality measure, designated later (Horiuchi and Wilmoth, 1997; Carey and Liedo, 1998) as the life-table aging rate (LAR), which captures the age-specific rate of mortality change for a given population $\bar{b}^*(x) = \ln\big(M(x)\big) - \ln\big(M(x-1)\big)$. The rate of individual aging defined as the relative derivative of the baseline hazard of death from senescent causes, is a different characteristic, which is constant whenever the aging process is captured by a Gompertz curve (for further discussion on the rate of individual aging, see Missov and Vaupel 2015, Missov and Ribeiro 2015).

Gampe (2010) finds evidence for a leveling-off of human mortality at ages 110-114. If a mortality plateau exists, then it speaks in favor of a relative-risk model (Missov and Vaupel 2015) with a Gompertz-Makeham baseline $\mu(x) = ae^{bx} + c$ (Gompertz 1825; Makeham 1860), where $a$ measures the mortality level at the starting adult age, $b$ is the individual rate of aging itself, and $c$ captures the risk of dying that is not associated with the aging process. Unobserved heterogeneity (frailty) can be captured by a gamma distribution with a unit mean and $\gamma$ variance at the starting age (Vaupel et al. 1979, Missov and Finkelstein 2011, Missov and Vaupel 2015). This leads to the gamma-Gompertz-Makeham frailty model (Vaupel et al. 1979), which we will shortly address as the ΓGM. If we estimate its parameters $a$, $b$, $c$ and $\gamma$, we can take advantage of the LAR representation by Vaupel and Zhang (2010) to estimate the population rate of aging (LAR).

Horiuchi, Cheung and Robine, 2012 focused on reconstructing model-based LARs by fitting a Kannisto model for homogeneous populations. In this chapter we focus on a ΓGM heterogeneous model to reflect the perception that populations consist of individuals that share the same baseline hazard, to which they are susceptible in a different (random) way. We also incorporate a Makeham term to account for possible (non-negligible) extrinsic mortality. If $c$ is statistically significant

and is left out of the model, the estimates for the other ΓGM parameters will be biased (Missov and Nemeth 2014). As a result LAR will be also unspecified and it will be impossible to capture its bell-shaped pattern (Horiuchi and Coale 1990). This is perhaps one of the main reasons that Gavrilova and Gavrilov (2014) find no evidence of a deceleration pattern in the rate of population aging after age 80 in their simulation study. In the same paper, the empirical finding based on 24 single-year birth cohorts for four different countries (Canada, France, Sweden and the United States of America) using Human Mortality Database (2014) suggested, once more, that LAR does not change significantly with age. We believe that this results from the omission of the two-step "smoothing" procedure, essential to calculate LAR (Horiuchi and Coale, 1990).

In this chapter we first fit the ΓGM model to five countries: two from Southern Europe (Spain and Portugal), one from Western Europe (France), one from Northern Europe (Sweden), and one from Asia (Japan). Similarly to what was done in Chapter 2, our choice was based on the qualitatively different patterns of life-expectancy evolution over time. France and Sweden register high life expectancy at birth in the 1950s, but its rate of increase drops in the following decades. Spain, Portugal and Japan, on the other hand, experience a lower life expectancy at birth in the 1950s, but the rates of increase surpass the ones for the life-expectancy leaders at the time. As a result the three countries caught up: life expectancy in Spain even surpassed the one registered in Sweden, whereas Japan became the world leader best-practice country.

Second, we elaborate on the relationship between the estimated LARs and the rate of life expectancy increase in the chosen countries, as well as show how the estimated LARs reflect the age patterns of mortality deceleration – not only for the overall mortality, but also across causes of death (COD). At the same time we illustrate how well the LAR formula by Vaupel and Zhang (2010), which uses the estimated ΓGM parameters, fits the actual LAR.

Third, we test the "heterogeneity hypothesis" by Horiuchi and Wilmoth (1998), which states that a) deceleration occurs for the most major CODs, being less pronounced for CODs with lower death rates; and b) mortality deceleration should occur at later ages due to selection effects.

## 4.2. Data

Data on *overall death counts* $D(x,y)$ and *exposures* $E(x,y)$ derived from the *Human Mortality Database* (HMD, 2014: www.mortality.org) and *deaths by COD* $D_i(x,y)$ from the *World Health Organization Mortality Database* (WHOMD, 2014).

Like it was explained on the previous chapters, WHOMD cause of death (COD) data are only available by five-year age groups and once that we extract death counts according to ICD10, the timeline is restricted to the last available decade (depending on the country (see Table 4.1). We leave Portugal out of the analysis by COD as the last open-end age group is 85+ and not 95+ and that could interfere with obtained estimates. To avoid low subpopulation sizes and any lack of representativeness, we work with major COD groups: 1) Neoplasms, 2) Ischaemic Heart Diseases; 3) Cerebrovascular Diseases; 4) Remaining Diseases of the Circulatory System; 5) Diseases of the Respiratory System; 6) Diseases of the Digestive System; 7) External Causes of death; and 8) Remaining Causes of death. Following the WHO recommendation (1977) to avoid uncertainty that comes from changes and updates in the classification system, we base our research on the *underlying cause of death*, *i.e.*, the disease or injury, which initiated the series of events that lead to death.

**Table 4.1:** List of countries and years, for which we are able to reconstruct LAR for overall mortality (source: HMD, 2014) and by COD according to ICD10 (source: WHOMD, 2014), by fitting a ΓGM model

| Countries | Study Period (Overall Mortality) | Study Period (COD) |
|---|---|---|
| **Portugal** | 1950 - 2012 | — |
| **Spain** | 1950 - 2012 | 1999 - 2011 |
| **Sweden** | 1950 - 2011 | 1997 - 2010 |
| **France** | 1950 - 2012 | 2000 - 2010 |
| **Japan** | 1950 - 2012 | 1995 - 2011 |

**Source:** WHOMD and HMD 2014, own elaboration

## 4.3. Methods

### 4.3.1. The life-table aging rate

If data are available for single-year age groups, the rate of population aging (LAR), here addressed as $\bar{b}(x)$, can be obtained by the following formula (Horiuchi and Coale, 1990):

$$\bar{b}^*(x) = \ln\big(M(x)\big) - \ln\big(M(x-1)\big)\,, \tag{4.1}$$

where $M(x)$ is the central death rate at age *x*.

Nevertheless, the small number of deaths at very old ages results in a large stochastic variation in death rates and, consequently, a two-step procedure need to be followed (Horiuchi and Coale, 1990):

a. apply a five-year moving average to the central death rates $M(x)$ and then calculate LAR using (4.1);
b. taking nine-year weighted moving averages on the results obtained by (4.1) applying:

$$\bar{b}_{emp}(x) = \sum_{n=-4}^{4} \frac{(5-|n|)}{25} * \bar{b}^*(x+n). \tag{4.2}$$

This procedure lowers fluctuations due to possible high variation of the death rates and produces similar curves of $\bar{b}_{emp}(x)$.

### 4.3.2. Specifying LAR under a gamma-Gompertz-Makeham framework

Human populations are constituted by a combination of different heterogeneous subpopulations, where despite sharing the same hazard of death, individuals present different levels of susceptibility to death. Within this framework, we assume that the baseline hazard $\mu(x)$ follows a Gompertz-Makeham pattern (Gompertz, 1825; Makeham, 1860):

$$\mu(x) = a\, e^{bx} + c, \tag{4.3}$$

where the aging process is captured by $b$, obtained by the relative derivative of $ae^{bx}$, i.e., the Gompertz part of the equation, $a$ refers to the starting level of mortality for a given adult age (where $x = 0$) and $c$ corresponds to non-senescent mortality. Gampe in 2010, in her research, found evidence for a human mortality plateau at older age mortality when realized that mortality rates are leveling off beyond age 110, being favorable to the application of relative-risk models (Missov and Vaupel, 2015).

Again, if we assume frailty as being gamma-distributed with a unit mean and $\gamma$ variance at the starting age of analysis, which is an additional standard (Beard, 1959; Vaupel et al., 1979) already proved theoretically (Steinsaltz and Watcher, 2006; Missov and Finkelstein, 2011), we end-up with a *gamma-Gompertz-Makeham* (ΓGM) *frailty model*. Thus, within a ΓGM theoretical framework, the hazard for the population is given by (Vaupel et al., 1979; Vaupel, 2002; Vaupel and Missov, 2014):

$$\bar{\mu}(x) = \frac{a\, e^{bx}}{1+\frac{\gamma a}{b}\left(e^{bx}-1\right)} + c. \tag{4.4}$$

where, $a$, $b$ and $c$ maintain the same meaning explained before and $\gamma$ is the frailty variance at the initial age of analysis.

Like it was said before, considering the model in (4.4), the individual rate of aging is captured by the relative derivative of the Gompertz part $ae^{bx}$, but in opposition, the relative derivative of $\bar{\mu}(x)$ results in the obtainment of the population rate of aging. If the first is constant across age, corresponding to $b$ in (3), the second, proposed by Horiuchi and Coale in 1990 and addressed later as the *life-table aging rate* (LAR), varies age-wise presenting a characteristic bell-shaped pattern (Horiuchi and Coale, 1990; Horiuchi and Wilmoth, 1997, 1998; Vaupel and Zhang, 2010). LAR has been widely studied, either for human populations (e.g., Horiuchi and Wilmoth, 1997, 1998) or non-human (e.g., Carey and Liedo, 1998), and in 2010, Vaupel and Zhang, explored an explicit relationship between the individual rate of mortality increase and the population rate of aging, proving that, not only $b$ differs from LAR, but also contributes to the estimation of the second.

The life-table aging rate (Horiuchi and Coale 1990), measures the rate of aging at age $x$ for a population, whose mortality follows a hazard function $\mu(x)$, is defined as:

$$\bar{b}(x) = \frac{1}{\mu(x)} \frac{d\mu(x)}{dx} = \frac{d \ln \mu(x)}{dx}, \tag{4.5}$$

In a ΓGM framework, an explicit relationship between the individual and the population rate of aging is presented by Vaupel and Zhang (2010):

$$\bar{b}(x) = b\left(1 - \frac{c}{\mu(x)}\right) - \gamma\left(1 - \frac{c}{\mu(x)}\right)(\mu(x) - c). \tag{4.6}$$

As it was explained in the chapter *introduction*, the inclusion of *c* in the model is important for capturing the bell-shaped pattern of $\bar{b}(x)$ as "*not all monotonically increasing logistic* $\mu(x)$ *result in bell-shaped* $\bar{b}(x)$ *patterns*" and "*if the factor c is excluded from the individual-level equation, then the resulting aggregate-level* $\mu(x)$ *function does not lead* $\bar{b}(x)$ *to a bell-shaped pattern*" (Horiuchi and Coale, 1990), and its omission can even result in biased estimates for the other parameters (Missov and Nemeth, 2014).

The age at which the relative derivative of $\mu(x)$ reaches its maximum is the age when mortality starts to decelerate. In a ΓGM framework we can easily derive a closed-form expression for the age of mortality deceleration:

$$x^* = \frac{1}{b} \ln\left(\frac{(b + c\,\gamma)\,c}{2\,a\,b} + \frac{\sqrt{(b + c\,\gamma)c\,\gamma\big((b + c\,\gamma)c - 4b(a\,\gamma - b)\big)}}{2\,a\,b\,\gamma}\right) \tag{4.7}$$

### 4.3.3. Fitting overall and cause-specific mortality

To capture accurately mortality dynamics across different periods we fitted model (4.4). As a result, in year *y*, we capture the overall force of mortality by:

$$\bar{\mu}(x,y) = \frac{a(y)\, e^{b(y)x}}{1+\frac{\gamma(y)a(y)}{b(y)}\left(e^{b(y)x}-1\right)} + c, \tag{4.8}$$

where $a(y)$ is the starting level of mortality, $b(y)$ is the rate of individual aging, $c(y)$ is the Makeham term, $\gamma(y)$ the frailty variance at the initial age of analysis $x_0$ $(x_0 < x)$ among survivors from cohort $y$ - $x$.

Studying different subpopulations from COD $i$, we assume that exposures by cause are the same as exposures for the overall mortality $E_i(x,y) = E(x,y)$ for all $i, x$ and $y$. Following this assumption, cause-specific force of mortality can be expressed by:

$$\bar{\mu}_i(x,y) = \frac{a_i(y)\, e^{b_i(y)x}}{1+\frac{\gamma_i(y)a_i(y)}{b_i(y)}\left(e^{b_i(y)x}-1\right)} + c_i(y). \tag{4.9}$$

We are thus estimating a unique starting level of mortality $a_i(y)$, the rate of individual aging $b_i(y)$, the frailty's variance $\gamma_i(y)$ at the starting age of analysis, and Makeham's term $c_i(y)$ by COD $i$.

Introduced the model framework, fitting procedure holds on the assumption that $D_i(x,y) \sim Poisson\left(E(x,y) * \bar{\mu}_i(x,y)\right)$ (Brillinger, 1986), where $D_i(x,y)$ denote the cause-specific death counts $i$, and $E(x,y)$ denote the age specific exposures, both in year $y$. Thus, for each $\mathrm{COD}_i$ separately in year $y$ we maximize a Poisson log-likelihood:

$$\ln L\left(a_i(y), b_i(y), \gamma_i(y), c_i(y)\right) = \sum_x \left[D_i(x,y) * \ln \bar{\mu}_i(x,y) - E(x,y) * \bar{\mu}_i(x,y)\right] \tag{4.10}$$

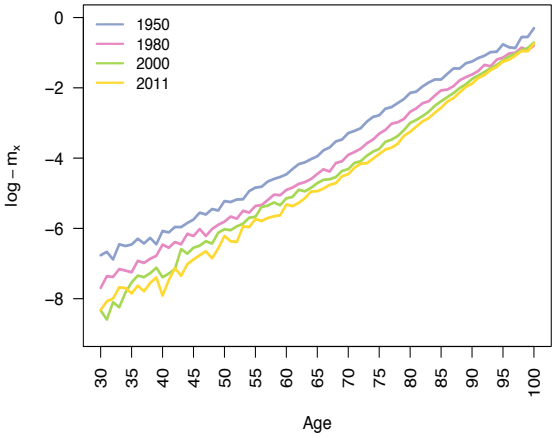
The same procedure is adopted to estimate the parameters for all causes combined (when $i = \emptyset$, we refer to (8)).

We start fitting both mentioned models (4.8) and (4.10) at age 65 for overall and cause-specific mortality. If in overall mortality, from this point onwards the mortality patterns follow an almost linear pattern on a logarithmic scale, followed by eventual deceleration, for some $\mathrm{COD}_i$ subpopulations, the underlying mortality

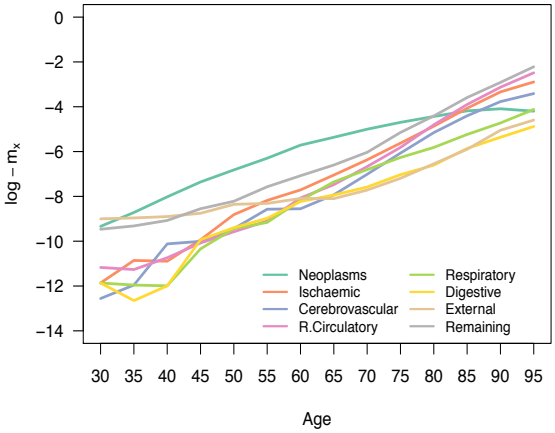
patterns do not seem to follow a ΓGM-curve, particularly at earlier ages (see Figure 4.1) and parameter estimation would be meaningless.

**Figure 4.1:** Mortality rates for overall and cause-specific mortality, Sweden - Females

Panel 1: Overall mortality rates




Panel 2: Mortality rates by COD, 2011




**Source:** WHOMD and HMD 2014, own elaboration

### 4.3.4. Data Smoothing

As explained before, we assume that the total number of deaths across age and year follow a Poisson distribution, but sometimes there is evidence for overdispersion (Breslow, 1984; Cameron and Trivedi, 1986; Camarda, 2008 and 2012). Overdispersion can be mainly found in countries with relatively poor data or historical data trends and is generally caused by age heaping or digit preference, i.e., the tendency to round counts or measurements to pleasant digits (Camarda, 2008). In order to stabilize the high variance that is associated with high age-specific death rates, we consider the latter on a log-scale and smooth them.

It is true that the considered model (ΓGM) is also a valid approach to smooth mortality[2], but once that overparametrization may influence the estimation procedure, our choice fell on a more flexible approach to describe age patterns and time trends. *"Because mortality developments generally display regular patterns, using smoothing approaches is a more natural choice for analyzing mortality changes than imposing a model structure"* (Camarda, 2012).

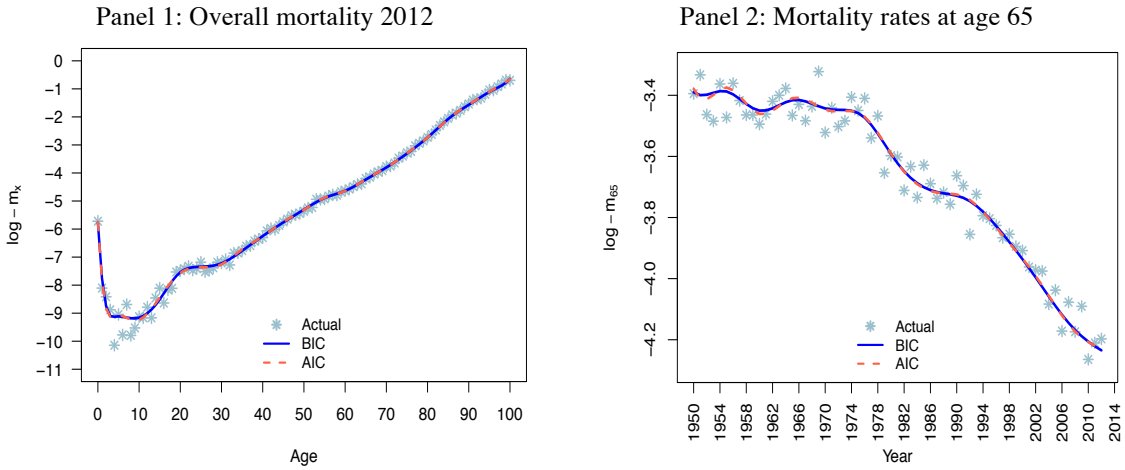
[2] Similarly, in the HMD the Kannisto model is used to smooth mortality rates at older ages (Wilmoth et al., 2007).

The use of smoothed data to construct life-tables results, as expected, in lower variance, providing therefore, better estimates of life expectancy (Booth, Hyndman and Tickle, 2014). Since we elaborate on model-based LAR estimates resulting from a ΓGM framework, data should be leveled among the selected countries to enable proper and accurate comparisons.

Although several methodologies have been proposed to deal with either one or two-dimensional data structures, we focus on the two-dimensional level, taking advantage of the MortalitySmooth (Camarda, 2012) R package (R Development Core Team, 2014). This package employs an approach using two-dimensional regression splines, or to be more specific, B-splines with penalties: P-splines (Camarda, 2012). Within this framework, and to be able to handle a smoothing procedure, the model needs to achieve an "optimal" value (or values) for the smoothing parameter. A non-optimal value influence negatively and increase estimates variance. Two of the most know procedures for this type of model construction are the Akaike information criterion (AIC) (Akaike, 1973), suggested by Eilers and Marx (1996, 2002), and the Bayesian information criterion (BIC) developed by Schwarz in 1978, penalizing more heavily the model complexity. Nevertheless, a solider fit, which is given by BIC, is desired when mortality rates are smoothed applying the P-splines approach (Currie *et al*., 2004; Camarda, 2012).

Figure 4.2 exemplifies the differences between estimated smoothed curves for Portugal (the second-smallest in population size among the countries under study, known for its lower data quality prior to 1970) using both information criteria, BIC and AIC, for male overall mortality (panel 1) and at age 65 (panel 2), in 1950 and 2012. Both P-spline approaches are capturing well the evolution of mortality patterns over age and time. In panel 2, one can see a small difference in the first 8 years of fit, showing that if we employ the BIC penalization, the degree of smoothness does not lead to the overestimation of small fluctuations that are possibly caused by randomness.

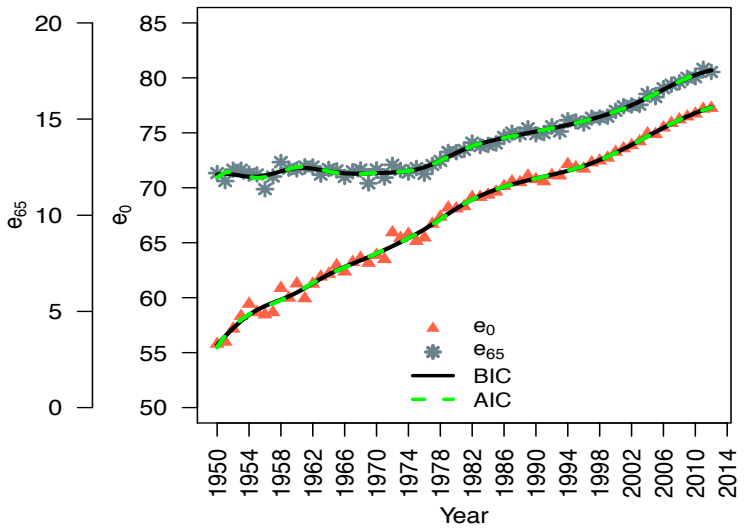
**Figure 4.2:** Actual and fitted death rates from a P-spline approach, Portugal - Males




**Source:** HMD 2014, own elaboration

As expected, smoothing mortality rates does not change life expectancy estimations (Figure 4.3), and similarly to what as shown in Figure 4.2, the differences between both penalties (BIC and AIC) are almost negligible and the overall trend is well captured.

**Figure 4.3:** Actual and fitted life expectancy from a P-spline approach, Portugal - Males



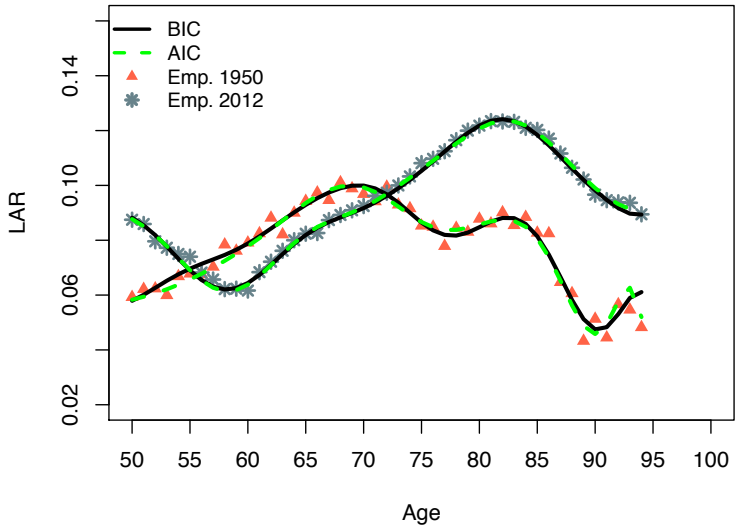

**Source:** WHOMD and HMD 2014, own elaboration

Nevertheless, it is not our intention to elaborate exclusively on life expectancy dynamics, but on the possible connection between life expectancy and the life-table aging rate. Figure 4.4, proves, once more, that the P-spline approach does not change the original information and fits well empirical LAR. Again, some minor differences

can be registered between both penalizations but the degree of smoothness resulting from BIC approach does not lead to the overestimation of small fluctuations.

The examples presented here reinforce the idea of BIC as the best approach, and especially that the use of smoothed data in our study will not influence final outcomes and conclusions.

**Figure 4.4:** Empirical and fitted LAR from a P-spline approach, Portugal - Males




**Source:** HMD 2014, own elaboration

### 4.3.5. Segmenting life expectancy dynamics

To elaborate on the relationship between estimated LARs and life expectancy dynamics, we differentiate between different period segments on the overall timeline, i.e., we estimate independently different regression lines that incorporate a piece-wise linear relationship between life expectancy and calendar year. This results in two (or more) line segments. Assuming a changing point $i$, the relationship between the different life expectancies $(e_i)$ registered across years and the calendar year itself $(y_i)$ is captured by:

$$e_i = \alpha + \beta_1 y_i + \beta_2 (y_i - \psi)_+ \tag{4.11}$$

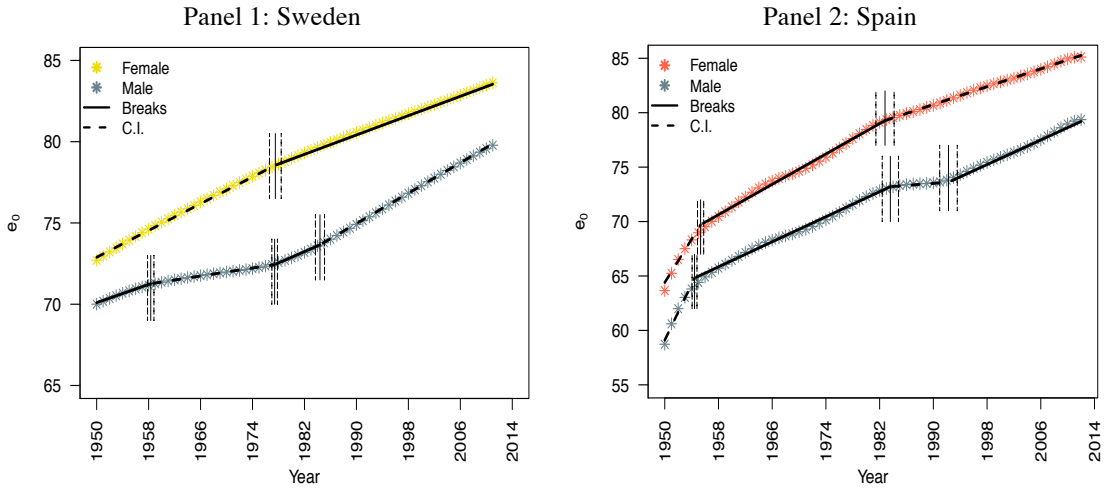
where $\alpha$ is the intercept, $\beta_1$ is the first segment slope, $\beta_2$ the difference-in-slopes for the second segment, $\psi$ denotes the breakpoint, and $(y_i - \psi)_+ = (y_i - \psi) *$

$I(y_i > \psi)$ (Muggeo, 2003). The indicator function $I(.)$ equals one when the condition in its argument is true. When the model does not detect a breakpoint, we end up with a simple linear regression model, i.e., $\psi$ does not exist and $\beta_2$ is a statistical zero.

Figure 4.5 presents not only life expectancy at birth for Sweden and Spain, already calculated based on smoothed data, but also the segments that are statistically significant. It is easy to see that between 1950 and 2012 there exist segments with different slopes. In the Swedish case, the slope declined in 1977, which resulted in lower life-expectancy increase and let France, Spain and Japan move ahead (see Figure 2.1, Chapter 2). In comparison with males, females are exposed to fewer breaks in their life expectancy at birth over time, but it is clear that in the last segment for each country, males are catching up.

The inclusion of confidence intervals for the breaks in the plots provides additional insight. In the example of Spain (panel 2), the break registered in 1983 does not differ statistically between sexes, but it refers to two different slopes in life expectancy increase. For Sweden (panel 1), similar behavior was detected for the break estimated in 1977.

**Figure 4.5:** Segmented life expectancy at birth




**Source:** HMD 2014, own elaboration

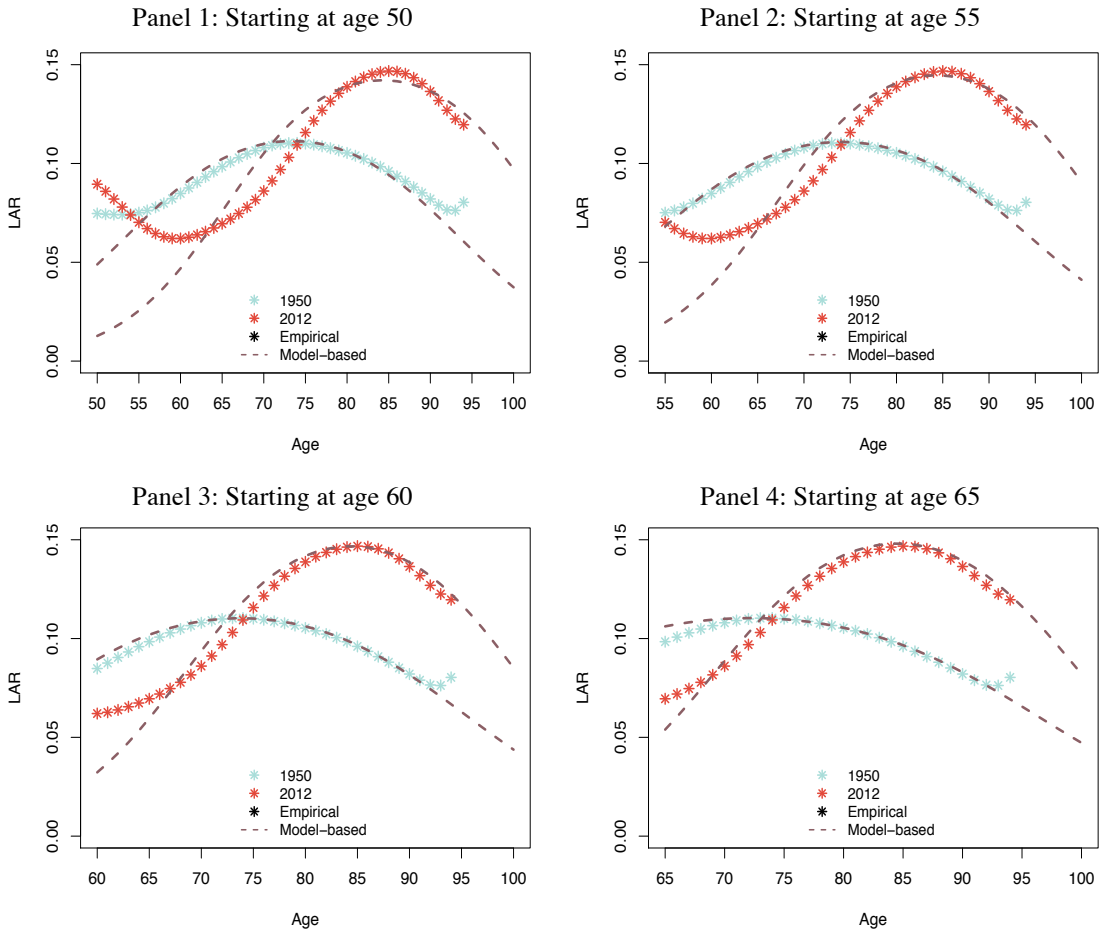
### 4.3.6. The starting age

As it was already widely studied and exemplified (Horiuchi and Coale, 1990; Horiuchi and Wilmoth, 1997 and 1998, among others), LAR patterns are not constant

but follow a distinguishing bell-shaped pattern. The exact starting age of this pattern is difficult to identify due to continuous mortality changes across time thus, it becomes important to identify the "best starting age" for fitting the ΓGM and evaluating its accuracy.

Figure 4.6 presents the results obtained by fitting a ΓGM model with four different starting ages *x*: 50, 55, 60 and 65. Our intention was to explore if a change in the starting age would affect model accuracy. As one can see, the higher the starting age the better the obtained accuracy for both sexes. Despite the fact that all model-based LARs seem to generate very accurate estimates for the age of mortality deceleration, Figure 4.6 shows that the best choice for males might be age 60 and for females age 65. However, choosing different starting ages by sex would open another discussion. Bearing in mind that we aim the best fit for both sexes and across all the selected countries, we decide to start our entire fitting procedures at age 65.

**Figure 4.6:** Model-based LAR with different starting ages, France - Female




**Source:** HMD 2014, own elaboration

We focus on the last 60 years of mortality history (since 1950s), but always taking into account the limitations (availability and time range) associated with data quality and availability and for each selected country. Therefore, for each year in the available period (see Table 4.1), we estimate LAR for the overall mortality by fitting a ΓGM model beyond age 65.

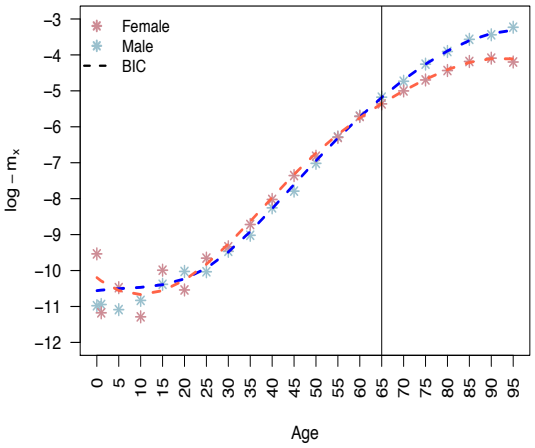
### 4.3.7. Cause of death

Low subpopulation sizes are often problematic when fitting statistical model, so we can expect less accurate results for Portugal (10.5 M) and Sweden (9.6 M), the countries with the smallest population size in the list. Disaggregating COD data into subgroups lowers subpopulation sizes even more. As in the case of overall mortality, we smooth the data to lower variability and at the same time increase fitting accuracy. With COD we are dealing with even lower subpopulation sizes and even more distinct data fluctuation and as we saw before, smoothing the data applying a P-spline approach using BIC, penalizes more the model complexity and produces smoother results. Thus, we decided to employ directly the BIC approach instead of comparing both fits.

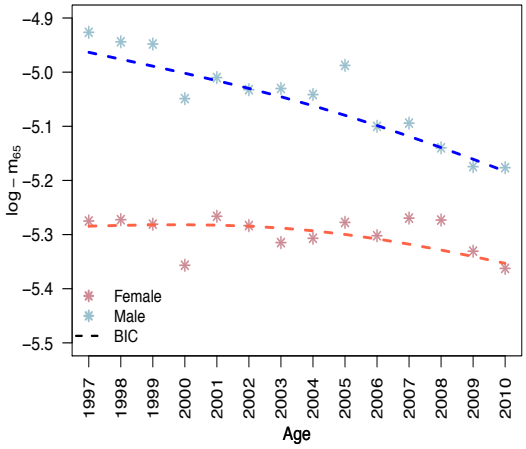
Figure 4.7, presents the results for Sweden, which is the country with the smallest population size in our list. Panel 1 shows that, beside the fact that original data are well approximated, the mortality patterns over age become smoother and after age 65 accuracy increases. Panel 2 provides a closer point of view, where the mortality rates registered at age 65 across the available years for Neoplasms are presented on a smaller $y$-axis scale. Thus, one can conclude that both, accuracy and smoothness are ensured, providing a better illustration of the mortality patterns.

**Figure 4.7:** Actual and fitted death rates from a P-spline approach, Sweden - Neoplasms

Panel 1: Mortality rates over age, 2010




Panel 2: Mortality rates at age 65

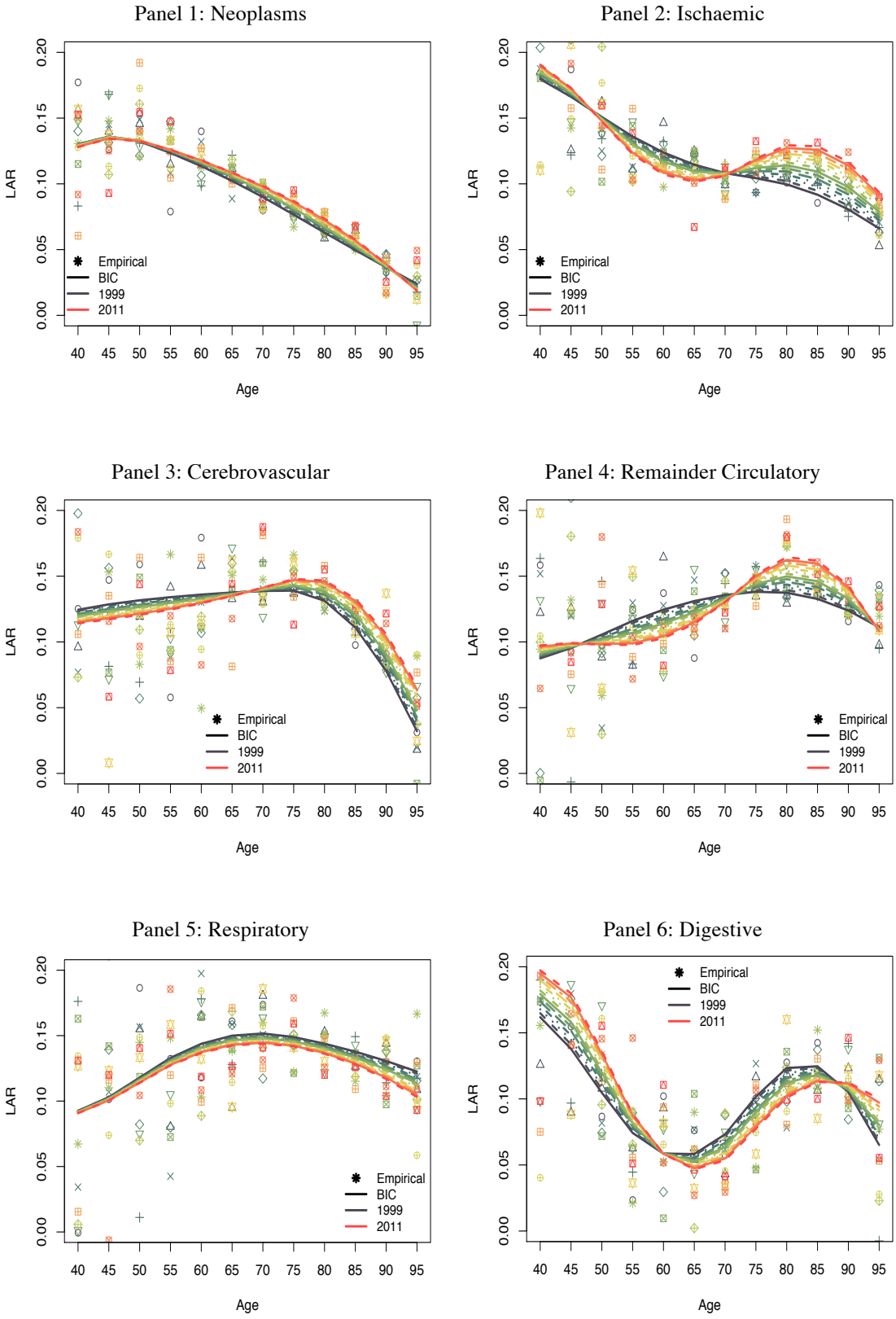



**Source:** WHOMD and HMD 2014, own elaboration

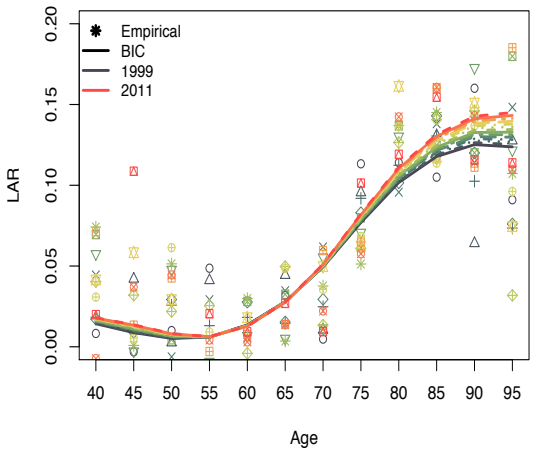
Nevertheless, like in the case of overall mortality, we expect that the smoothing procedure will not affect negatively the empirical LAR patterns. Figure 4.8 demonstrates that the P-spline approach applied to COD subpopulations does smooth empirical LAR, expressing clearly the associated patterns. We can clearly see in Sweden a mortality deceleration for neoplasms starts around age 45, in the male case. Between 1999 and 2011, there are some CODs that affect Swedish males mortality, presenting more pronounced bell-shaped patterns with time (Ischaemic, Circulatory and Respiratory diseases). Some other presented a shift in the age of mortality deceleration to older ages at the same time (Cerebrovascular, Digestive and External causes). Changes in LAR for neoplasms are almost imperceptible but perspectives some variations beyond age 60 and the group including remaining causes present not only a more pronounced pattern, but also a non-expected shift to younger ages. This situation might be associated with possible changes in how different CODs affect overall mortality, and some non-specified causes might become more influential than previously.

Figure 4.8 also shows that the starting adult age chosen to fit the ΓGM model will probably have higher influence on model-based LAR accuracy than for overall mortality, because some LAR deceleration pattern start at earlier ages and some other at older ages.

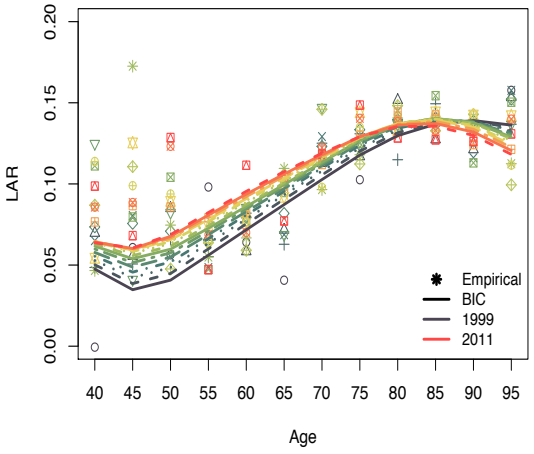
**Figure 4.8:** Empirical and fitted LAR from a P-spline approach by COD, Sweden - Male



Panel 7: External




Panel 8: Remaining Causes



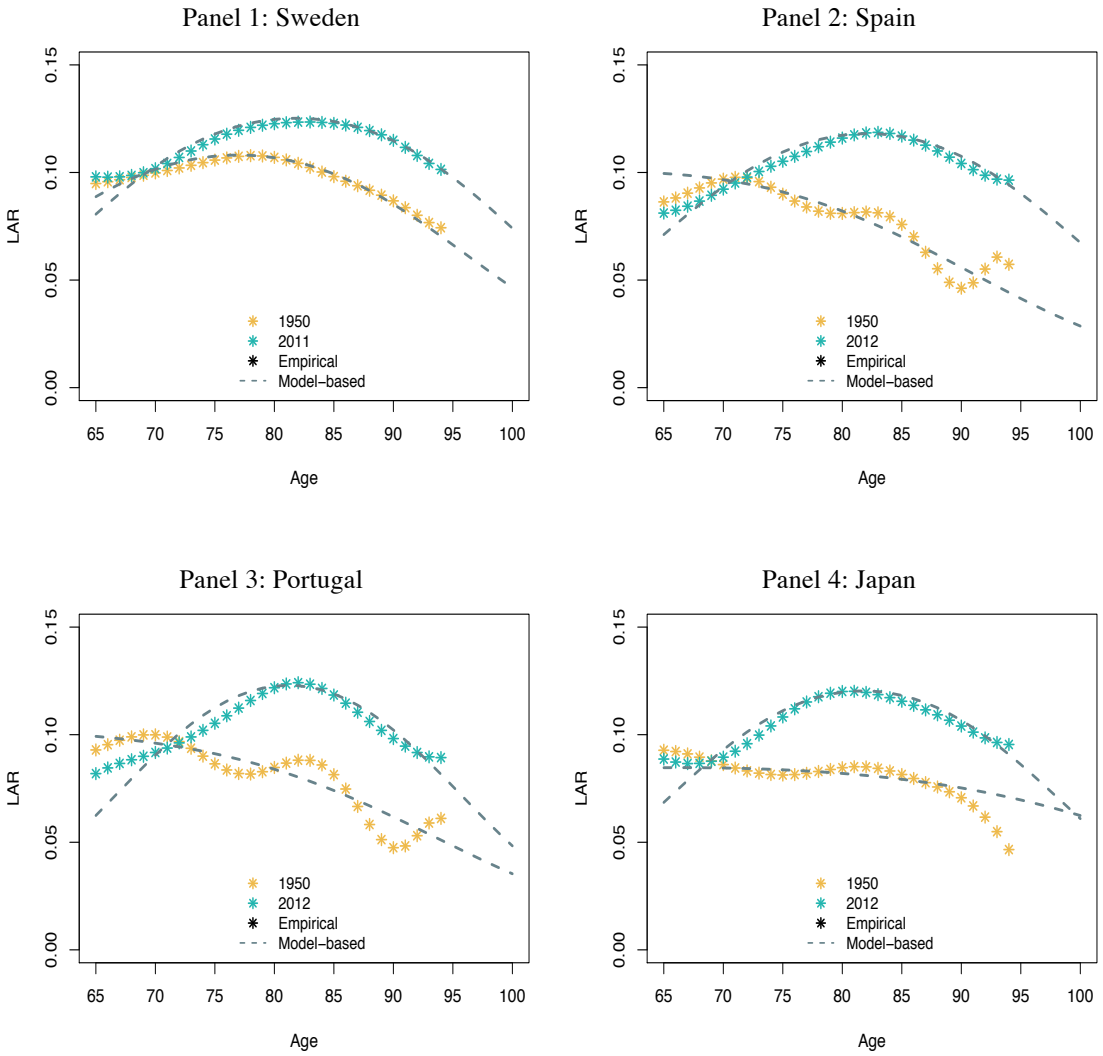

**Source:** WHOMD and HMD 2014, own elaboration

## 4.4. Results

### 4.4.1. Overall mortality

By fitting a ΓGM model from age 65 onwards, we estimate the population rate of aging $\bar{b}(x)$ by country and gender. Results for France and Spain, presented in Figure 4.9 indicate that the ΓGM model-based LAR fits well observed/empirical LAR. At the same time, it captures the observed shift in the age of mortality deceleration between 1950 and 2012, for both sexes, confirming therefore point b) of the "heterogeneity hypothesis": with increasing lifespans, mortality deceleration shifts and occurs always at older ages. In panels 2 to 4, we can also detect a more pronounced pattern with time.

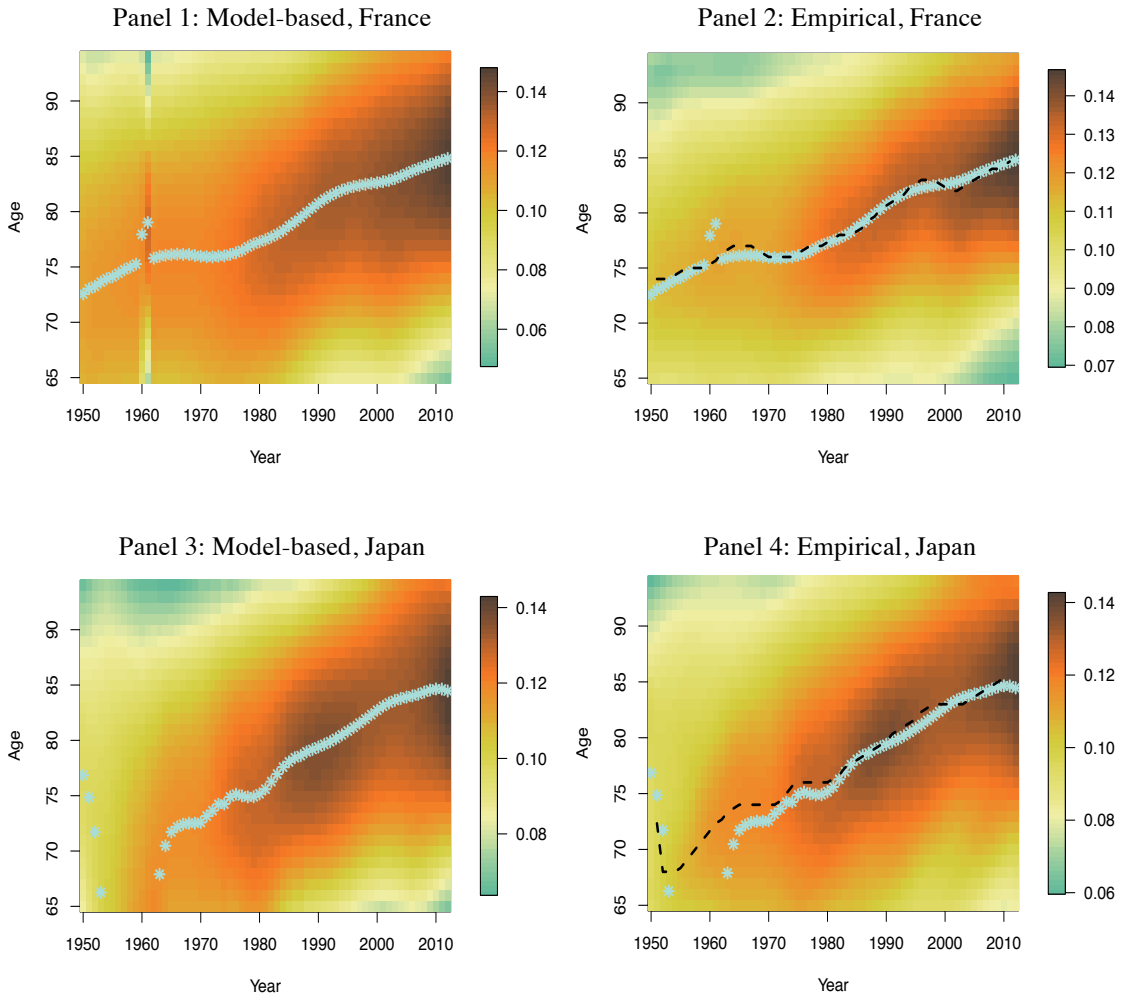
**Figure 4.9:** Model-based LAR goodness of fit for the Male example




**Source:** HMD 2014, own elaboration

Model-based LAR estimates a flatter pattern (larger darker shadow on model-based estimates compared to the empirical results) than it is really observed (Figures 4.9 and 4.10), but the age of mortality deceleration seems to be well captured for the French females (panel 1 and 2), being pretty similar to the empirical LAR. While in the French case we only find two main "deviations" from the observed values (panel 1, years 1960 and 1961), in the Japanese example the model captures the age of mortality deceleration well only after 1981. This difficulty in estimating the point where LAR finds its maximum results from the poor accuracy of model fitting in those years.

**Figure 4.10:** Model-based, Empirical LAR and the age of mortality deceleration (fitted: light-blue star dot; empirical: black dashed line), Females




**Source:** HMD 2014, own elaboration

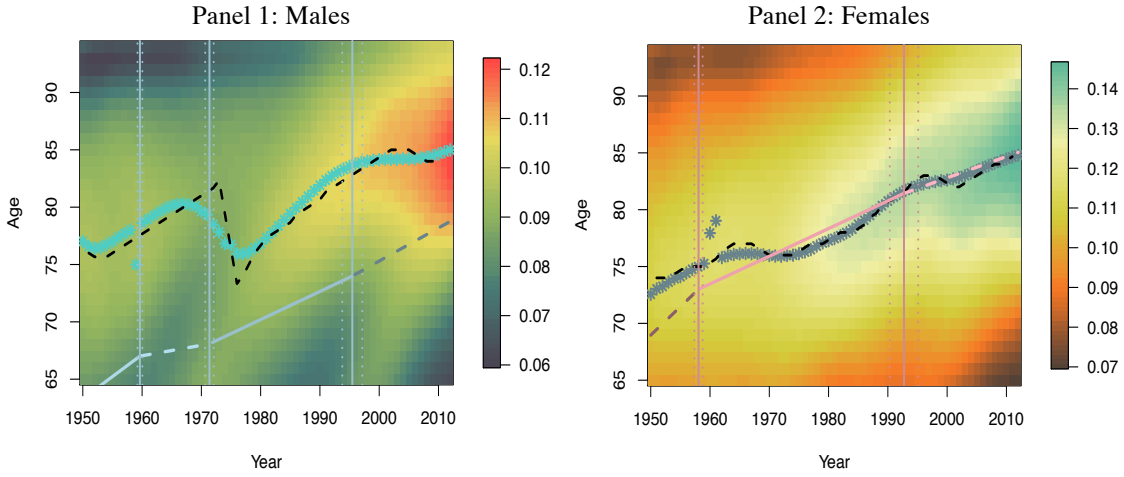
Figure 4.11 reinforces that the formula advanced in (4.6) estimates well LAR patterns for the overall mortality, despite the model estimation of a flatter pattern than really observed, especially in more recent years. If we add to the image (see French example in Figure 4.11) the segmented life expectancy patterns and corresponding breaks, we can see that even though the age of mortality deceleration considerably differs from life expectancy itself, the estimated breaks seem to detect some associated changes in the slope of life expectancy increase.

The results for French females (panel 2) suggest that at the first breakpoint we observe at the same time a steeper increase of life expectancy and, in the age of mortality deceleration (estimated and empirical). At the second breakpoint, there is a decline in the rate of life expectancy increase that comes along with a period of

additional turbulence in the age of mortality deceleration. At the third and last breakpoint, a new decline in the rate of life expectancy is noticeable and both patterns ($x^*$ and $e_0$) look similar. In the male case (panel 1), the estimated age of mortality deceleration shows higher deviation from the empirical one (calculated based on empirical LAR), but the patterns are very alike.

In contrast to females, in the male case the estimated breaks and corresponding rates of increase in life expectancy substantially differ from the age of mortality deceleration. However, it seems, once again, that the estimated breaks suggest some connection between these two mortality indicators and changes in one pattern is complemented by changes in the other. From all the countries, despite that we only present here Japanese and French examples, France is the only one that fits better the observed LAR and gives better $x^*$estimates for the entire observed period. We believe this might be due to the high life expectancy values from the 1950s onwards. In Japan, for example, estimates become better when life expectancy increased substantially. It is also our guess that at the time when the male/female gap in life expectancy declines, $x^*$ will be better captured by the model and life expectancy values will be closer to the age of mortality deceleration.

**Figure 4.11:** Empirical LAR, the age of mortality deceleration (fitted: light-blue star dot; empirical: black dashed line) and life expectancy segments, France



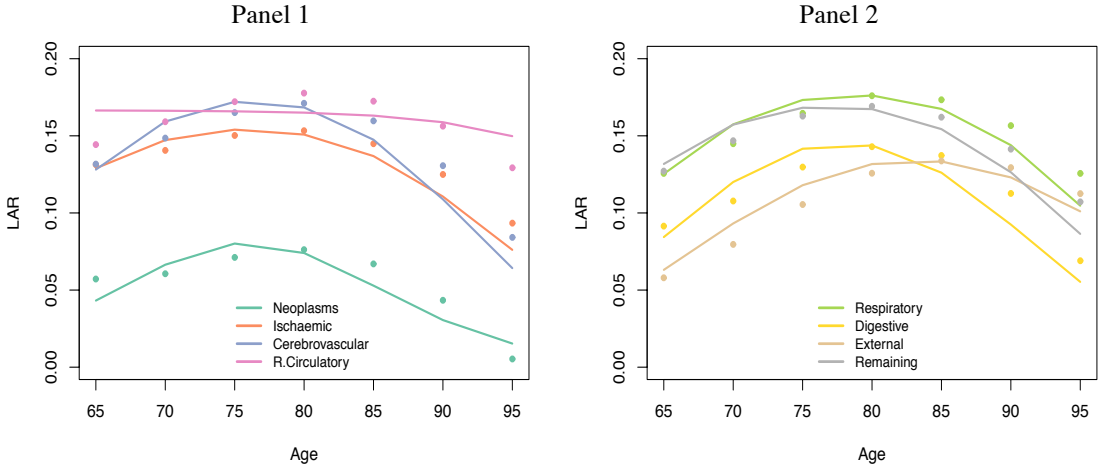

**Source:** HMD 2014, own elaboration

### 4.4.2. Causes of death as subpopulations

Considering different causes of death as subpopulations we maximize ln $L$ presented in (4.10). As a result, we estimate 4 parameters by COD for each year, resulting in a total of 32 parameters estimated per year. We start fitting the model mentioned in (4.9) at age 65, i.e., from the 65-69 age group onwards. As discussed before, starting from this point onward the mortality patterns for all major CODs follow an almost linear pattern on a logarithmic scale, followed (in some cases) by an eventual deceleration (see Figure 1). Thus, fitting a ΓGM model (4.9) from age 65 onwards for the different COD subpopulations, we estimate the population rate of aging $\bar{b}(x)$ by country, gender and cause of death.

Results for Spain, presented in Figure 4.12 show that the ΓGM model-based LAR by COD does not fit well observed/empirical LAR. In general model-based LAR appears to capture well empirical patterns, however, in some cases seems to anticipate the age of mortality deceleration. In the example of Spain in Figure 4.12, the only COD that diverges completely from the observed pattern is the Remaining Diseases of the Circulatory System.

**Figure 4.12:** LAR by cause of death, Spain 2011 - Females

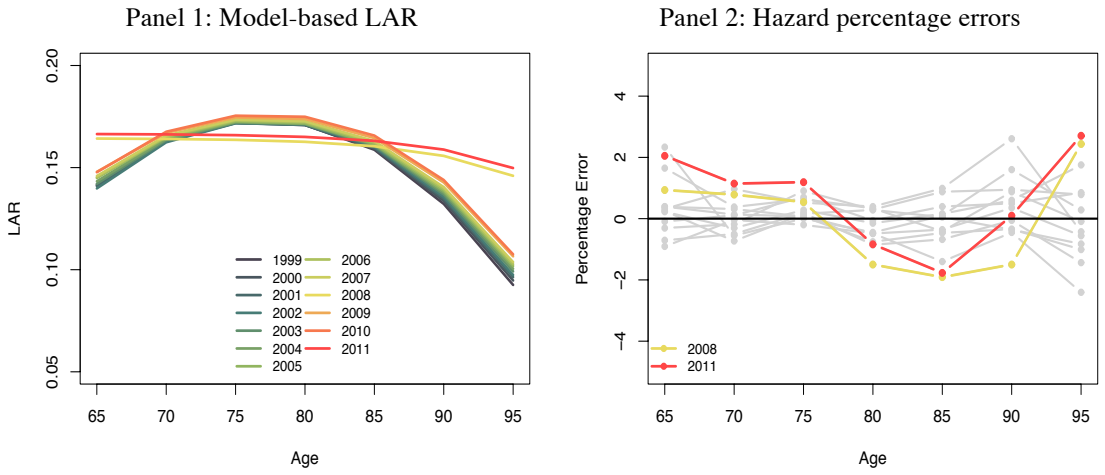



**Source:** WHOMD and HMD 2014, own elaboration

Trying to understand why, in the year of 2011, ΓGM estimated LARs are not capturing the empirical pattern, in Figure 4.13 we have all the model-based LAR estimated for the remaining diseases of the circulatory system across the 13 available years for Spain (panel 1) and the associated percentage error for the estimated hazards

of death. First, more than one year is identified presenting the same flat and incorrect LAR pattern, 2008 and 2011. Second, observing the percentage errors associated to the estimated hazards, we realize that, despite small, the associated errors for those two years are the highest for the age groups 80-84, 85-89, and 95+. In 2011, the same is registered for the age groups 70-74 and 75-79. Thus, we can conclude that even a small percentage error across age might influence the estimation of the bell-shaped patter observed empirically.

**Figure 4.13:** Model-based LARs and hazards percentage errors for remaining diseases of the circulatory systems, Spain - Females



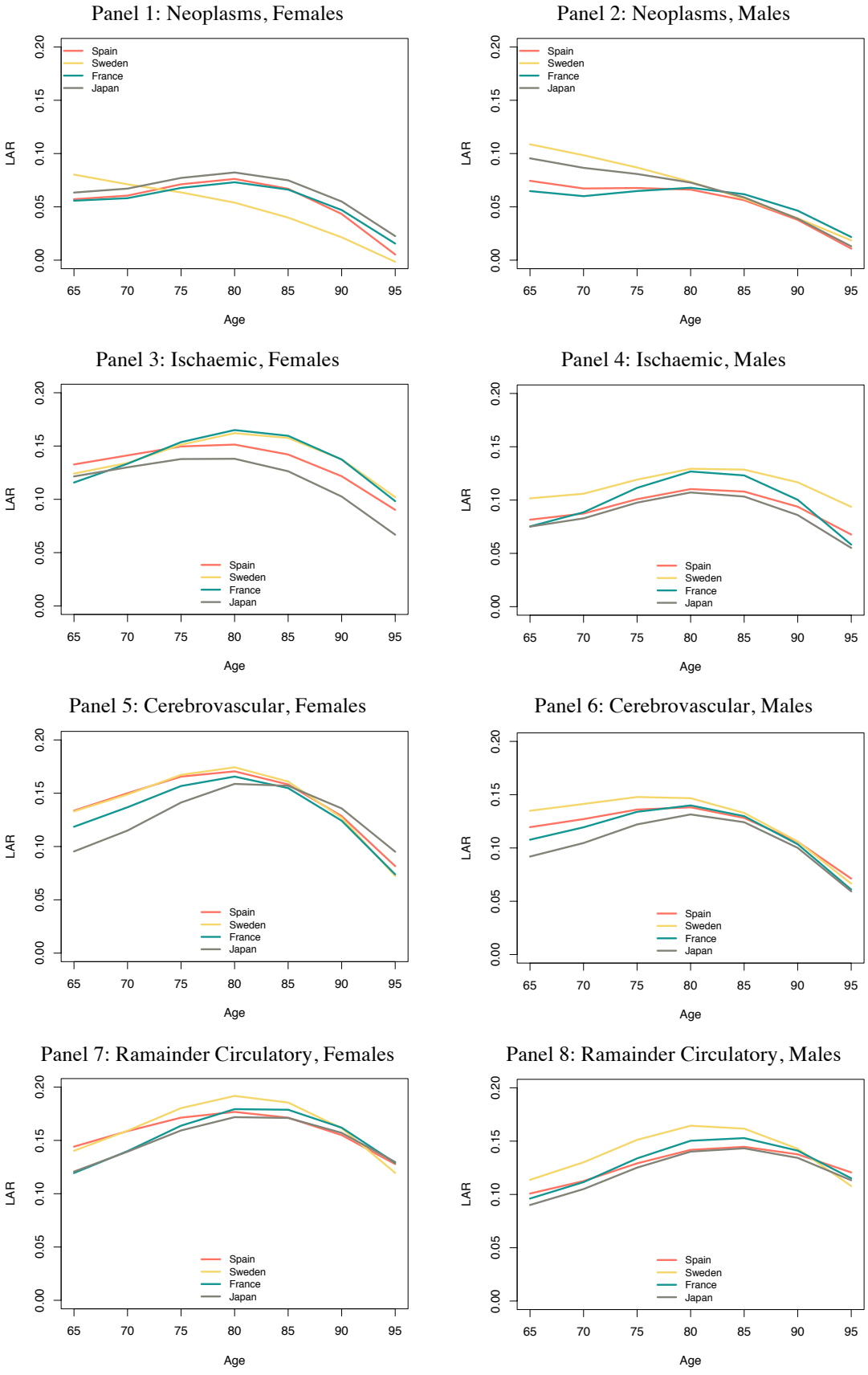

**Source:** WHOMD and HMD 2014, own elaboration

Figure 4.14 presents the obtained results for empirical LAR between ages 65 and 95. Each panel corresponds to the obtained LAR results by subpopulations (CODs) and sex, where the last available and transversal to all countries, year is presented. Our choice of presenting empirical LAR in opposition to the model-based comes from the difficulty that the formula advanced in (4.6) has to estimate the corresponding observed patterns by COD.

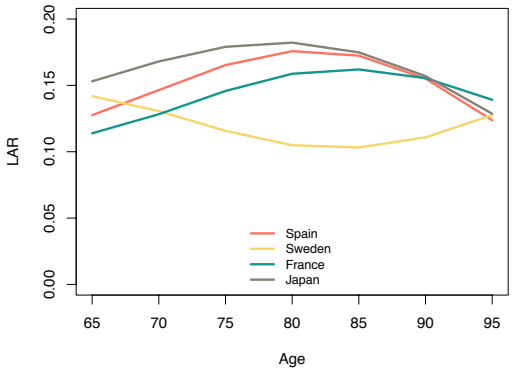
The obtained results confirm that for the considered major COD groups, deceleration is observed. However, we do not find clear evidence that CODs with lower death rates present less pronounced deceleration patterns.

In panels 9, 15 and 16, very distinct and non-bell-shaped patterns are found, however, in our opinion this is explained by the fact that mortality deceleration in those specific cases does not occur in the considered age interval.

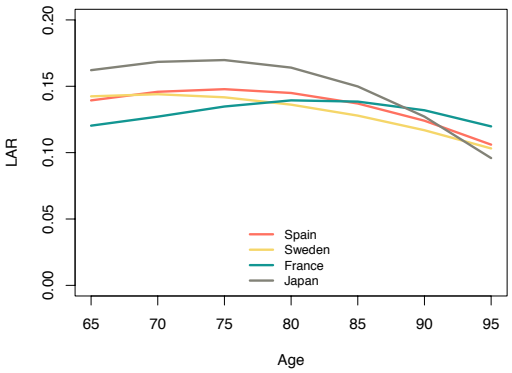
**Figure 4.14:** Empirical LAR by sex, COD, and country - 2010



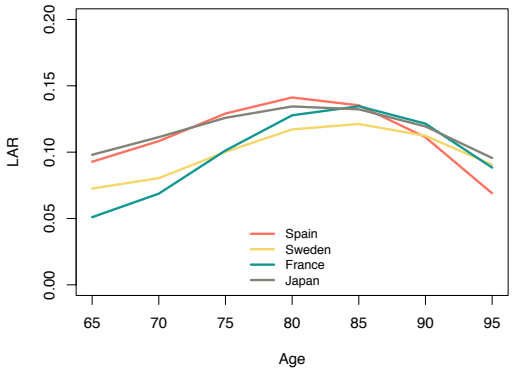
Panel 9: Respiratory, Females



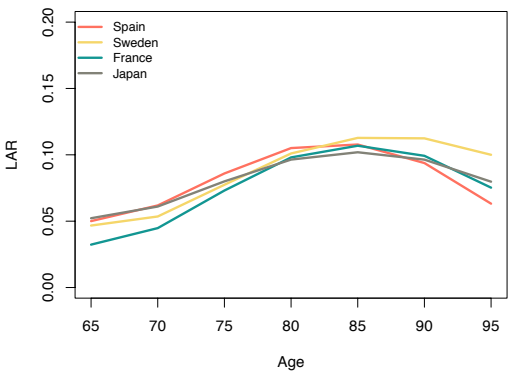

Panel 10: Respiratory, Males



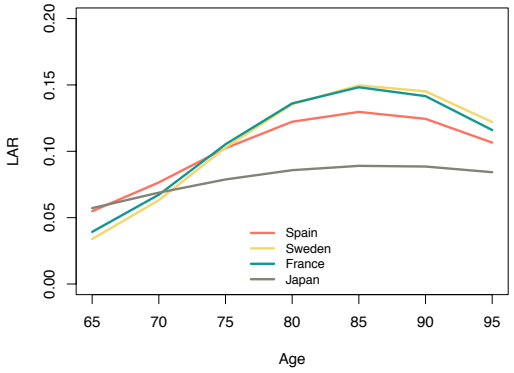

Panel 11: Digestive, Females



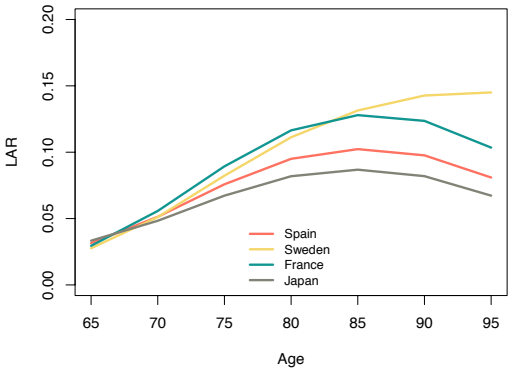

Panel 12: Digestive, Males



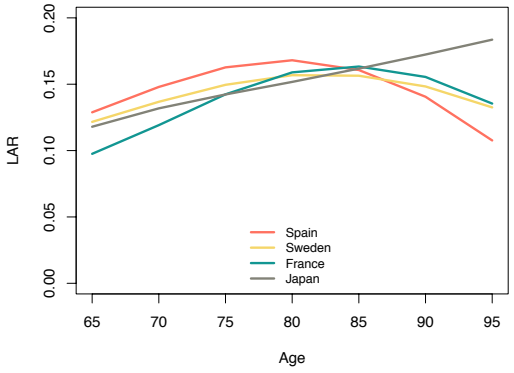

Panel 13: External, Females



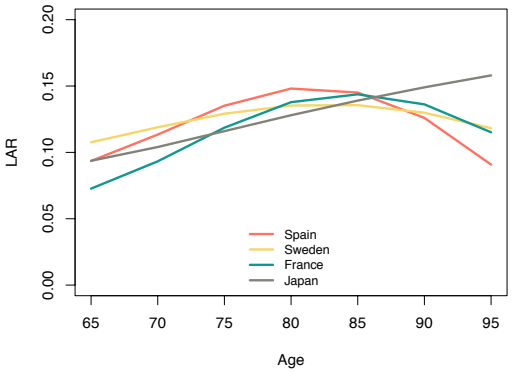

Panel 14 External, Males




Panel 15: Remaining Causes, Females




Panel 16: Remaining Causes, Males




**Source:** WHOMD and HMD 2014, own elaboration

## 4.5. Discussion

In opposition to the individual rate of aging, the population rate of aging, here addressed as LAR, requires the estimation of all four parameters in the model. Thus, within a ΓGM framework LAR requires the calculation of all $a$, $b$, $c$ and $\gamma$ (see Vaupel and Zhang, 2010).

A constant life-table aging rate would indicate that mortality increases almost linearly in a logarithmic scale. Nevertheless, either for overall mortality or discriminating by CODs, the obtained results capture an expected decrease with age. Thus, it indicates that the age-related increase in mortality rates at older ages is decelerating. Both, the estimated population and COD-specific LARs (when able to capture the observed pattern) present a non-constant pattern, expressing, excluding some rare exceptions, its characteristic bell-shaped pattern. For the exceptional cases, the factors that could have influenced estimates and observed patterns may be associated with 1) the use of aggregated data for CODs, which provides less detail than data for single ages, 2) the choice of fitting all models after age 65, when the underlying mortality patterns for some CODs might not completely follow a ΓGM-curve, 3) data credibility, specifically in the analysis by CODs, because especially at older ages, death certificates do not always reflect accurate information, 4) due to known differences in the mortality patterns associated to men and women, the model may present better fits when includes earlier information (i.e., if we start fitting at a younger or later age), 5) low subpopulation sizes (CODs or countries).

The estimation of the age of mortality deceleration seems either to be influenced by model accuracy and mortality improvements that appear to stabilize LAR patterns, presenting more defined and pronounced LAR patterns as it maximum shifts to older ages. France is a good example, as in the 1950s, the associated life expectancy at birth was already high (as a sign of better health) when compared with the other countries and sexes, still being today one of the best-practice countries in the analysis. Thus, we believe that improvements in health result in more distinct bell-shaped patters of LAR and better accuracy on the estimates.

Even when poorly approximated, the age of mortality deceleration denotes a possible connection with the life expectancy rate of increase, reacting differently within each break statistically significant.

## 4.6. Conclusions

ΓGM model-based LARs (for overall mortality and by COD) appear to be consistent with the "heterogeneity hypothesis" advanced by Horiuchi and Wilmoth (1998) as the age of mortality deceleration shifts to older ages with time in overall mortality and only neoplasms, as one of the CODs with lower mortality rates after age 65, presents less pronounced patterns. The ΓGM model-based LAR (Vaupel and Zhang 2010) fits observed LAR with high accuracy and captures the connection relationship between the observed shift and the rate of life expectancy increase in the five selected countries for overall mortality. Presented results for overall mortality are statistically more accurate because the analysis is based on a large number of observations in each age group. Although COD data are organized by five-year age groups, we sometimes run into problems associated with low subpopulation sizes, which might influence the accuracy of ΓGM parameter estimates. Disaggregation of causes of death into single-age groups can benefit further estimation of the associated LAR patterns.

Despite that our findings are mainly confirming previous findings of a bell-shaped pattern associated to the rate of aging for populations, with our results we contribute for a better understanding of the differences between this measure and the individual rate of aging.

# CHAPTER 5

# FORECASTING MORTALITY PATTERNS BY CAUSE OF DEATH: A COHERENT APPROACH

## 5.1. Introduction

Across time profound changes occurred in demographic paradigms. Some resulted in an extraordinary life expectancy increase and now the high rates of mortality of the past are being experienced later in life. Currently, the economic crisis witnessed in Europe, especially in the south, might disturb demographic evolutionary trends. Evolutionary mortality patterns accordingly to different causes of death are essential to give an insight not only for demographers, but also to policymakers and create robust foundations for future planning proposes.

In Japan, a female born in 2012 could expect to live slightly more than 86 years, resulting from an average 0.5 yearly increase since 1947 (HMD, 2014). It is well known that this increase is only possible due to significant improvements in health and consequent reductions in mortality rates (Vaupel, 2010). Those rates have been widely studied attempting to generate a universal law of mortality. Gompertz (1825) proposed a simple parametric model $\mu = ae^{bx}$ to explain adult mortality, accounting for the level of mortality at the starting age $a$, and for the rate of mortality increase with age $b$. Later, Makeham (1860) add a constant to the model $\mu = ae^{bx} + c$ improving the results. The inclusion of this new parameter allows differentiating either between background ($c$) and intrinsic ($a$) mortality. Despite the improvements brought by the inclusion of a third parameter in the model, mortality is still overestimated at oldest ages, leading to the suggestion of employing logistic models (Perks, 1932; Heligman and Pollard, 1980; Thatcher, 1999). Nevertheless, demographers view populations as a heterogeneous mixture of individuals that share the same baseline hazard of death, to which they are susceptible in a different and random way. Within this framework, by assumption (Gompertz, 1825; Vaupel et al., 1979), the baseline hazard follows a Gompertz curve.

Individual susceptibility can be reflected in different individual $a$*'s* (relative risk models), in different $b$'s (accelerated life models), or in both. However, recent evidence for a human mortality plateau (Gampe, 2010) speaks in favor of relative risks only. Letting a random variable $Z$, called frailty (Brass, 1971) capture individual susceptibility, leads, very generically, to the widely used gamma-Gompertz frailty model.

The models presented so far only capture changes in death rates over age. Several other approaches have been created to model different changes observed over time. One example is the Brass (Brass, 1971) relational model, where the author suggested a logit transformation of the probability of surviving, allowing to relate the standard and actual population by applying a simple regression function. One other example corresponds to the *age-period-cohort* (APC) models, and acknowledges possible changes in those three dimensions. Yet, the APC models struggle often with identification problems due to the linear relationship between age, period and cohort (Clayton and Schifflers, 1987). A third example corresponds to the method developed by Lee and Carter (1992). This method reduces the APC complexity by introducing a bi-linear model for the logarithmic mortality-rates: $\ln m_{x,t} = a_x + b_x * k_t + \varepsilon_{x,t}$. Since then, this methodology has been widely used in demography and it can be considered the standard in modeling and forecasting death rates (Camarda, 2008), even with the inclusion of some variants (Lee and Miller, 2001; Booth et al., 2002; Hyndman and Ullah, 2007), or even expressed in a Compositional Data Analysis equivalent definition (Oeppen, 2008). Nonetheless, in modeling mortality rates for two or more sub-populations it is required that the forecasts do not diverge from the ones obtained from the total population, being coherent. A very recent example of a coherent method is the product-ratio method developed by Hyndman, Booth and Yasmeen (2013). This method achieves coherence through the convergence to a set of appropriate constants of forecast age-specific ratios of death rates for any two sub-populations.

*"As is well known, the estimation stage of Lee-Carter is a special case of principal component analysis, where the log-mortality data is summarized using only the first principal component"* (Girosi and King, 2007) and that makes the model not appropriate for all causes of death independently. Nevertheless, in a theoretical perspective many authors support that breaking down mortality forecasts by cause

results in higher accuracy but practice also proves the opposite (Booth and Tickle, 2008). Studies like the one from Wilmoth (1995) found that decomposing mortality forecasts result not-rarely in higher mortality forecasts, however, expressing the Lee-Carter model in a conditional form results in very similar estimates in both approaches (Oeppen, 2008).

As a result, in this chapter we make use of the Oeppen's proposal of expressing the Lee-Carter method in compositional form, to elaborate coherent medium-term forecasts distinguishable by causes of death for countries with different cultural backgrounds and distinctive mortality patters, as could be seen in the previous chapters. Thus, we forecast mortality trends differentiated by cause of death for the next 30 years for Portugal, Japan, France, Sweden and Spain.

## 5.2. Lee-Carter model and (selected) variants

### 5.2.1. Lee and Carter (1992)

Lee and Carter (1992) proposed one of the most used methods to forecast mortality trends. Widely known as the Lee-Carter method, the method combines a demographic model of mortality with time series methods of forecasting (Booth et al., 2006). Originally, the authors made use of USA population and for the longest available time series (between 1900 and 1989) and defined log-mortality rates as:

$$\ln m_{x,t} = a_x + b_x * k_t + \varepsilon_{x,t} \tag{5.1}$$

where $m_{x,t}$ is the central mortality rate at age $x$ and time $t$, $a_x$ the average pattern of mortality by age, $b_x$ the relative speed of mortality change at different ages, and $k_t$ refers to the level of mortality at time $t$. Consequently, $\varepsilon_{x,t}$ is the set of disturbances that measure the divergence between the model and observed log-mortality rates. Parameter estimation is based on the average $\ln m_{x,t}$ over time for $a_x$, while $b_x$ and $k_t$ are estimated by singular value decomposition (SVD) (Booth et al., 2006).

Estimates are based on a set of factors for each considered age and time (Torri, 2009), and the described parameters have the same length as the number of ages and defined time periods, being need to add some constrains to parameter estimation

become well succeeded (Camarda, 2008): $b_x$, as the pattern of deviations from the previous ages as the parameter $k_t$ changes, is constrained to sum to the unity; $k_t$, as the time varying mortality level index, sum to 0; and consequently $a_x$ are set to equal the means over time of $\ln m_{x,t}$: $a_x = \frac{1}{2}\sum_{t=1}^{n} \ln m_{x,t}$.

Before forecasting, a second stage estimation of $k_t$ needs to be accomplished, where the parameter is readjusted by refitting to total observed deaths, giving higher weight to ages at which deaths are higher counterbalancing the effect of using log-mortality estimates. Originally, $k_t$ is extrapolated by ARIMA time series model, or more specifically, by a random walk with drift model:

$$k_t = k_{t-1} + d + e_t \tag{5.2}$$

where $d$ is the average annual change in $k_t$ and $e_t$ refers to the uncorrelated errors. In this first model approach, the authors used the rates in the last year of fitting (jump-off year) as the jump-off rates, in opposition with, e.g., what Lee and Miller proposed later, in 2001.

### 5.2.2. Lee and Miller (2001)

Likewise it was said before, the Lee-Carter methodology was the starting point for many other variants proposed with the intention of getting improved outcomes. Lee and Miller (2001), e.g., proposed an approach that differs from the original one essentially in three ways (Booth et al., 2006): (1) the fitting period was narrowed, and instead of accounting information since 1900, the fitting period is starting now in 1950; (2) $k_t$ is re-estimated by matching observed life expectancy at birth ($e_0$) rather than the observed number of deaths; and thirdly (3), instead of using the fitted rates as jump-off rates, actual observed rates are considered in the jump-off year. This last step was adopted by the authors to avoid the use of population data as necessarily required for fitting to death counts.

Overall outcome from this variant presents major improvements, mainly because one of the main error source was the mismatch between fitted rates and for the last year of the fitting period and actual death rates in that year (Booth et al., 2006).

### 5.2.3. Booth, Maindonald and Smith (2002)

The variant proposed by Booth, Maindonald and Smith (BMS) in 2002, introduced, once again some changes based on the original model. Booth et al. (2006), identified, once more, three main changes: (1) the fitting period is chosen based on a routine that identifies the most adequate and suitable fitting period, i.e., the fitting period choice is based on statistical goodness-of-fit criteria under the assumption of a linear period index $k_t$; (2) the readjustment of $k_t$ is now based on fitting to the age distribution of deaths, using a Poison distribution to model death process; and (3) the jump-off rates are now, consequently different from the originals once that they are now taken to be the fitted rates based on the new methodological approach.

The original Lee carter approach lies on the assumption of a linear and constant decline in mortality rates over the fitting period (represented by $k_t$), however, sometimes that linearity does not hold on the overall period. In addiction, the assumption of a constant $b_x$ also increases estimates bias. Restricting the fitting period to maximize the linearity assumption, the BMS method tries to solve linearity issues and obtain more accurate results and the choice of the fitting period is done based on the ratio of the mean deviances of the fit of the original Lee-Carter method to the overall linear fit.

### 5.2.4. Hyndman and Ullah (2002)

In 2007, Hyndman and Ullah proposed a slightly different extension of the original Lee-Carter method, being expressed by:

$$\ln m_{x,t} = a(x) + \sum_{j=1}^{J} k_{t,j} b_J(x) + e_t(x) + \sigma_t(x)\varepsilon_{x,t} \tag{5.3}$$

where $a(x)$ is the average level of mortality by age across the different periods (it differs from $a_x$ so that it corresponds to a smooth function of age where age obtained by applying a P-spline regression), $b_J(x)$ is the age coefficient and $k_{t,j}$ the time series coefficient. $k_{t,j}$ and $b_J(x)$ are estimated by using a principal component decomposition. The inclusion of two error terms in the equation allows distinguishing

concerning the differences between the observed rates and the smoothed curves $\sigma_t(x)\ \varepsilon_{x,t}$; and the difference between the smoothed curves and the fitted curves from the model $e_t(x)$.

Resuming, the Hyndman and Ullah (2007) approach uses the functional data paradigm developed by Ramsay and Silverman (2005) for modeling mortality rates, resulting in the extension of the Lee-Carter method in five main points Booth et al. (2006): (1) smoothed mortality rates are used instead, being estimated by applying nonparametric smoothing methods, as the P-spline regression; (2) more than one set of $b_x$ and $k_t$ is used; (3) different methods for modeling time series are used, as the state space models for exponential smooth; (4) robust estimation is an option in cases of external perturbations, as wars or epidemics, and finally (5) it does not readjust parameter $k_t$.

## 5.3. Compositional Data Analysis and the CoDa equivalent Lee-Carter method for mortality forecasting

### 5.3.1. Compositional Data Analysis (CoDa)

When we are dealing with many vectors of information expressed in percentages or densities, all having the same sum, we end up with compositional data. A composition thus, is defined as a vector of D positive components $\mathrm{x} = [x_1, \ldots, x_D]$ summing up to a given constant *k* (Oeppen, 2008; Boogaart and Tolosana-Delgado, 2013).

Aitchison (1986) argued that compositional data is significant for many subjects, revealing frequently noticeable variability from vector to vector. Despite that a typical example of compositional data concerns different subjects as Geology, Chemistry or Economics. Oeppen (2008) introduced it in demographic forecasts by modeling life-table $d_x$, which always sum to the life-table radix ($l_0$). The best way to deal with sum-constrained data is to work on the simplex. Nevertheless, working with relative information is not always straightforward, mainly because the unit-sum "*it is either ignored or improperly incorporated into the statistical modeling and from there, results an inadequate or irrelevant analysis with a doubtful or distorted inference*" (Aitchison, 1986), and the solution is employ a log-ratio transformation.

Therefore, the simplex is defined as the set of compositions (closed, once that are summing up to a constant). Therefore, a set of possible closed compositions can be defined as (Boogaart and Tolosana-Delgado, 2013):

$$\begin{aligned}\mathbb{S}^D &:= \left\{\mathrm{x} = (x_i)_{i=1,\dots,D} : x_i \geq 0, \sum_{i=1}^{D} x_i = 1\right\} \\ &= \left\{\mathrm{x} = (x_1, \dots, x_D) : x_i \geq 0, \sum_{i=1}^{D} x_i = 1\right\}\end{aligned} \tag{5.4}$$

i.e., each vector corresponds to a D-part of the *simplex*. Within the simplex, classical algebraic/geometric operations as addition, subtraction or multiplication, need to be replaced by compositional equivalents. Perturbation plays the role of addition and subtraction and is a closed component-wise product of the involved compositions (Oeppen, 2008; Boogaart and Tolosana-Delgado, 2013):

$$x = z \oplus \hat{\xi} = C\left[z_1\hat{\xi}_1, \dots, z_D\hat{\xi}_D\right] \tag{5.5}$$

$$z = x \ominus \hat{\xi} = C\left[\frac{x_1}{\hat{\xi}_1}, \dots, \frac{x_D}{\hat{\xi}_D}\right] \tag{5.6}$$

On both cases, the closure operator ensures a unit sum:

$$C[x_1, \dots, x_D] = \frac{(w_1, \dots, w_D)}{(w_1 + \ \dots + w_D)} \tag{5.7}$$

Powering or power transformation replaces the product of a vector by a scalar and is defined as the closed powering of the components by a given scalar (Boogaart and Tolosana-Delgado, 2013), i.e., the compositional multiplication:

$$\lambda \otimes x = C\left[x_1^{\lambda}, \dots, x_D^{\lambda}\right] \tag{5.8}$$

Lastly, the Aitchison scalar product for compositions provides a replacement for the conventional scalar product and is defined as:

$$\langle x, y \rangle_A = \frac{1}{D} \sum_{i>j}^{D} \ln \frac{x_i}{x_j} \ln \frac{y_i}{y_j} \tag{5.9}$$

Conversely, the set of compositions together with these three operations build a $(D-1)$-dimensional Euclidean space structure on the simplex. "*This means that we can translate virtually anything defined for real vectors to compositions, as an Euclidean space is always equivalent to the real space*" (Boogaart and Tolosana-Delgado, 2013). Having a data set of D columns and N rows, where all sum to unit, the centered log-ratio transformation is defined as:

$$CLR(z) = ln\left[\frac{z_1}{g(z)}, \dots, \frac{z_D}{g(z)}\right] \tag{5.10}$$

and its inverse by:

$$CLR^{-1}(z) = C[\exp(z_1), \dots, \exp(z_D)] \tag{5.11}$$

Centering the same data set is done by getting the composition geometric mean $\xi$, and subtracting it from each row.

$$\begin{aligned} \xi = cen(x) &= C[exp\{E(\ln x)\}] \\ &= C[g_1, \dots, g_D] \end{aligned} \tag{5.12}$$

### 5.3.2. Low rank approximation

A usual task when we have a given matrix **A** with *m* columns and *n* rows $(m \times n)$ is to determine an approximate factorization, i.e., elaborate a low-rank approximation of a matrix. Imagine that the given matrix **A** can be approximated by:

$$\underset{m \times n}{\mathrm{A}} \approx \underset{m \times r}{\mathrm{B}} \quad \underset{r \times n}{\mathrm{C}} \tag{5.13}$$

where the inner dimension $r$ is called the numerical approximation of a matrix, and then a ran-$r$ approximation of the matrix can be computed.

One way of decomposition of a $m \times n$ matrix, real or complex, is to proceed a *singular value decomposition* (SVD):

$$\mathrm{A} = \mathrm{U}\Sigma\mathrm{V}^{*} \tag{5.14}$$

where U corresponds to a $m \times r$ unitary matrix (U columns are called the *left singular vectors*), V is other $r \times n$ unitary matrix (V columns are called the *right singular vectors*), and Σ is a strictly positive $r \times r$ diagonal matrix with $s_{\square}$ singular values:

$$\Sigma = \begin{bmatrix} s_1 & & \\ & \ddots & \\ & & s_r \end{bmatrix} \tag{5.15}$$

Thus, assuming that **A** corresponds to a compositional data matrix, applying the compositional operators above defined, we get:

$$A_n^{(r)} = \hat{\xi} \oplus (U_{n1} s_1 \otimes V_1) \oplus \ldots \oplus (U_{nr} s_r \otimes V_r), \qquad r < D \tag{5.16}$$

where $U$ correspond to the left singular vectors, $s$ to the singular values, and finally $V$ to the centered log ratio of the transposed right singular vectors.

### 5.3.3. The Lee-Carter CoDa equivalent mortality forecasting model

The CoDa equivalent to the Lee-Carter method for forecasting mortality trends suggested by Oeppen (2008) allows not only forecasting mortality trends for overall changes mortality rates (*single-decrement forecast*), but also disaggregate those by cause of death (*multiple-decrement forecast*). In opposition to most known approaches, Oeppen suggested using the life-table distribution of deaths $d_x$ and once that the sum equals the life-table radix $(l_0)$, we end up with compositional data. $d_x$ for overall mortality and $d_x^i$ for cause-specific mortality can be obtained by single and

multiple-decrement life-tables, respectively. Following Preston et al. (2001), we have that:

$$\sum_i {}_n d_x^i = {}_n d_n \tag{5.17}$$

and

$$\sum_x \sum_i {}_n d_x^i = 1 \tag{5.18}$$

Despite the existence of some studies ensuring that independent forecast of cause of death mortality do not produce plausible results (e.g., Wilmoth, 1995), the constraint imposed by the sum to the unit of each of the $d_x^i$ compositional vector, ensures that *"changes in the density by age and cause have to be compensated by changes in other ages and causes"* (Oeppen, 2008).

The suggested method can be summarized in the following steps (Oeppen, 2008):

I. Construction of a matrix $A$, with $N * D$ size of the $d_{x,t}$, where $t$ corresponds to the study years $(t = 1 \dots N)$ organized by row, and $x$ to ages $(x = 1 \dots D)$ organized by column. As explained before, each row of matrix $A$ corresponds to the constrained sum of 1 (the life-table radix).

II. Center the matrix $A$ by calculating the age-specific and subtracting it from each row by using a CoDa operator. Centering the matrix provides a better visualization of the structure. After this procedure, we end up with a different matrix $B$.

III. The next step is to transform matrix $B$ into the real space, obtaining consequently a matrix $C$, by calculating the centered log-ratios of each row.

IV. Then, we proceed to the decomposition of matrix $C$ by applying SVD decomposition.

V. Construct the low rank-r approximation of matrix $C$, where the forecasted rows are already included.

VI. At this step we transform back the matrix into compositional data and for that we use the inverse of the centered log-ratio, ending up with matrix $B^*$.

VII. Finally, using again a CoDa operator, we add back the geometric means, obtaining not only the a low rank compositional matrix $A^*$ with fitted $\hat{d}_{x,t}$, but also with the forecast.

Likewise Oeppen (2008) suggested, in our study, since that modeling is focused on $d_{x,t}$ it seems to have no reason to adjust the left singular vector to match average life expectancy or deaths in total or by age, or scaling the right singular vectors as they sum to zero. In opposition with the original Lee-Carter method, while defining its CoDa equivalent, it was not found evidence for using an ARIMA model (0,1,0), but rather an ARIMA (0,2,2), which offers a better fit to cause of death mortality trends.

## 5.4. Data

Data on *overall death counts* $D(x,y)$ and *exposures* $E(x,y)$ derived from the *Human Mortality Database* (HMD, 2014: www.mortality.org) and *deaths by COD* $D_i(x,y)$ from the *World Health Organization Mortality Database* (WHOMD, 2014).

Like it was explained on the previous chapters, WHOMD cause of death (COD) data is only available by five-year age groups. In this chapter longer time series were needed to produce a more accurate forecast, thus, our choice fell on the combination of ICD9 and ICD10 COD classification. Disruptions between both classifications should be almost imperceptible once that major changes correspond to large COD desegregation and we are dealing with major CODs groups.

Again, to avoid low subpopulation sizes and any lack of representativeness, and now big disruptions between ICD classifications, we work with major COD groups: 1) Neoplasms, 2) Ischaemic Heart Diseases; 3) Cerebrovascular Diseases; 4) Remaining Diseases of the Circulatory System; 5) Diseases of the Respiratory System; 6) Diseases of the Digestive System; 7) External Causes of death; and 8) Remaining Causes of death.

We used five selected countries to follow a concise and complementary analysis throughout entire monograph, correspond once again to France, Portugal,

Japan, Sweden and Spain. Portugal, is a special case here, once that on the WHOMD Portuguese data for both ICDs presents some changes in the classification over time, we make use of EUROSTAT, where COD data is available between 1994 and 2010.

Consequently, due to data issues, Portugal is here the country with the smallest time series (Table 5.1), while Japan (1979 to 2011), France (1979 to 2011) and Spain (1980 to 2012) present the largest ones. Lastly, Sweden is in intermediary position, with data available between 1987 and 2012.

**Table 5.1:** Discrimination of International Classification of Diseases (ICD) by Country

| Countries | ICD 9 | ICD 10 |
|---|---|---|
| **Portugal** | — | 1994 - 2010 |
| **Spain** | 1980 - 1998 | 1999 - 2011 |
| **Sweden** | 1987 - 1996 | 1997 - 2010 |
| **France** | 1979 - 1994 | 1995 - 2011 |
| **Japan** | 1979 - 2000 | 2001 - 2011 |

**Source:** WHOMD and EUROSTAT 2014, own elaboration

## 5.5. Results

### 5.5.1. Distribution of deaths by cause across age

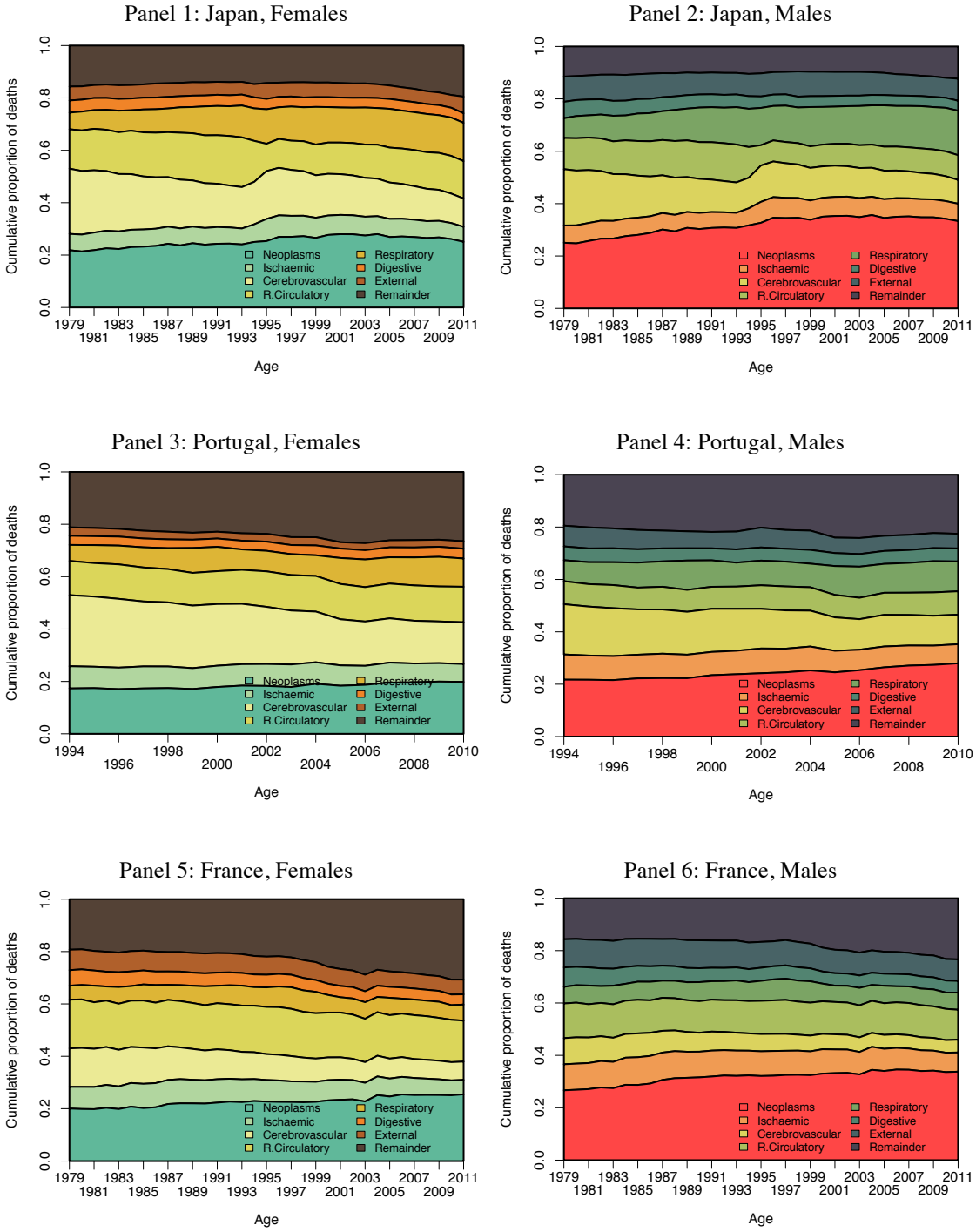
The elaboration of a Stack plot (Figure 5.1) allows not only to identify the impact of the different CODs by sex and country, but also to identify possible disruptions caused by changes in the ICD classificatory system. We can immediately identify that Japan is the country with the biggest disruption in 1995, when the ICD10 data starts. This disruption is especially identified related to diseases of the circulatory system (here represented by: ischaemic heart diseases, cerebrovascular diseases, and remaining causes of the circulatory system).

France, even in a much smaller scale, is one other country that can be identified possible perturbing disruptions in what concerns the forecasting process. It seems that till year 2000, almost all COD groups besides neoplasms and remaining causes, were declining and after that year onwards their proportion on overall mortality increased.

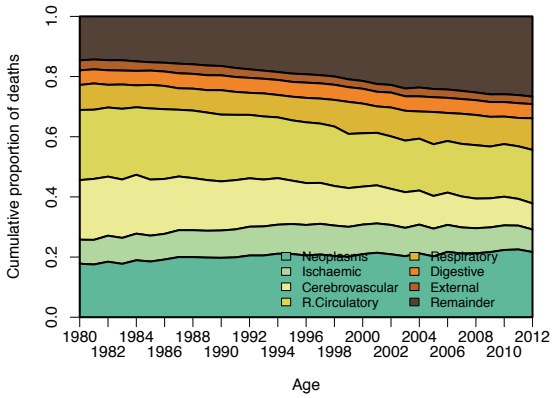
All the other countries present much less disruption when the ICD change occurs (Table 5.1), but is still curious to observe that Portugal, that only refers to ICD

10, also presents some changes in the observed patterns consistent with changes in the classification of diseases.

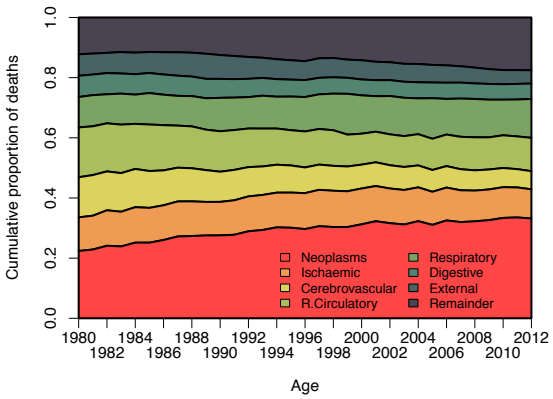
**Figure 5.1:** Cumulative proportion of deaths across time by COD



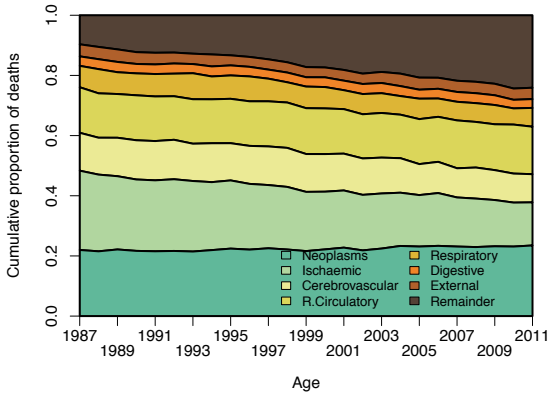
Panel 7: Spain, Females



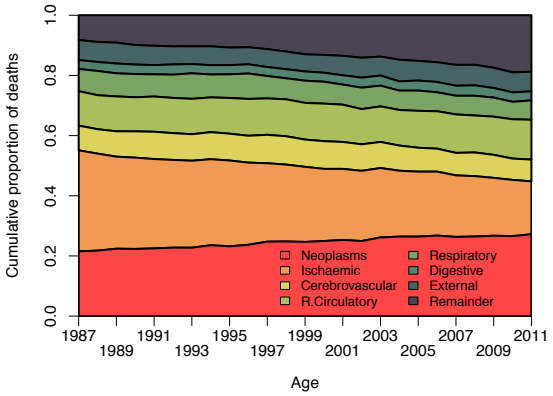

Panel 8: Spain, Males




Panel 9: Sweden, Females




Panel 10: Sweden, Males




**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

Analyzing now Figure 5.1 distribution of deaths by cause and not only identifying possible disruptions caused by changes in ICD, it is possible to identify three main general facts common to all countries:

1) in the past were the diseases of the circulatory system that played the major role, i.e., contributed to overall mortality with the higher number of deaths;
2) deaths caused by neoplasms were already numerous in the beginning of each time series, and its influence seems to grow as time goes by;
3) in the beginning of each time series, deaths were mainly caused by circulatory system diseases and neoplasms, but now it is possible to identify a raising influence of a mixture of remaining causes that had a smaller negative impact.

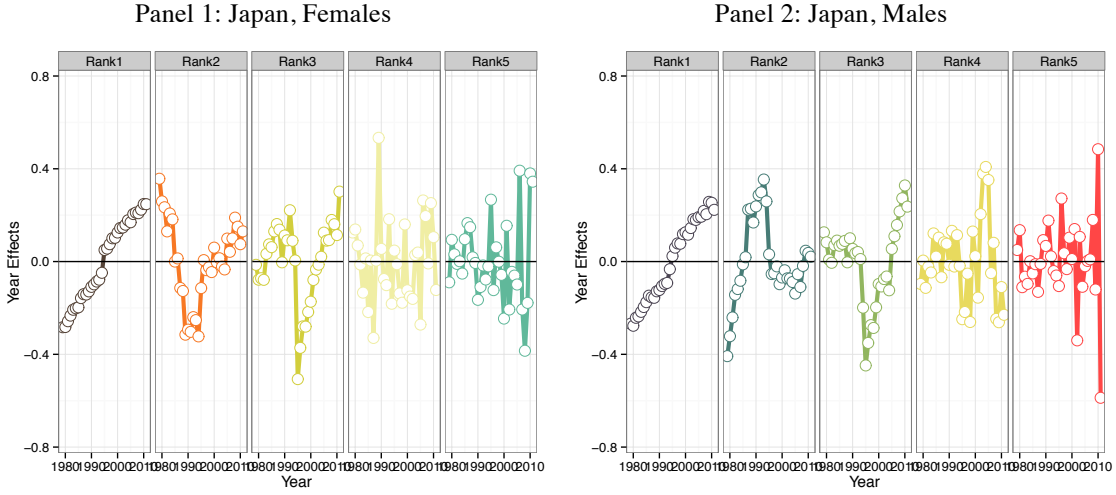
### 5.5.2. The singular vector

As it was explained above, the CoDa equivalent Lee-Carter model to forecast mortality is, similarly to the original, based on a low rank matrix approximation. In this case however, we can define the rank-r approximation to use. Figure 5.2 represents the first five left singular vectors by sex and country to "help" us to decide which low rank to apply. Vectors presenting identifiable patterns rather than random noise suggest that these vectors still have an important contribution to the model. Lets analyze the Japanese example. Independently of sex, it can be seen that from the fourth vector onwards, we are only able to identify basically a random noise. Consequently, Japanese forecasts are based on a rank-3 matrix approximation.

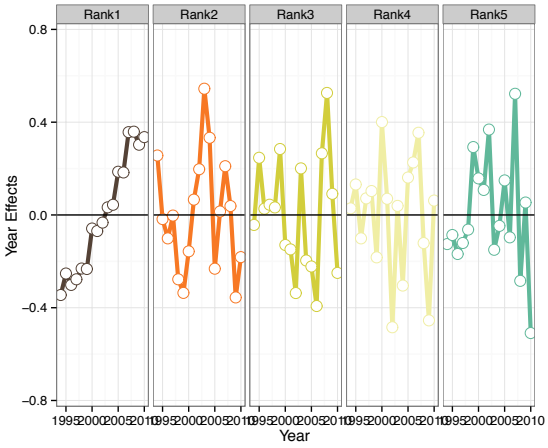
The Spanish case is one other example of a rank-3 choice for matrix approximation, once that the same pattern identified for Japan is repeating here, and especially in the male case.

In a general way, it seems that for remaining three countries (Portugal, France and Sweden), a rank-2 approximation is the best choice. In the Swedish female specific case, it even seems that a rank-1 approximation would be enough, but once that we are dealing with a time series that includes two different ICDs (and a shorter one for Portugal), our choice was to perform a rank-2 approximation for those countries.

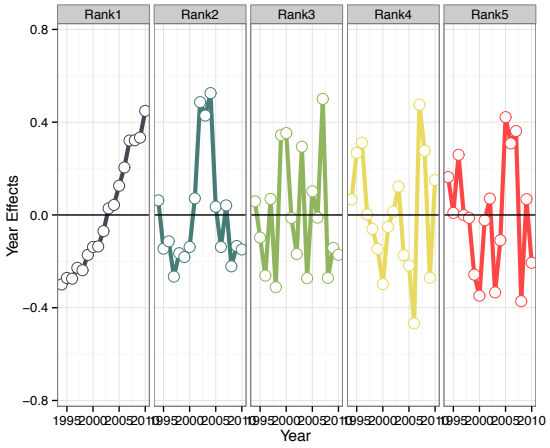
**Figure 5.2:** First five left singular vectors by sex and country



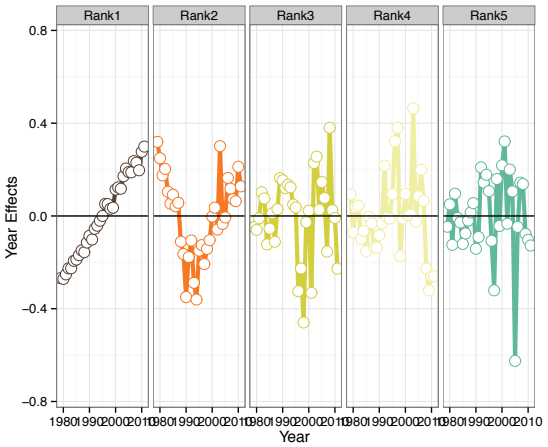
Panel 3: Portugal, Females



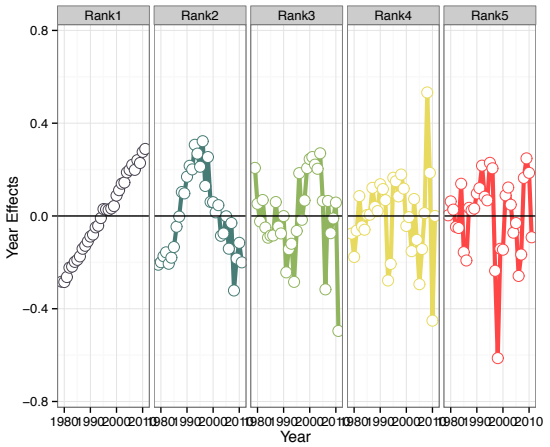

Panel 4: Portugal, Males



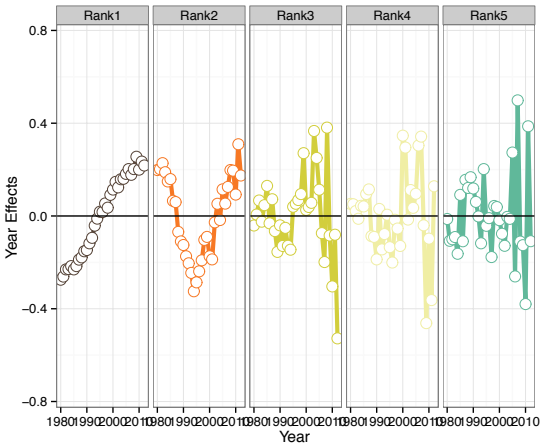

Panel 5: France, Females



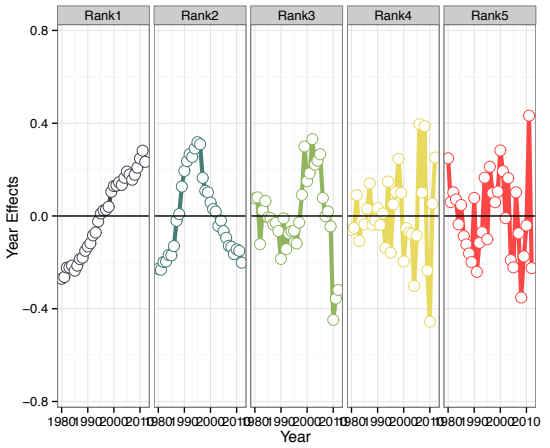

Panel 6: France, Males




Panel 7: Spain, Females

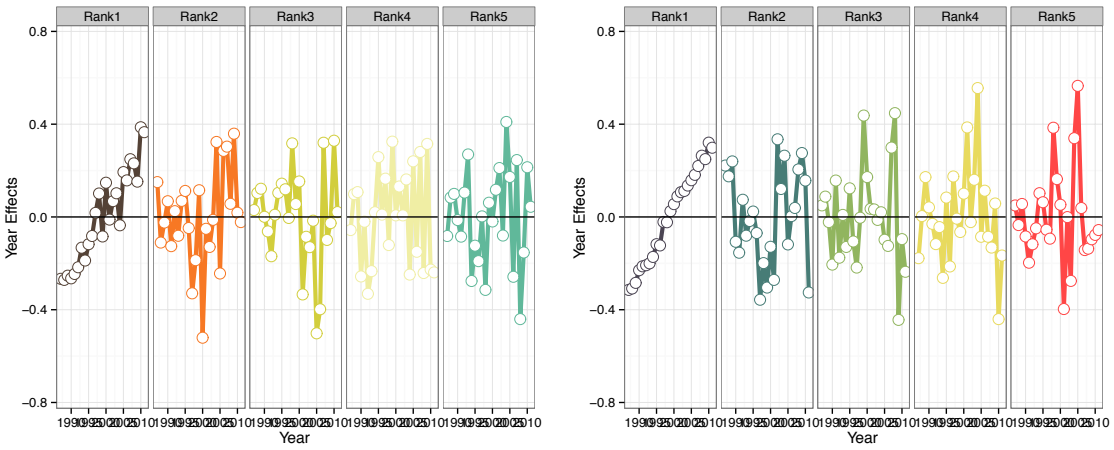



Panel 8: Spain, Males



Panel 9: Sweden, Females

Panel 10: Sweden, Males




**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

Data presented in Figure 5.3 correspond to the first age right singular vectors, i.e., to the age factors for the all analyzed CODs. This information is presented here deriving from LOESS[3] smoothing curves to allow a better understanding of obtained results. When the presented values are positive, it indicates an increase of deaths related to the associated COD, while negative values are result of exactly the opposite.

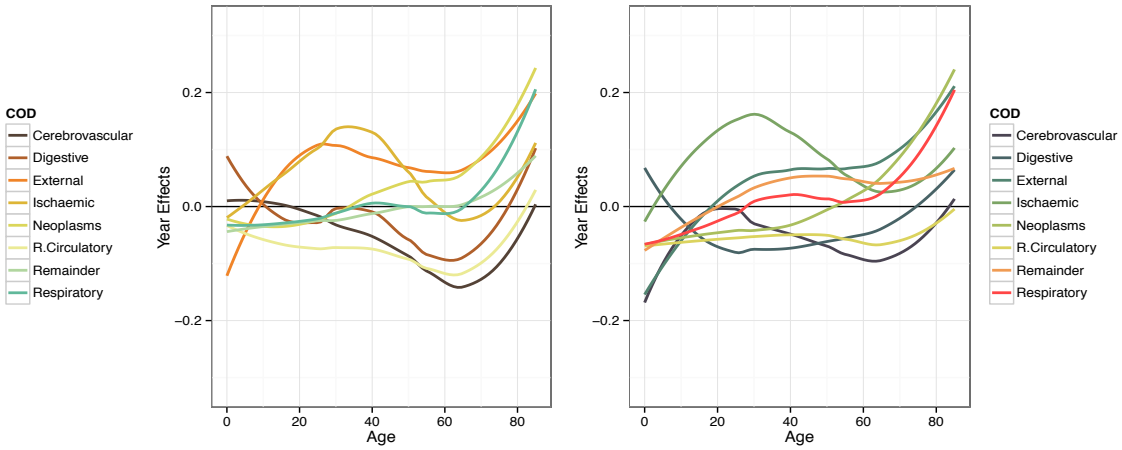
Thus, the obtained results confirm what was identified before, recognizing Neoplasms and the group corresponding to the remaining CODs as the ones that mostly increase, especially after age 20. At older ages was registered an increase of deaths referent to almost all causes. This situation is related with the fact that nowadays, deaths are occurring mainly at older ages and even a small "positive" influence is detected.

[3] LOESS is a powerful non-parametric but simple method for fitting smooth curves to data.

**Figure 5.3:** First right singular vectors by sex and country (*loess smooth*)

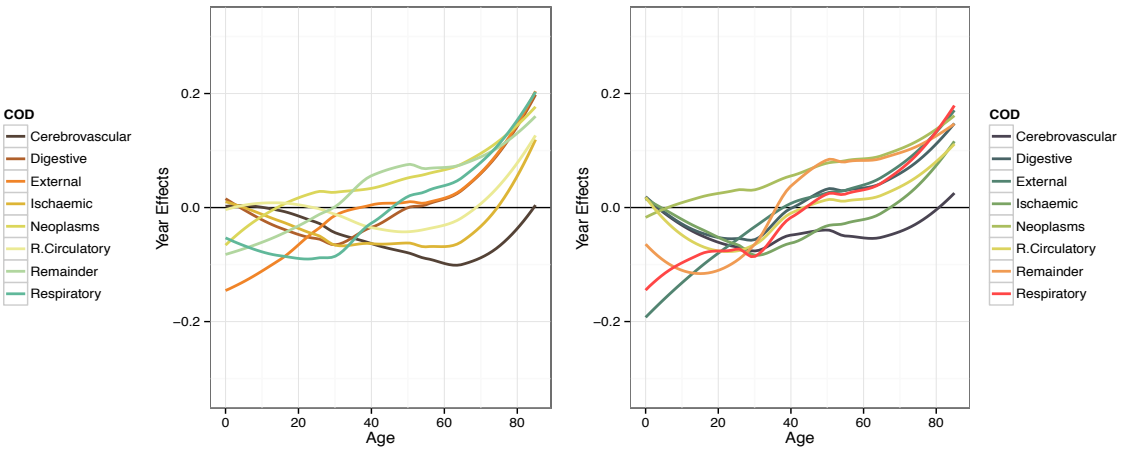
Panel 1: Japan, Females

Panel 2: Japan, Males



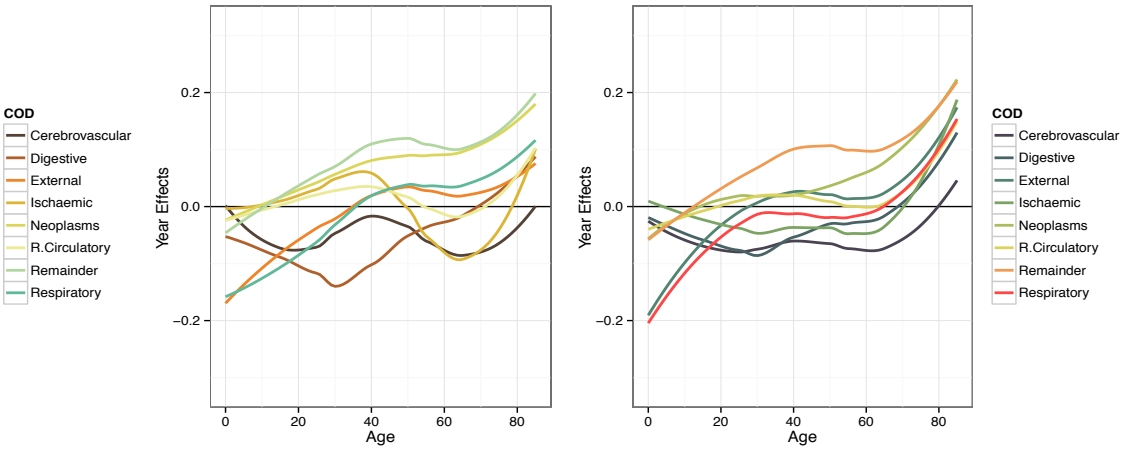

Panel 3: Portugal, Females

Panel 4: Portugal, Males



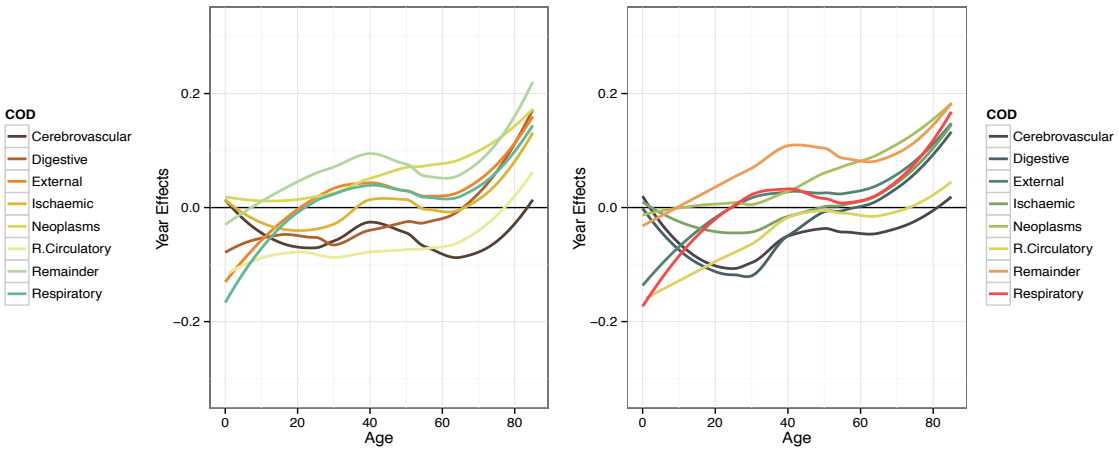

Panel 5: France, Females

Panel 6: France, Males



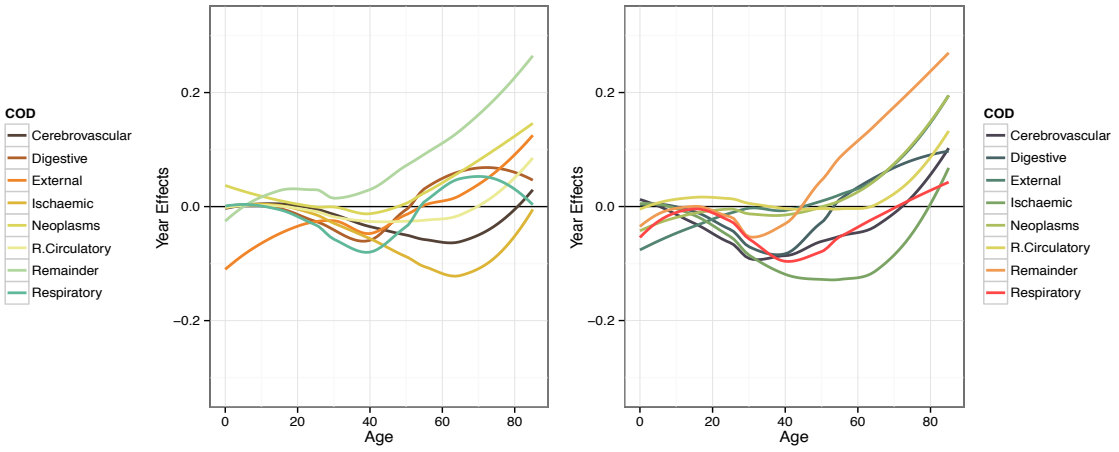
Panel 7: Spain, Females

Panel 8: Spain, Males




Panel 9: Sweden, Females

Panel 10: Sweden, Males




**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

### 5.5.3. Decomposing mortality forecasts by COD

Figure 5.4 shows the period life-table probability that a newborn has to die from a specific cause, where circles correspond to the used data to fit the model (observed), continuous lines represent the rank-r approximation (identified above), and dashed lines are the forecasted trends.

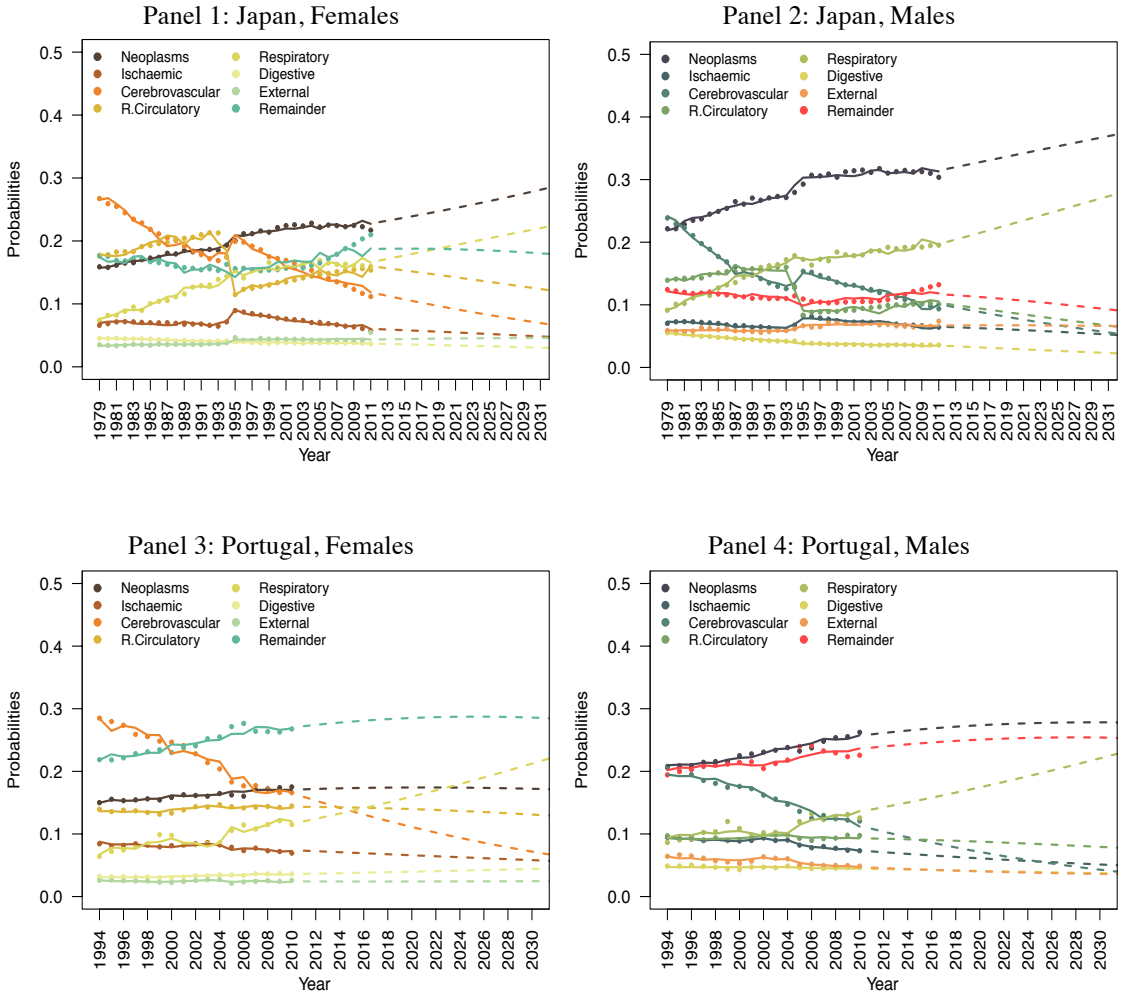
Generally it's discernible that the low rank approximation used accordingly to each country, presents very alike results, even in presence of very high fluctuations as the one observed in the Japanese situation. Nevertheless, it seems that those fluctuations interfere with the forecasts and in some CODs present very unconformable results. The clearest example is related to the remaining causes of death group, to which real data is presenting an increasing pattern over time, and the

forecast predicts a decline. However, problems with forecasts associated to neoplasms and respiratory diseases are also recorded.

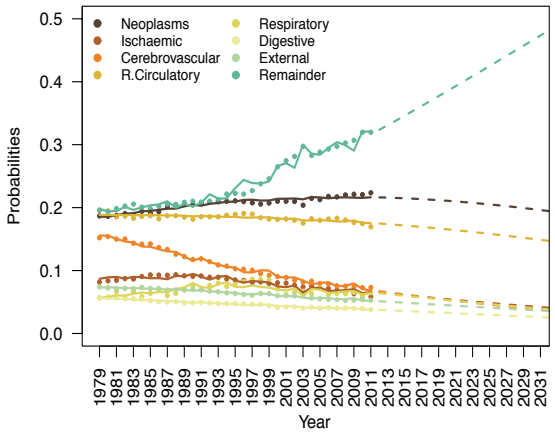
For all other countries, it's possible to realize that forecasted trends follow previous evolution and seem to progress accordingly. Obtained results suggest that the probability of dying from neoplasms is going to be kept constant over time, but there are very different CODs (i.e., the remaining COD group) that need some intervention once that they are already leading death probabilities for females in France, Spain and Sweden.

From the group from the selected analyzed countries, Portugal presents distinctive evolutionary patterns from the rest. The increasing mortality pattern associated to neoplasms is similar to the other countries, however, more than the remaining group of CODs, it seems that if not controlled, the diseases of the respiratory system will become one of the biggest death contributors.

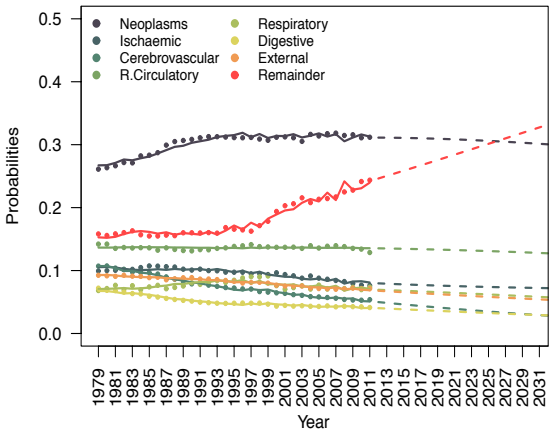
**Figure 5.4:** Period life-table probability at birth of dying from a specific COD



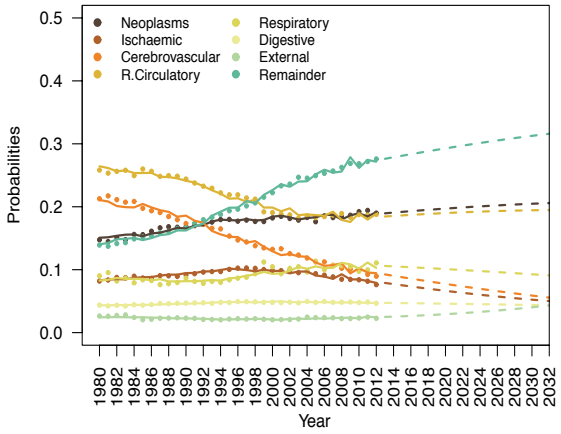
Panel 5: France, Females



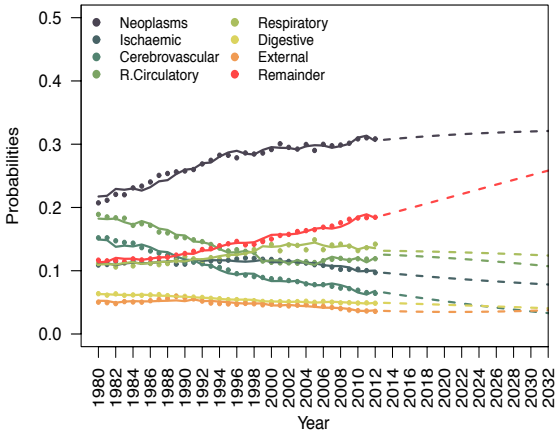

Panel 6: France, Males



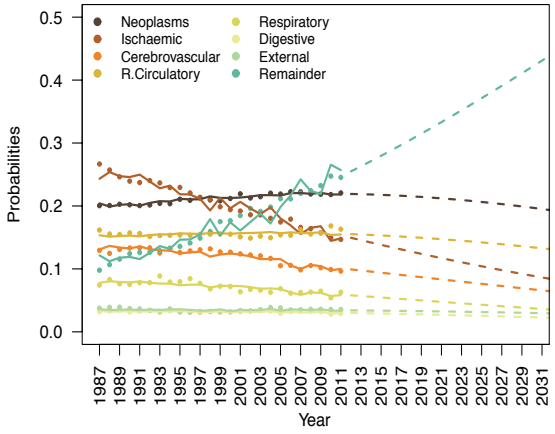

Panel 7: Spain, Females



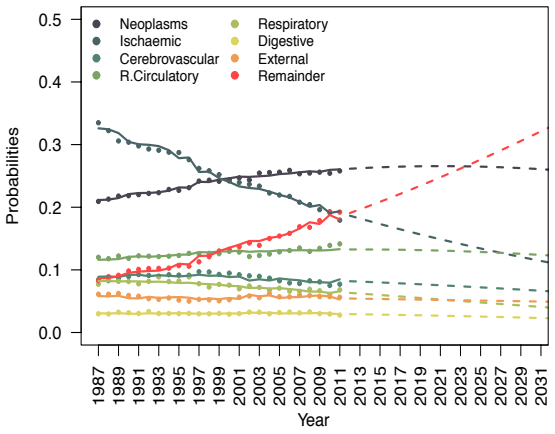

Panel 8: Spain, Males




Panel 9: Sweden, Females




Panel 10: Sweden, Males



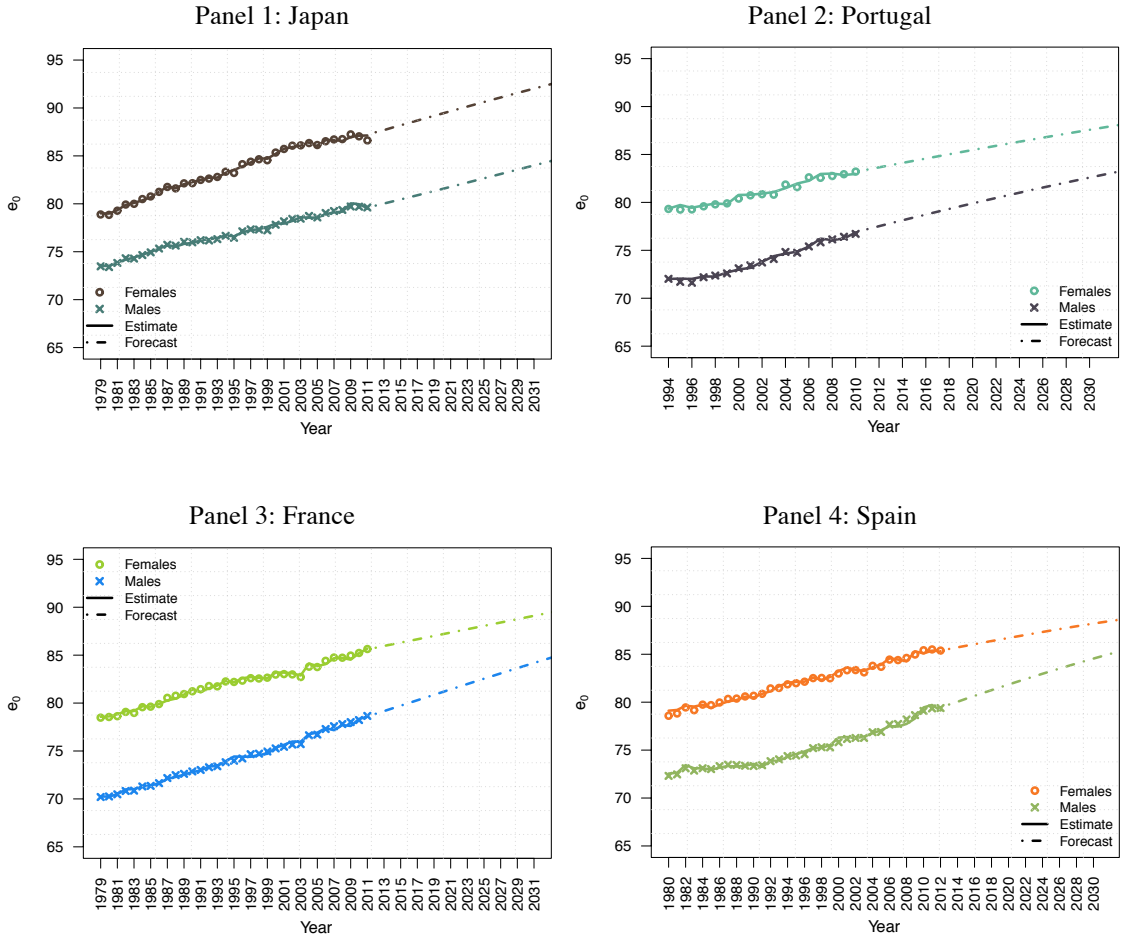

**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

### 5.5.4. Prospective $e_0$

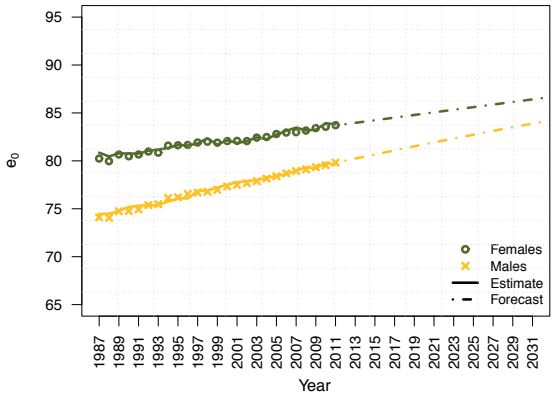
Figure 5.5 presents the life expectancy at birth estimated (continuous lines) and forecasted (dashed lines) from the multiple-decrement approach for all the countries under observation and by sex. Obtained results suggest that the multiple-decrement model is able to estimate with high accuracy the already observed life expectancy at birth.

From an overall point of view, the obtained results suggest that the life expectancy at birth gap that differentiate both sexes tends to decline with time. Japan is the only country that seems to contradict this observation.

**Figure 5.5:** Observed and forecast $e_0$ by country and sex



Panel 5: Sweden




**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

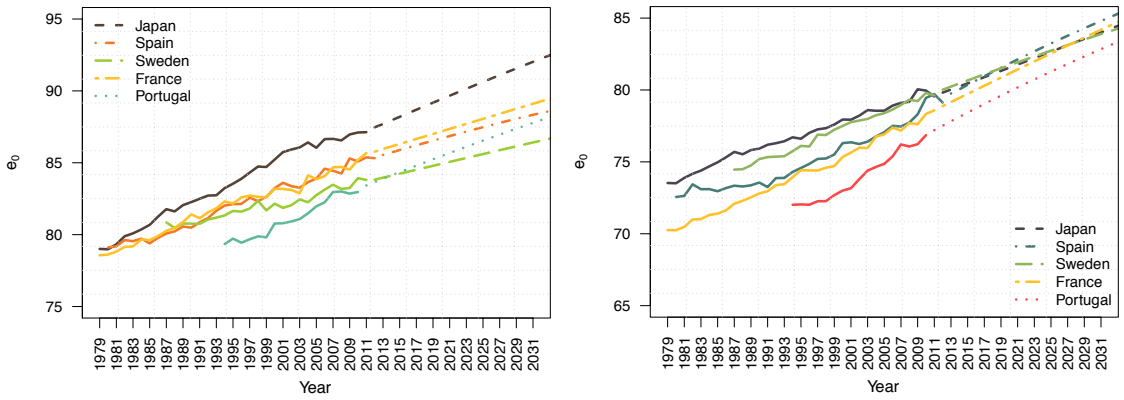
Comparing forecasted $e_0$ within sexes (Figure 5.6) demonstrates that if forecasts became reality, Japanese females will be still leading in 2030 and all the other countries will find difficulties to reduce the gap. We also can expect that Portuguese females leave the bottom and around 2030 present a very narrow gap when compared with France and Spain.

Male forecasts indicate that the slope of increase suggests a steeper evolution of life expectancy, but here, Portugal is not expected to leave the bottom. Spain, on the contrary, is expected to take the lead around 2023.

**Figure 5.6:** $e_0$ prospective patterns aggregated by sex

Panel 1: Females

Panel 2: Males




**Source:** WHOMD, HMD and EUROSTAT 2014, own elaboration

## 5.6. Discussion

The CoDa equivalent to the Lee-Carter model to forecast mortality trends proposed by Oeppen (2008) is definitely an excellent option to consider when the goal is to forecast multiple decrement processes as mortality by COD.

Obtained estimates for observed values concerning life expectancy at birth and the period life-table probability at birth of dying from a specific COD, revealed high accuracy and are not more pessimistic as identified for other methods by Wilmoth (1995). Nevertheless, in opposition with the original study when the method was proposed (Oeppen, 2008), it seems that forecasted trends for Japan are not conclusive and not accurate enough. Nevertheless, despite the accuracy presented by the model here employed, the true is that most of COD forecasts seem not reliable at this level.

At our knowledge, accuracy might be mainly connected with the fact that the jump-off is not being corrected, likewise some above explained variants of the original methodology. This thought arises from the fact that the CoDa approach has difficulty to estimate accurately most recent patterns. In the female Japanese case, e.g., the model is completely overestimating observed life expectancy at birth for 2011. Once again, if we take another careful look to the forecast decomposed by COD, the same situation is registered, and the extrapolation of past trends seems to be more accurate if the last available year of information is fitted well.

Smoothing the data before model fitting also may bring higher accuracy to estimates once that variance is reduced. Nonetheless, we guess that the major cause for inaccuracy problems related with this method resulsts from changes in the ICD.

Disaggregation of causes of death into single-age groups could also benefit further estimates and forecast of multiple-decrement mortality patterns.

## 5.7. Conclusions

The CoDa model produces undeniable good approximates for observed mortality patterns and overall results indicate that, in most of the countries, there is a distinctive group of remaining cause of death with growing implications on overall mortality. Neoplasms do not seem to be expected to reduce their participation on overall mortality, and a constant pattern of evolution is extrapolated. Together with

neoplasms in both sexes, is expected that the remaining diseases of the circulatory system not specified here, continue to negatively influence female mortality.

Portugal was the only country under observation where is expected to observe an increase on the probability of dying from respiratory system diseases, however, it appears not influencing negatively the evolution of life expectancy at birth, mainly in the female case.

# CHAPTER 6

# CONCLUSIONS

## 6.1. Overall conclusions

As exposed in the Introduction Chapter (Chapter 1), the overall aim of this study is to contribute to mortality research with important knowledge that comes from investigating mortality trends and its related processes.

As a result, we can confirm that likewise some other previous studies: neoplasms, diseases of the circulatory and respiratory system are the principal CODs and the ones that influence the most, negatively, life expectancy for populations. However, we perspective that if the rate of increase in life expectancy at birth keeps recent evolutionary patterns, it is possible that the male/female gap keep diminishing and all analyzed countries can aim for Japanese values. Despite fewer attention given to less expressive causes in overall mortality, we identify that the group of remaining CODs is one of the most important in influencing negatively life expectancy. Likewise Oliveira and Mendes acknowledged (2010) the emergent importance associated with this wide-ranging group of CODs might be intimately related with shift of high rates of mortality to older ages.

Seeking to test Vaupel's hypothesis on the individual rate of mortality increase, we were also able to distinguish between the individual's rate of aging, and the widely studied LAR (e.g., Horiuchi and Wilmoth, 1997, 1998). The two measures present very distinctive patterns. The individual rate of aging is constant across time, and LAR is varying age-wise, creating a bell-shaped pattern. $b$ not only differs from LAR, but also contributes to its estimation (Vaupel and Zhang, 2010). Despite the fairly stable evolution estimated $b$ across different CODs, sexes and selected countries, we cannot fully support Vaupel's hypothesis. With the exception of neoplasms, the estimates obtained for overall mortality are always lower when compared with different $\hat{b}_i(y)$ and it seems that the different $\hat{b}_i(y)$ associated to different CODs contribute to the "average" rate of individual aging. Accordingly with Brody and Schneider (1986), our results present lower rates of aging for causes considered close to non-senescent processes, like neoplasms or external causes of

death, and higher values for the ones in opposite direction, i.e., for example the case of the deaths by diseases of the circulatory system. The case of cancer strikes out as the cause that has the lowest rate of aging of all, factor that can be explained by the fact that *"in the human species, the population that reaches advanced age and has a decreased incidence of cancer, could be less prone to develop cancer and hence more fit to reach the maximum lifespan"* (Macieira-Coelho, 1986). Another explanation can be directly related with the origin of cancer, which is connected with the unregulated growth of new cells, being a multistage process that starts with a pre-cancerous lesion and ends up with a malignant tumor. Nevertheless, at older ages the proliferation of cells is declining and possibly increases the time between cancer development stages (Ukrainsteva and Yashin, 2003).

ΓGM model-based LARs (for overall mortality and by COD) appear to be consistent with the "heterogeneity hypothesis" advanced by Horiuchi and Wilmoth (1998) as the age of mortality deceleration shifts to older ages with time in overall mortality and only neoplasms, as one of the CODs with lower mortality rates after age 65, presents less pronounced patterns. The ΓGM model-based LAR (Vaupel and Zhang 2010) fits observed LAR with high accuracy and captures the connection relationship between the observed shift and the rate of life expectancy increase in the five selected countries for overall mortality.

The CoDa equivalent to the Lee-Carter model to forecast mortality trends proposed by Oeppen (2008) is definitely an excellent option to consider when the purpose is to forecast multiple decrement processes as mortality by COD. Obtained estimates for observed values concerning life expectancy at birth and the period life-table probability at birth of dying from a specific COD, revealed high accuracy and are not more pessimistic as identified for other methods by Wilmoth (1995). Forecasts identified a distinctive group of remaining cause of death with growing implications on overall mortality. Neoplasms do not seem to be expected to reduce their participation on overall mortality, and a constant pattern of evolution is extrapolated.

Portugal was the only country under observation where is expected to observe an increase on the probability of dying from respiratory system diseases, however, it appears not influencing negatively the evolution of life expectancy at birth, mainly in the female case.

Summarizing, despite that the main motivation of this study did not revealed full confirmation, we strongly believe that the analysis complementary to all the subject resulted in precious information that may contribute to changes in specific areas seeking to improve public health.

The constant rate of aging across all individuals, under the same COD was proved to be a reality. But if proved to be real for the individual exposed to all competing risks and with different behaviors (e.g., smokers vs. non-smokers), it *"would fundamentally contribute to our understanding of how and why we age"* (Vaupel, 2010). Our findings are contributing, at least partially, on this direction. We also provide a complete and in-depth examination of the population by applying the formulation on (4.6), showing that the rate of individual aging not only differs from the rate of aging for the population, but also contributes for its calculation.

## 6.2. Insights and contributions for future research

Any investigation, even when is not able to confirm previously stated hypothesis, gives important contributions to future research. In our case, even that the obtained results cannot fulfill Vaupel's hypothesis, we understand that, due to the different contributing risks to which all individuals are exposed (Chiang, 1991), a possible complementary way is testing by the estimate of the individual rate of individual aging accordingly to groups of individuals that share the same behavioral pattern, e.g., smokers and non-smokers; athletes and non-athletes; or, alcohol consumption and non-consumption individuals. Disaggregation of causes of death into single-age groups can benefit further estimations.

In what concerns to the performed mortality forecasts, at our knowledge, accuracy might be essentially connected with the fact that the jump-off is not being rectified likewise some above explained variants of the original methodology, and that should be evaluated. Smoothing the data before model fitting also may bring higher accuracy to estimates once that variance is reduced. Nonetheless, we guess that the major cause for inaccuracy problems related with this method come from changes in the ICD.

## 6.3. Limitations of the study

During the study elaboration, many difficulties were found and almost all are related with data availability. First of all, data available for mortality discriminated by COD, only exists in the aggregate form of five-year age groups. Second, the open age interval for those kind of data is almost always 85+, and with increasing lifespan, it is not enough and might interfere with the obtained results. Thirdly, when we disaggregate data by COD and sex, we end up with smaller data subpopulations, increasing the estimates variance. This situation becomes even worst when we are focusing on countries with small population, as e.g. Portugal or Finland. Fourthly, changes between ICD in the different countries resulted in disruptions in the correspondent year of transition that seem to influence the outcome.

Nonetheless, we also can refer here some theoretical limitations, or better, limitations that will always need to be in mind when we are dealing with CODs. Some CODs are intimately connected with behavioral patterns, for example, around 30 % of neoplasms *"are due to five leading behavioral and dietary risks: high body mass index, low fruit and vegetable intake, lack of physical activity, tobacco use, alcohol use"* (WHO, 2014). Another issue is related to the existence of competing risks to which each individual is exposed that need always to be taken into account.

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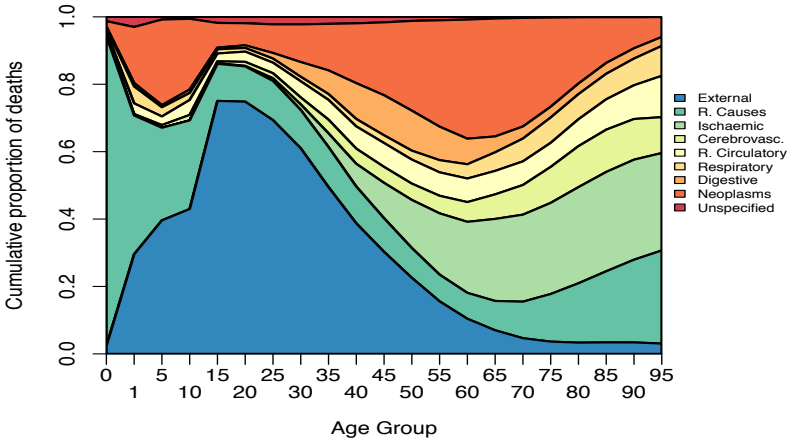
# Appendix

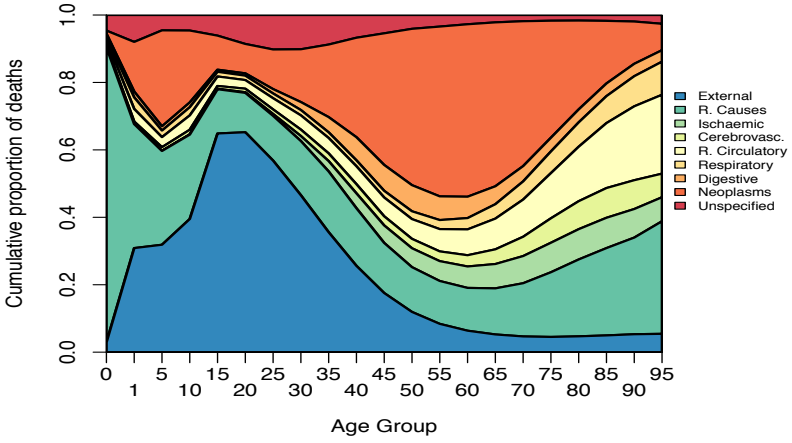
## To Chapter 3 – The Individual rate of aging by cause of death: testing Vaupel's hypothesis

**Figure A. 1: Proportion of age-specific deaths by cause**

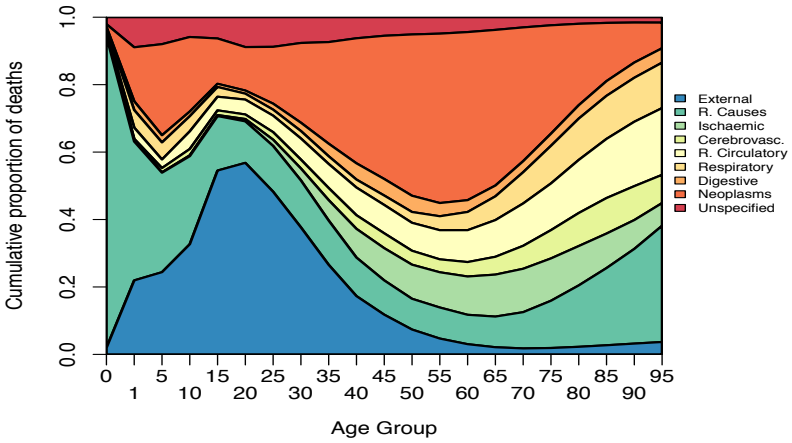
Panel 1: Finland. 1996-2009



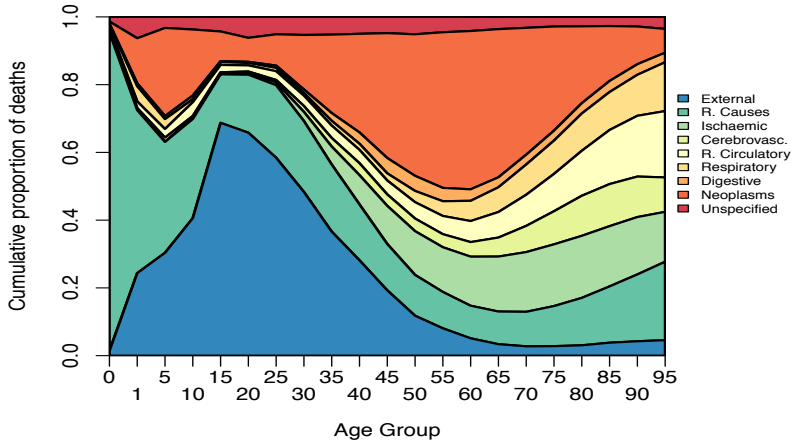

Panel 2: France. 2000-2009



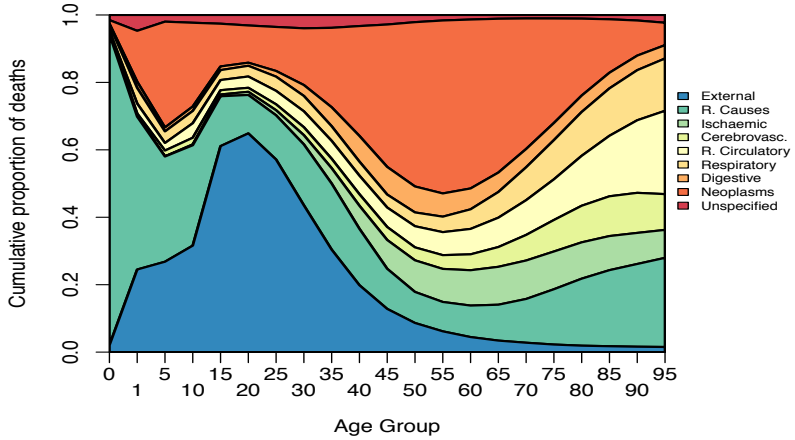

Panel 3: Netherlands. 1996-2009



Panel 4: Norway. 1996-2009




Panel 5: Spain. 2003-2009




**Source:** WHOMD 2014, own elaboration

**Table A. 1: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00339 | 0,00046 | 0,076 | 0,007 | 0,281 | 0,0716 | 0,00000010 | 0,00109416 |
| **2004** | 0,00323 | 0,00044 | 0,081 | 0,008 | 0,379 | 0,0768 | 0,00000003 | 0,00180696 |
| **2005** | 0,00326 | 0,00044 | 0,077 | 0,007 | 0,336 | 0,0729 | 0,00000018 | 0,00077657 |
| **2006** | 0,00318 | 0,00035 | 0,081 | 0,006 | 0,402 | 0,0642 | 0,00002167 | 0,00037077 |
| **2007** | 0,00310 | 0,00032 | 0,082 | 0,006 | 0,424 | 0,0625 | 0,00000006 | 0,00096547 |
| **2008** | 0,00302 | 0,00031 | 0,083 | 0,006 | 0,431 | 0,0644 | 0,00000009 | 0,00079030 |
| **2009** | 0,00308 | 0,00033 | 0,079 | 0,006 | 0,323 | 0,0625 | 0,00000001 | 0,00221177 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2003** | 0,00753 | 0,00142 | 0,085 | 0,012 | 0,326 | 0,0825 | 0,00130855 | 0,00147083 |
| **2004** | 0,00729 | 0,00113 | 0,088 | 0,010 | 0,380 | 0,0717 | 0,00126775 | 0,00117839 |
| **2005** | 0,00557 | 0,00081 | 0,105 | 0,010 | 0,510 | 0,0764 | 0,00280427 | 0,00085590 |
| **2006** | 0,00785 | 0,00122 | 0,080 | 0,009 | 0,307 | 0,0647 | 0,00032538 | 0,00126022 |
| **2007** | 0,00795 | 0,00111 | 0,082 | 0,008 | 0,351 | 0,0617 | 0,00000026 | 0,00160098 |
| **2008** | 0,00761 | 0,00092 | 0,085 | 0,007 | 0,386 | 0,0568 | 0,00000286 | 0,00095604 |
| **2009** | 0,00437 | 0,00059 | 0,118 | 0,010 | 0,642 | 0,0827 | 0,00363643 | 0,00063979 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 2: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00075 | 0,00006 | 0,148 | 0,006 | 0,424 | 0,0681 | 0,00000001 | 0,00044633 |
| **2004** | 0,00069 | 0,00005 | 0,150 | 0,006 | 0,448 | 0,0666 | 0,00000000 | 0,00129817 |
| **2005** | 0,00062 | 0,00004 | 0,159 | 0,006 | 0,554 | 0,0674 | 0,00000000 | 0,00075806 |
| **2006** | 0,00057 | 0,00004 | 0,155 | 0,006 | 0,472 | 0,0692 | 0,00000001 | 0,00047005 |
| **2007** | 0,00058 | 0,00004 | 0,147 | 0,005 | 0,314 | 0,0659 | 0,00000000 | 0,00068815 |
| **2008** | 0,00053 | 0,00004 | 0,150 | 0,005 | 0,367 | 0,0659 | 0,00000000 | 0,00085026 |
| **2009** | 0,00046 | 0,00003 | 0,155 | 0,005 | 0,355 | 0,0612 | 0,00000000 | 0,00054517 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2003** | 0,00255 | 0,00042 | 0,101 | 0,012 | 0,157 | 0,0834 | 0,00000924 | 0,00043587 |
| **2004** | 0,00140 | 0,00019 | 0,143 | 0,011 | 0,443 | 0,0859 | 0,00095129 | 0,00021672 |
| **2005** | 0,00202 | 0,00036 | 0,111 | 0,013 | 0,216 | 0,0935 | 0,00031747 | 0,00038137 |
| **2006** | 0,00140 | 0,00021 | 0,132 | 0,012 | 0,360 | 0,0916 | 0,00074560 | 0,00023573 |
| **2007** | 0,00200 | 0,00041 | 0,102 | 0,014 | 0,105 | 0,1042 | 0,00000026 | 0,00060271 |
| **2008** | 0,00181 | 0,00031 | 0,104 | 0,012 | 0,102 | 0,0906 | 0,00000005 | 0,00099896 |
| **2009** | 0,00164 | 0,00046 | 0,114 | 0,021 | 0,213 | 0,1604 | 0,00005535 | 0,00048675 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 3: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00059 | 0,00003 | 0,185 | 0,004 | 0,673 | 0,0533 | 0,00000000 | 0,00046301 |
| **2004** | 0,00056 | 0,00003 | 0,180 | 0,005 | 0,642 | 0,0575 | 0,00000000 | 0,00065174 |
| **2005** | 0,00054 | 0,00003 | 0,179 | 0,005 | 0,607 | 0,0574 | 0,00000000 | 0,00081648 |
| **2006** | 0,00051 | 0,00003 | 0,173 | 0,004 | 0,513 | 0,0560 | 0,00000001 | 0,00033212 |
| **2007** | 0,00050 | 0,00003 | 0,171 | 0,004 | 0,493 | 0,0561 | 0,00000000 | 0,00087809 |
| **2008** | 0,00047 | 0,00003 | 0,171 | 0,004 | 0,500 | 0,0577 | 0,00000000 | 0,00047876 |
| **2009** | 0,00045 | 0,00002 | 0,163 | 0,004 | 0,301 | 0,0524 | 0,00000000 | 0,00050953 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00111 | 0,00012 | 0,154 | 0,009 | 0,375 | 0,0727 | 0,00000007 | 0,00035200 |
| **2004** | 0,00093 | 0,00012 | 0,159 | 0,011 | 0,421 | 0,0857 | 0,00011719 | 0,00013403 |
| **2005** | 0,00100 | 0,00012 | 0,153 | 0,010 | 0,373 | 0,0814 | 0,00000019 | 0,00022252 |
| **2006** | 0,00092 | 0,00016 | 0,148 | 0,015 | 0,302 | 0,1140 | 0,00000001 | 0,00137042 |
| **2007** | 0,00091 | 0,00011 | 0,150 | 0,010 | 0,361 | 0,0843 | 0,00000269 | 0,00012633 |
| **2008** | 0,00078 | 0,00011 | 0,158 | 0,012 | 0,455 | 0,0996 | 0,00008255 | 0,00012373 |
| **2009** | 0,00072 | 0,00009 | 0,160 | 0,011 | 0,445 | 0,0965 | 0,00006033 | 0,00010828 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 4: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00080 | 0,00004 | 0,172 | 0,004 | 0,215 | 0,0485 | 0,00000001 | 0,00043717 |
| **2004** | 0,00077 | 0,00004 | 0,168 | 0,004 | 0,165 | 0,0473 | 0,00000000 | 0,00086714 |
| **2005** | 0,00077 | 0,00004 | 0,170 | 0,004 | 0,183 | 0,0471 | 0,00000000 | 0,00101342 |
| **2006** | 0,00069 | 0,00003 | 0,173 | 0,004 | 0,232 | 0,0468 | 0,00000001 | 0,00031879 |
| **2007** | 0,00072 | 0,00003 | 0,169 | 0,003 | 0,156 | 0,0426 | 0,00000000 | 0,00156180 |
| **2008** | 0,00071 | 0,00003 | 0,169 | 0,003 | 0,134 | 0,0419 | 0,00000000 | 0,00086651 |
| **2009** | 0,00065 | 0,00002 | 0,171 | 0,003 | 0,198 | 0,0392 | 0,00000000 | 0,00206201 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00128 | 0,00015 | 0,139 | 0,010 | 0,000 | 0,0723 | 0,00030004 | 0,00017275 |
| **2004** | 0,00124 | 0,00015 | 0,140 | 0,010 | 0,037 | 0,0747 | 0,00026726 | 0,00017122 |
| **2005** | 0,00116 | 0,00014 | 0,145 | 0,010 | 0,051 | 0,0735 | 0,00030340 | 0,00015661 |
| **2006** | 0,00113 | 0,00015 | 0,141 | 0,011 | 0,031 | 0,0825 | 0,00026114 | 0,00017019 |
| **2007** | 0,00129 | 0,00016 | 0,135 | 0,010 | 0,000 | 0,0789 | 0,00007501 | 0,00017971 |
| **2008** | 0,00126 | 0,00015 | 0,135 | 0,010 | 0,011 | 0,0783 | 0,00008794 | 0,00017047 |
| **2009** | 0,00098 | 0,00011 | 0,150 | 0,010 | 0,127 | 0,0793 | 0,00034841 | 0,00013031 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 5: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00045 | 0,00003 | 0,179 | 0,005 | 0,350 | 0,0622 | 0,00000000 | 0,00069918 |
| **2004** | 0,00040 | 0,00003 | 0,173 | 0,005 | 0,291 | 0,0661 | 0,00000001 | 0,00033285 |
| **2005** | 0,00046 | 0,00003 | 0,178 | 0,005 | 0,338 | 0,0589 | 0,00000001 | 0,00037466 |
| **2006** | 0,00038 | 0,00002 | 0,169 | 0,005 | 0,166 | 0,0611 | 0,00000000 | 0,00091057 |
| **2007** | 0,00043 | 0,00002 | 0,167 | 0,004 | 0,174 | 0,0572 | 0,00000001 | 0,00031291 |
| **2008** | 0,00041 | 0,00002 | 0,167 | 0,004 | 0,121 | 0,0554 | 0,00000000 | 0,00115766 |
| **2009** | 0,00038 | 0,00002 | 0,167 | 0,004 | 0,104 | 0,0517 | 0,00000000 | 0,00147060 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00114 | 0,00010 | 0,199 | 0,008 | 0,679 | 0,0615 | 0,00064334 | 0,00012435 |
| **2004** | 0,00148 | 0,00013 | 0,161 | 0,008 | 0,343 | 0,0619 | 0,00000005 | 0,00049797 |
| **2005** | 0,00170 | 0,00014 | 0,158 | 0,007 | 0,315 | 0,0572 | 0,00000002 | 0,00078011 |
| **2006** | 0,00138 | 0,00013 | 0,155 | 0,008 | 0,265 | 0,0644 | 0,00000228 | 0,00015006 |
| **2007** | 0,00144 | 0,00013 | 0,162 | 0,008 | 0,366 | 0,0624 | 0,00000004 | 0,00051051 |
| **2008** | 0,00133 | 0,00012 | 0,161 | 0,008 | 0,319 | 0,0639 | 0,00000006 | 0,00039651 |
| **2009** | 0,00132 | 0,00011 | 0,157 | 0,007 | 0,301 | 0,0620 | 0,00000007 | 0,00034135 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 6: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00041 | 0,00005 | 0,138 | 0,009 | 0,361 | 0,1021 | 0,00000000 | 0,00115913 |
| **2004** | 0,00008 | 0,00000 | 0,215 | 0,004 | 0,670 | 0,0816 | 0,00051691 | 0,00002073 |
| **2005** | 0,00008 | 0,00000 | 0,215 | 0,004 | 0,670 | 0,0828 | 0,00051691 | 0,00002158 |
| **2006** | 0,00008 | 0,00000 | 0,215 | 0,005 | 0,670 | 0,0833 | 0,00051691 | 0,00002271 |
| **2007** | 0,00037 | 0,00004 | 0,134 | 0,008 | 0,233 | 0,0970 | 0,00000002 | 0,00026553 |
| **2008** | 0,00035 | 0,00003 | 0,138 | 0,007 | 0,284 | 0,0870 | 0,00000000 | 0,00084763 |
| **2009** | 0,00035 | 0,00003 | 0,135 | 0,007 | 0,269 | 0,0865 | 0,00000332 | 0,00004178 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00090 | 0,00030 | 0,097 | 0,023 | 0,000 | 0,1525 | 0,00024386 | 0,00031640 |
| **2004** | 0,00060 | 0,00017 | 0,123 | 0,021 | 0,148 | 0,1550 | 0,00049103 | 0,00018665 |
| **2005** | 0,00057 | 0,00015 | 0,132 | 0,020 | 0,302 | 0,1478 | 0,00050957 | 0,00016770 |
| **2006** | 0,00068 | 0,00022 | 0,104 | 0,023 | 0,000 | 0,1579 | 0,00037701 | 0,00023405 |
| **2007** | 0,00086 | 0,00030 | 0,094 | 0,024 | 0,000 | 0,1655 | 0,00014564 | 0,00031591 |
| **2008** | 0,00066 | 0,00021 | 0,111 | 0,023 | 0,133 | 0,1699 | 0,00028383 | 0,00022128 |
| **2009** | 0,00047 | 0,00012 | 0,134 | 0,020 | 0,327 | 0,1625 | 0,00048262 | 0,00013748 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 7: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00016 | 0,00006 | 0,106 | 0,025 | 0,000 | 0,2435 | 0,00011208 | 0,00006931 |
| **2004** | 0,00020 | 0,00007 | 0,106 | 0,022 | 0,000 | 0,2161 | 0,00003554 | 0,00007355 |
| **2005** | 0,00020 | 0,00006 | 0,109 | 0,019 | 0,000 | 0,1908 | 0,00003555 | 0,00006364 |
| **2006** | 0,00015 | 0,00004 | 0,121 | 0,018 | 0,000 | 0,1922 | 0,00007298 | 0,00004570 |
| **2007** | 0,00016 | 0,00004 | 0,117 | 0,017 | 0,000 | 0,1857 | 0,00004450 | 0,00004665 |
| **2008** | 0,00017 | 0,00004 | 0,113 | 0,016 | 0,000 | 0,1829 | 0,00002112 | 0,00004500 |
| **2009** | 0,00013 | 0,00003 | 0,124 | 0,014 | 0,000 | 0,1619 | 0,00006107 | 0,00003328 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00013 | 0,00006 | 0,167 | 0,036 | 0,533 | 0,2704 | 0,00060459 | 0,00007656 |
| **2004** | 0,00041 | 0,00017 | 0,096 | 0,028 | 0,000 | 0,1899 | 0,00024775 | 0,00018337 |
| **2005** | 0,00038 | 0,00022 | 0,097 | 0,040 | 0,000 | 0,2613 | 0,00028884 | 0,00023764 |
| **2006** | 0,00033 | 0,00016 | 0,104 | 0,034 | 0,012 | 0,2346 | 0,00028824 | 0,00017456 |
| **2007** | 0,00029 | 0,00013 | 0,112 | 0,034 | 0,034 | 0,2451 | 0,00029180 | 0,00014412 |
| **2008** | 0,00012 | 0,00005 | 0,177 | 0,036 | 0,638 | 0,2995 | 0,00047152 | 0,00006838 |
| **2009** | 0,00023 | 0,00009 | 0,133 | 0,030 | 0,311 | 0,2373 | 0,00030928 | 0,00010136 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 8: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in Spain**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00128 | 0,00006 | 0,165 | 0,004 | 0,290 | 0,0418 | 0,00000001 | 0,00052326 |
| **2004** | 0,00116 | 0,00005 | 0,168 | 0,004 | 0,356 | 0,0435 | 0,00000003 | 0,00029912 |
| **2005** | 0,00114 | 0,00005 | 0,171 | 0,003 | 0,374 | 0,0408 | 0,00000000 | 0,00083406 |
| **2006** | 0,00109 | 0,00005 | 0,168 | 0,003 | 0,328 | 0,0407 | 0,00000000 | 0,00639336 |
| **2007** | 0,00111 | 0,00004 | 0,167 | 0,003 | 0,293 | 0,0376 | 0,00000000 | 0,00415979 |
| **2008** | 0,00110 | 0,00004 | 0,167 | 0,003 | 0,283 | 0,0372 | 0,00000426 | 0,00005695 |
| **2009** | 0,00114 | 0,00004 | 0,162 | 0,003 | 0,220 | 0,0340 | 0,00000001 | 0,00040089 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2003** | 0,00159 | 0,00014 | 0,154 | 0,008 | 0,160 | 0,0590 | 0,00030170 | 0,00016602 |
| **2004** | 0,00176 | 0,00017 | 0,143 | 0,008 | 0,112 | 0,0614 | 0,00000015 | 0,00034951 |
| **2005** | 0,00184 | 0,00018 | 0,144 | 0,008 | 0,144 | 0,0617 | 0,00000016 | 0,00035655 |
| **2006** | 0,00148 | 0,00014 | 0,156 | 0,008 | 0,234 | 0,0650 | 0,00020280 | 0,00016449 |
| **2007** | 0,00135 | 0,00012 | 0,169 | 0,008 | 0,361 | 0,0656 | 0,00036668 | 0,00014626 |
| **2008** | 0,00157 | 0,00014 | 0,154 | 0,008 | 0,228 | 0,0627 | 0,00005087 | 0,00015896 |
| **2009** | 0,00127 | 0,00011 | 0,172 | 0,007 | 0,389 | 0,0628 | 0,00048178 | 0,00012922 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 9: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,01018 | 0,00103 | 0,139 | 0,008 | 0,192 | 0,0574 | 0,00118356 | 0,00118127 |
| **1997** | 0,01108 | 0,00117 | 0,130 | 0,008 | 0,121 | 0,0577 | 0,00013773 | 0,00131917 |
| **1998** | 0,01070 | 0,00110 | 0,129 | 0,007 | 0,109 | 0,0565 | 0,00000001 | 0,00867534 |
| **1999** | 0,00964 | 0,00104 | 0,140 | 0,008 | 0,226 | 0,0637 | 0,00012555 | 0,00119953 |
| **2000** | 0,00926 | 0,00092 | 0,139 | 0,007 | 0,180 | 0,0586 | 0,00053254 | 0,00106616 |
| **2001** | 0,00883 | 0,00090 | 0,139 | 0,007 | 0,176 | 0,0610 | 0,00069288 | 0,00104458 |
| **2002** | 0,00759 | 0,00075 | 0,150 | 0,007 | 0,228 | 0,0610 | 0,00169225 | 0,00090789 |
| **2003** | 0,00787 | 0,00078 | 0,145 | 0,007 | 0,205 | 0,0611 | 0,00116529 | 0,00091978 |
| **2004** | 0,00574 | 0,00059 | 0,159 | 0,008 | 0,306 | 0,0674 | 0,00319523 | 0,00073870 |
| **2005** | 0,00603 | 0,00064 | 0,152 | 0,008 | 0,230 | 0,0691 | 0,00248648 | 0,00078531 |
| **2006** | 0,00623 | 0,00065 | 0,147 | 0,008 | 0,186 | 0,0692 | 0,00200576 | 0,00077729 |
| **2007** | 0,00540 | 0,00053 | 0,155 | 0,007 | 0,218 | 0,0691 | 0,00294702 | 0,00065973 |
| **2008** | 0,00618 | 0,00060 | 0,145 | 0,007 | 0,148 | 0,0673 | 0,00190328 | 0,00072299 |
| **2009** | 0,00587 | 0,00053 | 0,146 | 0,007 | 0,162 | 0,0647 | 0,00219680 | 0,00065218 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e. $\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,02804 | 0,00470 | 0,095 | 0,012 | 0,024 | 0,0656 | 0,00003450 | 0,00489150 |
| **1997** | 0,01860 | 0,00294 | 0,129 | 0,013 | 0,229 | 0,0755 | 0,00796982 | 0,00319241 |
| **1998** | 0,01991 | 0,00335 | 0,122 | 0,014 | 0,183 | 0,0786 | 0,00662657 | 0,00359371 |
| **1999** | 0,02253 | 0,00389 | 0,108 | 0,013 | 0,083 | 0,0737 | 0,00278095 | 0,00412313 |
| **2000** | 0,01839 | 0,00279 | 0,122 | 0,012 | 0,144 | 0,0694 | 0,00520186 | 0,00303321 |
| **2001** | 0,02196 | 0,00354 | 0,109 | 0,012 | 0,085 | 0,0690 | 0,00000117 | 0,00375497 |
| **2002** | 0,02217 | 0,00348 | 0,105 | 0,012 | 0,051 | 0,0657 | 0,00000135 | 0,00368799 |
| **2003** | 0,02070 | 0,00338 | 0,106 | 0,012 | 0,035 | 0,0676 | 0,00004048 | 0,00358712 |
| **2004** | 0,01744 | 0,00314 | 0,111 | 0,013 | 0,051 | 0,0760 | 0,00346777 | 0,00335876 |
| **2005** | 0,01784 | 0,00312 | 0,105 | 0,013 | 0,001 | 0,0730 | 0,00207163 | 0,00331083 |
| **2006** | 0,01847 | 0,00338 | 0,104 | 0,013 | 0,008 | 0,0784 | 0,00087293 | 0,00356306 |
| **2007** | 0,01224 | 0,00180 | 0,133 | 0,012 | 0,170 | 0,0741 | 0,00748102 | 0,00200498 |
| **2008** | 0,01584 | 0,00311 | 0,107 | 0,014 | 0,000 | 0,0868 | 0,00263763 | 0,00330948 |
| **2009** | 0,00919 | 0,00137 | 0,149 | 0,012 | 0,251 | 0,0815 | 0,01044860 | 0,00160300 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 10: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00373 | 0,00244 | 0,075 | 0,035 | 0,183 | 0,2251 | 0,00066248 | 0,00254026 |
| **1997** | 0,00467 | 0,00191 | 0,067 | 0,020 | 0,206 | 0,1374 | 0,00000001 | 0,01442005 |
| **1998** | 0,00429 | 0,00159 | 0,074 | 0,019 | 0,251 | 0,1384 | 0,00000056 | 0,00166289 |
| **1999** | 0,00406 | 0,00145 | 0,082 | 0,020 | 0,406 | 0,1587 | 0,00001814 | 0,00152318 |
| **2000** | 0,00415 | 0,00162 | 0,079 | 0,021 | 0,354 | 0,1601 | 0,00000034 | 0,00206517 |
| **2001** | 0,00389 | 0,00213 | 0,081 | 0,030 | 0,396 | 0,2384 | 0,00022399 | 0,00222672 |
| **2002** | 0,00399 | 0,00215 | 0,074 | 0,028 | 0,285 | 0,2071 | 0,00000025 | 0,00318920 |
| **2003** | 0,00411 | 0,00213 | 0,072 | 0,026 | 0,226 | 0,1912 | 0,00000278 | 0,00221289 |
| **2004** | 0,00140 | 0,00059 | 0,137 | 0,029 | 0,766 | 0,2614 | 0,00278243 | 0,00070222 |
| **2005** | 0,00376 | 0,00107 | 0,079 | 0,015 | 0,337 | 0,1286 | 0,00000007 | 0,00296060 |
| **2006** | 0,00262 | 0,00128 | 0,092 | 0,028 | 0,419 | 0,2425 | 0,00141252 | 0,00136745 |
| **2007** | 0,00380 | 0,00086 | 0,073 | 0,012 | 0,289 | 0,1139 | 0,00003110 | 0,00090672 |
| **2008** | 0,00400 | 0,00141 | 0,071 | 0,018 | 0,281 | 0,1515 | 0,00000008 | 0,00367305 |
| **2009** | 0,00398 | 0,00192 | 0,065 | 0,023 | 0,196 | 0,1844 | 0,00000083 | 0,00198724 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00820 | 0,00320 | 0,092 | 0,026 | 0,306 | 0,1530 | 0,00000014 | 0,00621545 |
| **1997** | 0,00770 | 0,00272 | 0,097 | 0,024 | 0,395 | 0,1501 | 0,00000024 | 0,00409855 |
| **1998** | 0,00805 | 0,00323 | 0,082 | 0,025 | 0,209 | 0,1401 | 0,00000023 | 0,00493389 |
| **1999** | 0,00790 | 0,00268 | 0,082 | 0,021 | 0,235 | 0,1213 | 0,00000019 | 0,00454051 |
| **2000** | 0,00736 | 0,00274 | 0,088 | 0,024 | 0,269 | 0,1396 | 0,00000029 | 0,00373888 |
| **2001** | 0,00668 | 0,00245 | 0,107 | 0,027 | 0,423 | 0,1669 | 0,00000521 | 0,00256882 |
| **2002** | 0,00698 | 0,00146 | 0,100 | 0,015 | 0,438 | 0,1041 | 0,00000006 | 0,00434283 |
| **2003** | 0,00689 | 0,00209 | 0,088 | 0,019 | 0,257 | 0,1159 | 0,00000011 | 0,00472403 |
| **2004** | 0,00657 | 0,00220 | 0,098 | 0,023 | 0,370 | 0,1427 | 0,00000009 | 0,00549566 |
| **2005** | 0,00621 | 0,00170 | 0,092 | 0,018 | 0,277 | 0,1128 | 0,00000003 | 0,00712662 |
| **2006** | 0,00631 | 0,00198 | 0,102 | 0,022 | 0,431 | 0,1477 | 0,00000011 | 0,00445835 |
| **2007** | 0,00619 | 0,00200 | 0,095 | 0,021 | 0,357 | 0,1421 | 0,00000591 | 0,00209127 |
| **2008** | 0,00607 | 0,00257 | 0,093 | 0,027 | 0,367 | 0,1829 | 0,00000052 | 0,00266184 |
| **2009** | 0,00625 | 0,00261 | 0,086 | 0,025 | 0,279 | 0,1628 | 0,00004575 | 0,00271180 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 11: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00272 | 0,00036 | 0,155 | 0,010 | 0,472 | 0,0853 | 0,00000007 | 0,00118714 |
| **1997** | 0,00242 | 0,00035 | 0,159 | 0,011 | 0,455 | 0,0939 | 0,00000003 | 0,00176893 |
| **1998** | 0,00246 | 0,00035 | 0,154 | 0,011 | 0,394 | 0,0900 | 0,00000007 | 0,00115988 |
| **1999** | 0,00202 | 0,00029 | 0,172 | 0,011 | 0,509 | 0,0960 | 0,00000000 | 0,01626090 |
| **2000** | 0,00181 | 0,00027 | 0,175 | 0,012 | 0,484 | 0,1000 | 0,00014978 | 0,00033361 |
| **2001** | 0,00174 | 0,00023 | 0,176 | 0,011 | 0,502 | 0,0938 | 0,00000001 | 0,00193346 |
| **2002** | 0,00152 | 0,00021 | 0,186 | 0,011 | 0,553 | 0,0961 | 0,00000006 | 0,00080278 |
| **2003** | 0,00139 | 0,00019 | 0,189 | 0,011 | 0,588 | 0,0964 | 0,00000011 | 0,00053287 |
| **2004** | 0,00107 | 0,00017 | 0,195 | 0,013 | 0,588 | 0,1157 | 0,00021883 | 0,00022606 |
| **2005** | 0,00099 | 0,00016 | 0,199 | 0,013 | 0,599 | 0,1182 | 0,00030345 | 0,00021821 |
| **2006** | 0,00113 | 0,00017 | 0,184 | 0,012 | 0,465 | 0,1137 | 0,00000003 | 0,00092306 |
| **2007** | 0,00112 | 0,00015 | 0,180 | 0,011 | 0,399 | 0,1069 | 0,00000000 | 0,00325391 |
| **2008** | 0,00105 | 0,00015 | 0,180 | 0,011 | 0,346 | 0,1154 | 0,00000004 | 0,00065480 |
| **2009** | 0,00093 | 0,00013 | 0,182 | 0,011 | 0,362 | 0,1164 | 0,00005260 | 0,00017205 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00953 | 0,00266 | 0,092 | 0,020 | 0,114 | 0,1076 | 0,00004212 | 0,00276594 |
| **1997** | 0,00516 | 0,00140 | 0,143 | 0,023 | 0,393 | 0,1413 | 0,00345327 | 0,00154462 |
| **1998** | 0,00640 | 0,00201 | 0,122 | 0,025 | 0,257 | 0,1486 | 0,00206662 | 0,00215333 |
| **1999** | 0,00595 | 0,00167 | 0,126 | 0,023 | 0,233 | 0,1345 | 0,00200717 | 0,00180662 |
| **2000** | 0,00488 | 0,00124 | 0,137 | 0,021 | 0,276 | 0,1262 | 0,00249869 | 0,00137429 |
| **2001** | 0,00669 | 0,00319 | 0,107 | 0,035 | 0,081 | 0,1924 | 0,00000016 | 0,00595897 |
| **2002** | 0,00640 | 0,00209 | 0,106 | 0,024 | 0,031 | 0,1345 | 0,00001887 | 0,00222556 |
| **2003** | 0,00572 | 0,00137 | 0,115 | 0,018 | 0,131 | 0,1086 | 0,00000149 | 0,00147056 |
| **2004** | 0,00554 | 0,00174 | 0,110 | 0,023 | 0,071 | 0,1330 | 0,00010031 | 0,00185403 |
| **2005** | 0,00314 | 0,00080 | 0,144 | 0,021 | 0,171 | 0,1296 | 0,00223340 | 0,00091805 |
| **2006** | 0,00368 | 0,00100 | 0,134 | 0,022 | 0,137 | 0,1366 | 0,00143872 | 0,00110811 |
| **2007** | 0,00206 | 0,00048 | 0,180 | 0,020 | 0,422 | 0,1359 | 0,00304555 | 0,00060407 |
| **2008** | 0,00413 | 0,00122 | 0,115 | 0,022 | 0,000 | 0,1390 | 0,00055894 | 0,00131763 |
| **2009** | 0,00236 | 0,00062 | 0,154 | 0,021 | 0,212 | 0,1458 | 0,00267023 | 0,00072970 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 12: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00123 | 0,00019 | 0,167 | 0,013 | 0,520 | 0,1095 | 0,00000001 | 0,00148485 |
| **1997** | 0,00117 | 0,00020 | 0,163 | 0,014 | 0,436 | 0,1151 | 0,00000002 | 0,00132397 |
| **1998** | 0,00096 | 0,00020 | 0,174 | 0,017 | 0,579 | 0,1446 | 0,00000659 | 0,00024860 |
| **1999** | 0,00072 | 0,00015 | 0,198 | 0,017 | 0,798 | 0,1482 | 0,00022061 | 0,00019889 |
| **2000** | 0,00089 | 0,00018 | 0,180 | 0,016 | 0,610 | 0,1412 | 0,00000009 | 0,00052332 |
| **2001** | 0,00086 | 0,00016 | 0,171 | 0,015 | 0,467 | 0,1331 | 0,00000000 | 0,00257366 |
| **2002** | 0,00059 | 0,00014 | 0,198 | 0,018 | 0,689 | 0,1611 | 0,00033210 | 0,00019178 |
| **2003** | 0,00080 | 0,00017 | 0,178 | 0,017 | 0,610 | 0,1518 | 0,00000001 | 0,00165131 |
| **2004** | 0,00072 | 0,00017 | 0,175 | 0,019 | 0,530 | 0,1728 | 0,00002377 | 0,00021501 |
| **2005** | 0,00067 | 0,00017 | 0,169 | 0,019 | 0,411 | 0,1755 | 0,00000078 | 0,00020428 |
| **2006** | 0,00044 | 0,00010 | 0,206 | 0,018 | 0,789 | 0,1738 | 0,00014845 | 0,00013341 |
| **2007** | 0,00057 | 0,00015 | 0,169 | 0,019 | 0,387 | 0,1916 | 0,00006471 | 0,00017821 |
| **2008** | 0,00051 | 0,00011 | 0,187 | 0,017 | 0,703 | 0,1742 | 0,00000000 | 0,00164867 |
| **2009** | 0,00056 | 0,00009 | 0,175 | 0,012 | 0,547 | 0,1362 | 0,00000945 | 0,00012469 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00177 | 0,00073 | 0,148 | 0,037 | 0,372 | 0,2242 | 0,00036467 | 0,00079786 |
| **1997** | 0,00109 | 0,00038 | 0,203 | 0,034 | 0,766 | 0,2202 | 0,00105516 | 0,00045883 |
| **1998** | 0,00137 | 0,00046 | 0,176 | 0,032 | 0,552 | 0,2048 | 0,00068502 | 0,00052925 |
| **1999** | 0,00127 | 0,00043 | 0,181 | 0,032 | 0,594 | 0,2074 | 0,00056659 | 0,00050493 |
| **2000** | 0,00141 | 0,00054 | 0,152 | 0,033 | 0,307 | 0,2033 | 0,00033151 | 0,00060953 |
| **2001** | 0,00155 | 0,00046 | 0,144 | 0,025 | 0,271 | 0,1592 | 0,00000000 | 0,00600225 |
| **2002** | 0,00145 | 0,00044 | 0,142 | 0,026 | 0,276 | 0,1649 | 0,00000002 | 0,00259190 |
| **2003** | 0,00148 | 0,00049 | 0,143 | 0,028 | 0,278 | 0,1756 | 0,00000005 | 0,00166704 |
| **2004** | 0,00118 | 0,00044 | 0,152 | 0,032 | 0,309 | 0,2017 | 0,00018311 | 0,00049992 |
| **2005** | 0,00107 | 0,00036 | 0,166 | 0,030 | 0,490 | 0,1985 | 0,00030977 | 0,00041652 |
| **2006** | 0,00117 | 0,00041 | 0,157 | 0,030 | 0,443 | 0,2058 | 0,00000009 | 0,00105103 |
| **2007** | 0,00107 | 0,00044 | 0,144 | 0,034 | 0,202 | 0,2248 | 0,00016877 | 0,00049815 |
| **2008** | 0,00119 | 0,00044 | 0,144 | 0,034 | 0,202 | 0,2248 | 0,00016877 | 0,00049815 |
| **2009** | 0,00099 | 0,00041 | 0,141 | 0,033 | 0,191 | 0,2262 | 0,00021356 | 0,00045969 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 13: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00046 | 0,00013 | 0,180 | 0,022 | 0,204 | 0,1758 | 0,00031240 | 0,00017194 |
| **1997** | 0,00059 | 0,00018 | 0,160 | 0,023 | 0,124 | 0,1812 | 0,00010449 | 0,00022043 |
| **1998** | 0,00062 | 0,00019 | 0,153 | 0,023 | 0,094 | 0,1831 | 0,00006415 | 0,00023887 |
| **1999** | 0,00034 | 0,00011 | 0,193 | 0,025 | 0,377 | 0,2007 | 0,00030098 | 0,00015390 |
| **2000** | 0,00063 | 0,00019 | 0,144 | 0,023 | 0,034 | 0,1846 | 0,00000001 | 0,00166816 |
| **2001** | 0,00048 | 0,00017 | 0,157 | 0,026 | 0,051 | 0,2122 | 0,00019938 | 0,00020802 |
| **2002** | 0,00060 | 0,00018 | 0,144 | 0,022 | 0,004 | 0,1790 | 0,00000000 | 0,00359209 |
| **2003** | 0,00043 | 0,00013 | 0,170 | 0,024 | 0,247 | 0,2034 | 0,00008786 | 0,00016616 |
| **2004** | 0,00046 | 0,00015 | 0,162 | 0,026 | 0,240 | 0,2234 | 0,00005950 | 0,00018774 |
| **2005** | 0,00025 | 0,00008 | 0,203 | 0,025 | 0,519 | 0,2295 | 0,00036384 | 0,00012484 |
| **2006** | 0,00043 | 0,00013 | 0,160 | 0,023 | 0,103 | 0,2145 | 0,00008812 | 0,00016685 |
| **2007** | 0,00035 | 0,00009 | 0,186 | 0,021 | 0,385 | 0,2087 | 0,00015870 | 0,00012773 |
| **2008** | 0,00036 | 0,00009 | 0,181 | 0,020 | 0,315 | 0,1984 | 0,00013072 | 0,00012786 |
| **2009** | 0,00041 | 0,00010 | 0,175 | 0,018 | 0,335 | 0,1885 | 0,00012634 | 0,00012745 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00056 | 0,00030 | 0,191 | 0,050 | 0,427 | 0,2984 | 0,00141121 | 0,00038650 |
| **1997** | 0,00081 | 0,00042 | 0,148 | 0,045 | 0,073 | 0,2561 | 0,00101103 | 0,00048610 |
| **1998** | 0,00146 | 0,00106 | 0,106 | 0,056 | 0,008 | 0,3041 | 0,00040917 | 0,00112790 |
| **1999** | 0,00128 | 0,00089 | 0,112 | 0,054 | 0,000 | 0,2967 | 0,00039790 | 0,00095698 |
| **2000** | 0,00114 | 0,00069 | 0,116 | 0,046 | 0,000 | 0,2515 | 0,00039153 | 0,00075366 |
| **2001** | 0,00112 | 0,00070 | 0,117 | 0,049 | 0,000 | 0,4423 | 0,00027566 | 0,00075225 |
| **2002** | 0,00100 | 0,00064 | 0,119 | 0,050 | 0,000 | 0,2803 | 0,00057726 | 0,00070888 |
| **2003** | 0,00121 | 0,00059 | 0,114 | 0,038 | 0,017 | 0,2150 | 0,00026409 | 0,00064776 |
| **2004** | 0,00060 | 0,00048 | 0,143 | 0,065 | 0,037 | 0,3748 | 0,00095816 | 0,00056060 |
| **2005** | 0,00059 | 0,00041 | 0,136 | 0,054 | 0,000 | 0,3086 | 0,00094451 | 0,00049451 |
| **2006** | 0,00059 | 0,00033 | 0,147 | 0,046 | 0,016 | 0,2860 | 0,00082908 | 0,00038607 |
| **2007** | 0,00090 | 0,00053 | 0,124 | 0,045 | 0,001 | 0,2741 | 0,00066419 | 0,00059320 |
| **2008** | 0,00077 | 0,00054 | 0,132 | 0,053 | 0,000 | 0,3243 | 0,00088791 | 0,00062246 |
| **2009** | 0,00038 | 0,00018 | 0,199 | 0,041 | 0,461 | 0,2820 | 0,00123691 | 0,00025868 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 14: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00049 | 0,00011 | 0,180 | 0,019 | 0,252 | 0,1522 | 0,00000002 | 0,00073923 |
| **1997** | 0,00048 | 0,00015 | 0,162 | 0,024 | 0,056 | 0,1848 | 0,00015753 | 0,00018894 |
| **1998** | 0,00055 | 0,00016 | 0,155 | 0,021 | 0,000 | 0,1684 | 0,00000000 | 0,01152571 |
| **1999** | 0,00056 | 0,00015 | 0,165 | 0,021 | 0,220 | 0,1708 | 0,00000001 | 0,00148511 |
| **2000** | 0,00051 | 0,00013 | 0,164 | 0,020 | 0,122 | 0,1653 | 0,00000001 | 0,00159184 |
| **2001** | 0,00040 | 0,00012 | 0,177 | 0,024 | 0,320 | 0,2052 | 0,00014396 | 0,00016232 |
| **2002** | 0,00047 | 0,00013 | 0,155 | 0,020 | 0,025 | 0,1720 | 0,00000000 | 0,00205414 |
| **2003** | 0,00040 | 0,00011 | 0,172 | 0,021 | 0,280 | 0,1882 | 0,00000000 | 0,00248831 |
| **2004** | 0,00034 | 0,00015 | 0,151 | 0,033 | 0,000 | 0,2803 | 0,00006752 | 0,00019158 |
| **2005** | 0,00020 | 0,00011 | 0,156 | 0,041 | 0,000 | 0,3471 | 0,00024151 | 0,00014625 |
| **2006** | 0,00026 | 0,00013 | 0,131 | 0,034 | 0,000 | 0,2993 | 0,00004332 | 0,00015650 |
| **2007** | 0,00014 | 0,00007 | 0,172 | 0,037 | 0,274 | 0,3477 | 0,00017874 | 0,00010381 |
| **2008** | 0,00011 | 0,00006 | 0,192 | 0,042 | 0,760 | 0,4226 | 0,00032006 | 0,00009574 |
| **2009** | 0,00037 | 0,00020 | 0,113 | 0,034 | 0,099 | 0,3078 | 0,00002354 | 0,00023082 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00192 | 0,00050 | 0,152 | 0,024 | 0,202 | 0,1452 | 0,00000000 | 0,00629348 |
| **1997** | 0,00193 | 0,00055 | 0,140 | 0,025 | 0,120 | 0,1492 | 0,00000001 | 0,00464478 |
| **1998** | 0,00199 | 0,00057 | 0,140 | 0,025 | 0,132 | 0,1500 | 0,00000001 | 0,00387180 |
| **1999** | 0,00168 | 0,00061 | 0,149 | 0,032 | 0,149 | 0,1914 | 0,00019978 | 0,00068143 |
| **2000** | 0,00165 | 0,00039 | 0,161 | 0,021 | 0,245 | 0,1328 | 0,00000000 | 0,00909384 |
| **2001** | 0,00169 | 0,00044 | 0,144 | 0,023 | 0,179 | 0,1410 | 0,00000003 | 0,00208758 |
| **2002** | 0,00144 | 0,00034 | 0,159 | 0,021 | 0,261 | 0,1342 | 0,00000001 | 0,00327586 |
| **2003** | 0,00141 | 0,00041 | 0,143 | 0,024 | 0,102 | 0,1508 | 0,00000003 | 0,00202416 |
| **2004** | 0,00089 | 0,00036 | 0,153 | 0,034 | 0,094 | 0,2058 | 0,00042679 | 0,00042096 |
| **2005** | 0,00112 | 0,00040 | 0,131 | 0,029 | 0,094 | 0,1810 | 0,00002289 | 0,00044022 |
| **2006** | 0,00099 | 0,00044 | 0,133 | 0,036 | 0,121 | 0,2323 | 0,00000002 | 0,00245833 |
| **2007** | 0,00118 | 0,00054 | 0,113 | 0,035 | 0,045 | 0,2154 | 0,00000004 | 0,00217271 |
| **2008** | 0,00059 | 0,00026 | 0,161 | 0,038 | 0,357 | 0,2635 | 0,00025165 | 0,00030480 |
| **2009** | 0,00053 | 0,00024 | 0,176 | 0,038 | 0,492 | 0,2748 | 0,00043125 | 0,00028722 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 15: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00016 | 0,00006 | 0,212 | 0,033 | 0,756 | 0,2748 | 0,00021330 | 0,00009313 |
| **1997** | 0,00028 | 0,00012 | 0,162 | 0,035 | 0,340 | 0,2783 | 0,00005435 | 0,00014961 |
| **1998** | 0,00023 | 0,00011 | 0,174 | 0,037 | 0,511 | 0,3025 | 0,00014345 | 0,00014172 |
| **1999** | 0,00040 | 0,00021 | 0,123 | 0,036 | 0,043 | 0,2778 | 0,00000005 | 0,00074489 |
| **2000** | 0,00037 | 0,00014 | 0,137 | 0,027 | 0,264 | 0,2284 | 0,00000000 | 0,00365064 |
| **2001** | 0,00020 | 0,00011 | 0,169 | 0,042 | 0,457 | 0,3564 | 0,00023676 | 0,00014503 |
| **2002** | 0,00021 | 0,00012 | 0,164 | 0,044 | 0,422 | 0,3725 | 0,00017983 | 0,00015479 |
| **2003** | 0,00005 | 0,00003 | 0,259 | 0,045 | 1,151 | 0,3983 | 0,00039444 | 0,00006951 |
| **2004** | 0,00036 | 0,00021 | 0,129 | 0,040 | 0,233 | 0,3377 | 0,00000062 | 0,00023735 |
| **2005** | 0,00024 | 0,00018 | 0,138 | 0,053 | 0,239 | 0,4576 | 0,00026754 | 0,00020799 |
| **2006** | 0,00030 | 0,00016 | 0,130 | 0,038 | 0,190 | 0,3355 | 0,00011189 | 0,00019022 |
| **2007** | 0,00020 | 0,00014 | 0,137 | 0,050 | 0,000 | 0,4523 | 0,00029188 | 0,00016838 |
| **2008** | 0,00020 | 0,00010 | 0,160 | 0,039 | 0,568 | 0,3856 | 0,00013955 | 0,00013220 |
| **2009** | 0,00018 | 0,00010 | 0,158 | 0,041 | 0,483 | 0,4145 | 0,00023590 | 0,00013170 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00012 | 0,00009 | 0,248 | 0,068 | 0,725 | 0,4235 | 0,00072499 | 0,00014092 |
| **1997** | 0,00011 | 0,00009 | 0,258 | 0,080 | 0,864 | 0,4924 | 0,00078404 | 0,00015884 |
| **1998** | 0,00021 | 0,00020 | 0,186 | 0,089 | 0,503 | 0,5476 | 0,00070778 | 0,00025900 |
| **1999** | 0,00021 | 0,00027 | 0,163 | 0,111 | 0,171 | 0,6285 | 0,00070273 | 0,00033481 |
| **2000** | 0,00011 | 0,00012 | 0,234 | 0,097 | 0,696 | 0,5811 | 0,00085647 | 0,00019347 |
| **2001** | 0,00030 | 0,00033 | 0,137 | 0,090 | 0,076 | 0,5137 | 0,00050376 | 0,00037592 |
| **2002** | 0,00013 | 0,00019 | 0,169 | 0,123 | 0,127 | 0,6967 | 0,00094494 | 0,00026337 |
| **2003** | 0,00005 | 0,00006 | 0,279 | 0,099 | 0,874 | 0,5981 | 0,00081382 | 0,00012905 |
| **2004** | 0,00016 | 0,00023 | 0,155 | 0,117 | 0,102 | 0,6724 | 0,00086266 | 0,00029357 |
| **2005** | 0,00006 | 0,00007 | 0,227 | 0,092 | 0,441 | 0,5640 | 0,00107593 | 0,00013233 |
| **2006** | 0,00006 | 0,00008 | 0,243 | 0,125 | 0,671 | 0,7937 | 0,00095740 | 0,00014827 |
| **2007** | 0,00015 | 0,00015 | 0,174 | 0,086 | 0,362 | 0,5621 | 0,00090853 | 0,00020523 |
| **2008** | 0,00004 | 0,00008 | 0,206 | 0,153 | 0,275 | 0,9987 | 0,00102952 | 0,00013146 |
| **2009** | 0,00004 | 0,00006 | 0,224 | 0,125 | 0,412 | 0,8350 | 0,00126865 | 0,00012819 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 16: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00016 | 0,00012 | 0,160 | 0,056 | 0,094 | 0,4154 | 0,00035218 | 0,00015604 |
| **1997** | 0,00025 | 0,00015 | 0,143 | 0,044 | 0,145 | 0,3388 | 0,00020717 | 0,00018143 |
| **1998** | 0,00023 | 0,00016 | 0,141 | 0,051 | 0,000 | 0,3841 | 0,00034347 | 0,00019139 |
| **1999** | 0,00006 | 0,00003 | 0,255 | 0,045 | 1,045 | 0,3842 | 0,00033046 | 0,00006916 |
| **2000** | 0,00021 | 0,00014 | 0,137 | 0,050 | 0,000 | 0,3897 | 0,00025230 | 0,00017046 |
| **2001** | 0,00014 | 0,00008 | 0,183 | 0,046 | 0,582 | 0,3907 | 0,00032102 | 0,00012262 |
| **2002** | 0,00009 | 0,00006 | 0,212 | 0,048 | 0,677 | 0,4088 | 0,00038285 | 0,00009678 |
| **2003** | 0,00028 | 0,00019 | 0,127 | 0,049 | 0,000 | 0,3851 | 0,00015879 | 0,00022675 |
| **2004** | 0,00019 | 0,00014 | 0,139 | 0,053 | 0,000 | 0,4400 | 0,00030963 | 0,00017006 |
| **2005** | 0,00017 | 0,00014 | 0,141 | 0,059 | 0,000 | 0,4981 | 0,00027595 | 0,00017073 |
| **2006** | 0,00013 | 0,00010 | 0,159 | 0,055 | 0,107 | 0,4963 | 0,00036752 | 0,00012864 |
| **2007** | 0,00003 | 0,00004 | 0,253 | 0,087 | 1,024 | 0,8243 | 0,00047862 | 0,00008283 |
| **2008** | 0,00016 | 0,00011 | 0,145 | 0,051 | 0,084 | 0,4881 | 0,00028629 | 0,00013633 |
| **2009** | 0,00004 | 0,00002 | 0,258 | 0,045 | 1,314 | 0,4764 | 0,00044239 | 0,00005778 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00000 | 0,00000 | 0,532 | 0,066 | 2,098 | 0,4136 | 0,00178794 | 0,00009312 |
| **1997** | 0,00024 | 0,00030 | 0,150 | 0,107 | 0,000 | 0,5881 | 0,00154010 | 0,00037615 |
| **1998** | 0,00014 | 0,00012 | 0,255 | 0,081 | 0,783 | 0,4907 | 0,00155233 | 0,00020469 |
| **1999** | 0,00009 | 0,00012 | 0,237 | 0,110 | 0,537 | 0,6395 | 0,00153778 | 0,00020420 |
| **2000** | 0,00014 | 0,00016 | 0,199 | 0,097 | 0,286 | 0,5567 | 0,00147474 | 0,00024044 |
| **2001** | 0,00038 | 0,00051 | 0,126 | 0,105 | 0,000 | 0,5630 | 0,00119191 | 0,00059529 |
| **2002** | 0,00016 | 0,00021 | 0,179 | 0,111 | 0,186 | 0,6345 | 0,00159978 | 0,00029998 |
| **2003** | 0,00004 | 0,00004 | 0,317 | 0,089 | 1,019 | 0,5356 | 0,00159490 | 0,00013373 |
| **2004** | 0,00020 | 0,00029 | 0,150 | 0,114 | 0,000 | 0,6320 | 0,00163116 | 0,00037332 |
| **2005** | 0,00011 | 0,00010 | 0,230 | 0,081 | 0,546 | 0,4942 | 0,00158741 | 0,00018691 |
| **2006** | 0,00000 | 0,00000 | 0,533 | 0,049 | 2,414 | 0,3713 | 0,00191723 | 0,00008675 |
| **2007** | 0,00011 | 0,00013 | 0,187 | 0,095 | 0,161 | 0,5934 | 0,00162058 | 0,00019724 |
| **2008** | 0,00014 | 0,00016 | 0,186 | 0,092 | 0,215 | 0,5926 | 0,00144383 | 0,00022459 |
| **2009** | 0,00007 | 0,00006 | 0,273 | 0,074 | 0,933 | 0,5103 | 0,00144386 | 0,00013532 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 17: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in Finland**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00101 | 0,00021 | 0,172 | 0,016 | 0,227 | 0,1305 | 0,00024723 | 0,00026261 |
| **1997** | 0,00100 | 0,00019 | 0,178 | 0,015 | 0,301 | 0,1226 | 0,00023950 | 0,00024476 |
| **1998** | 0,00110 | 0,00021 | 0,165 | 0,015 | 0,168 | 0,1210 | 0,00000005 | 0,00080013 |
| **1999** | 0,00116 | 0,00022 | 0,165 | 0,015 | 0,230 | 0,1218 | 0,00000001 | 0,00173407 |
| **2000** | 0,00103 | 0,00020 | 0,170 | 0,015 | 0,219 | 0,1260 | 0,00004948 | 0,00024649 |
| **2001** | 0,00102 | 0,00017 | 0,169 | 0,013 | 0,202 | 0,1126 | 0,00000000 | 0,00675175 |
| **2002** | 0,00113 | 0,00021 | 0,168 | 0,015 | 0,204 | 0,1238 | 0,00000007 | 0,00068899 |
| **2003** | 0,00122 | 0,00022 | 0,156 | 0,014 | 0,061 | 0,1186 | 0,00000004 | 0,00093358 |
| **2004** | 0,00100 | 0,00018 | 0,168 | 0,014 | 0,185 | 0,1248 | 0,00000001 | 0,00133997 |
| **2005** | 0,00076 | 0,00014 | 0,189 | 0,015 | 0,389 | 0,1363 | 0,00025667 | 0,00019192 |
| **2006** | 0,00101 | 0,00016 | 0,168 | 0,012 | 0,185 | 0,1138 | 0,00000002 | 0,00097220 |
| **2007** | 0,00096 | 0,00016 | 0,172 | 0,013 | 0,202 | 0,1274 | 0,00000004 | 0,00070655 |
| **2008** | 0,00105 | 0,00016 | 0,164 | 0,012 | 0,111 | 0,1166 | 0,00000001 | 0,00133118 |
| **2009** | 0,00099 | 0,00014 | 0,172 | 0,010 | 0,205 | 0,1099 | 0,00000004 | 0,00063820 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00142 | 0,00059 | 0,145 | 0,037 | 0,075 | 0,2168 | 0,00046384 | 0,00065842 |
| **1997** | 0,00099 | 0,00033 | 0,192 | 0,031 | 0,437 | 0,1929 | 0,00084215 | 0,00040201 |
| **1998** | 0,00135 | 0,00049 | 0,164 | 0,034 | 0,228 | 0,2050 | 0,00028934 | 0,00054489 |
| **1999** | 0,00166 | 0,00060 | 0,145 | 0,032 | 0,125 | 0,1876 | 0,00016870 | 0,00067162 |
| **2000** | 0,00081 | 0,00026 | 0,208 | 0,030 | 0,496 | 0,1890 | 0,00081657 | 0,00033987 |
| **2001** | 0,00058 | 0,00018 | 0,239 | 0,029 | 0,674 | 0,1826 | 0,00135505 | 0,00027172 |
| **2002** | 0,00110 | 0,00032 | 0,187 | 0,027 | 0,364 | 0,1703 | 0,00079491 | 0,00039697 |
| **2003** | 0,00114 | 0,00033 | 0,178 | 0,026 | 0,295 | 0,1643 | 0,00045913 | 0,00040072 |
| **2004** | 0,00115 | 0,00034 | 0,170 | 0,026 | 0,232 | 0,1647 | 0,00054826 | 0,00040695 |
| **2005** | 0,00130 | 0,00036 | 0,167 | 0,024 | 0,240 | 0,1552 | 0,00055468 | 0,00042687 |
| **2006** | 0,00170 | 0,00051 | 0,142 | 0,025 | 0,049 | 0,1599 | 0,00000008 | 0,00143173 |
| **2007** | 0,00119 | 0,00031 | 0,180 | 0,023 | 0,340 | 0,1559 | 0,00053069 | 0,00037479 |
| **2008** | 0,00148 | 0,00040 | 0,160 | 0,023 | 0,196 | 0,1577 | 0,00008606 | 0,00046481 |
| **2009** | 0,00087 | 0,00021 | 0,209 | 0,022 | 0,534 | 0,1566 | 0,00080556 | 0,00028496 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 18: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00747 | 0,00018 | 0,128 | 0,002 | 0,003 | 0,0195 | 0,00070134 | 0,00021242 |
| **2001** | 0,00707 | 0,00016 | 0,129 | 0,002 | 0,000 | 0,0192 | 0,00096048 | 0,00019648 |
| **2002** | 0,00708 | 0,00016 | 0,129 | 0,002 | 0,000 | 0,0191 | 0,00078990 | 0,00019278 |
| **2003** | 0,00691 | 0,00014 | 0,132 | 0,001 | 0,000 | 0,0180 | 0,00093440 | 0,00017599 |
| **2004** | 0,00625 | 0,00014 | 0,130 | 0,002 | 0,000 | 0,0188 | 0,00102167 | 0,00017026 |
| **2005** | 0,00589 | 0,00011 | 0,134 | 0,001 | 0,000 | 0,0168 | 0,00140542 | 0,00014819 |
| **2006** | 0,00550 | 0,00010 | 0,134 | 0,001 | 0,000 | 0,0164 | 0,00164684 | 0,00013747 |
| **2007** | 0,00508 | 0,00009 | 0,137 | 0,001 | 0,000 | 0,0165 | 0,00210556 | 0,00013044 |
| **2008** | 0,00518 | 0,00008 | 0,136 | 0,001 | 0,000 | 0,0161 | 0,00186926 | 0,00012375 |
| **2009** | 0,00518 | 0,00008 | 0,136 | 0,001 | 0,000 | 0,0159 | 0,00164954 | 0,00011976 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,01199 | 0,00053 | 0,131 | 0,003 | 0,148 | 0,0232 | 0,00963124 | 0,00060303 |
| **2001** | 0,01207 | 0,00055 | 0,130 | 0,004 | 0,136 | 0,0237 | 0,00866848 | 0,00061879 |
| **2002** | 0,01235 | 0,00059 | 0,126 | 0,004 | 0,101 | 0,0248 | 0,00782392 | 0,00066665 |
| **2003** | 0,01241 | 0,00059 | 0,128 | 0,004 | 0,111 | 0,0255 | 0,00718608 | 0,00066656 |
| **2004** | 0,01287 | 0,00066 | 0,120 | 0,004 | 0,087 | 0,0265 | 0,00514006 | 0,00072273 |
| **2005** | 0,01385 | 0,00068 | 0,112 | 0,004 | 0,000 | 0,0247 | 0,00417267 | 0,00074675 |
| **2006** | 0,01283 | 0,00063 | 0,113 | 0,004 | 0,000 | 0,0252 | 0,00435097 | 0,00068920 |
| **2007** | 0,01214 | 0,00055 | 0,115 | 0,003 | 0,000 | 0,0242 | 0,00462099 | 0,00060548 |
| **2008** | 0,01211 | 0,00055 | 0,116 | 0,003 | 0,006 | 0,0247 | 0,00408154 | 0,00060484 |
| **2009** | 0,00902 | 0,00037 | 0,136 | 0,003 | 0,162 | 0,0253 | 0,00698778 | 0,00043031 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 19: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00401 | 0,00043 | 0,069 | 0,006 | 0,175 | 0,0529 | 0,00000002 | 0,00200979 |
| **2001** | 0,00409 | 0,00040 | 0,066 | 0,005 | 0,113 | 0,0461 | 0,00000002 | 0,00208661 |
| **2002** | 0,00397 | 0,00037 | 0,070 | 0,005 | 0,200 | 0,0485 | 0,00000044 | 0,00041404 |
| **2003** | 0,00396 | 0,00035 | 0,068 | 0,004 | 0,136 | 0,0444 | 0,00000178 | 0,00036240 |
| **2004** | 0,00385 | 0,00033 | 0,069 | 0,004 | 0,162 | 0,0448 | 0,00000006 | 0,00098884 |
| **2005** | 0,00385 | 0,00029 | 0,068 | 0,004 | 0,146 | 0,0408 | 0,00004543 | 0,00031172 |
| **2006** | 0,00386 | 0,00026 | 0,065 | 0,003 | 0,087 | 0,0367 | 0,00002290 | 0,00027857 |
| **2007** | 0,00379 | 0,00026 | 0,067 | 0,003 | 0,150 | 0,0405 | 0,00000001 | 0,00167520 |
| **2008** | 0,00393 | 0,00027 | 0,064 | 0,003 | 0,109 | 0,0397 | 0,00000005 | 0,00087090 |
| **2009** | 0,00381 | 0,00023 | 0,065 | 0,003 | 0,085 | 0,0393 | 0,00000276 | 0,00025048 |

| Males | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\widehat{a}(y)$ | s.e.$\widehat{a}(y)$ | $\widehat{b}(y)$ | s.e.$\widehat{b}(y)$ | $\widehat{\gamma}(y)$ | s.e.$\widehat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00995 | 0,00792 | 0,063 | 0,041 | 0,083 | 0,2152 | 0,00001519 | 0,00806628 |
| **2001** | 0,00954 | 0,00202 | 0,067 | 0,011 | 0,125 | 0,0636 | 0,00017309 | 0,00206348 |
| **2002** | 0,00949 | 0,00181 | 0,064 | 0,010 | 0,078 | 0,0537 | 0,00022940 | 0,00184822 |
| **2003** | 0,00917 | 0,00133 | 0,069 | 0,008 | 0,128 | 0,0463 | 0,00000031 | 0,00174819 |
| **2004** | 0,00879 | 0,00569 | 0,072 | 0,036 | 0,160 | 0,2084 | 0,00000396 | 0,00584371 |
| **2005** | 0,00883 | 0,00103 | 0,069 | 0,006 | 0,123 | 0,0385 | 0,00000000 | 0,01106944 |
| **2006** | 0,00859 | 0,00111 | 0,069 | 0,007 | 0,127 | 0,0435 | 0,00002921 | 0,00114801 |
| **2007** | 0,00840 | 0,00114 | 0,069 | 0,007 | 0,111 | 0,0475 | 0,00003606 | 0,00117500 |
| **2008** | 0,00807 | 0,00108 | 0,073 | 0,007 | 0,174 | 0,0511 | 0,00000015 | 0,00206570 |
| **2009** | 0,00768 | 0,00106 | 0,075 | 0,008 | 0,177 | 0,0544 | 0,00031323 | 0,00109135 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 20: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00053 | 0,00003 | 0,156 | 0,005 | 0,482 | 0,0580 | 0,00000000 | 0,00116172 |
| **2001** | 0,00051 | 0,00003 | 0,153 | 0,004 | 0,403 | 0,0561 | 0,00000000 | 0,00050981 |
| **2002** | 0,00048 | 0,00003 | 0,151 | 0,004 | 0,308 | 0,0550 | 0,00000000 | 0,00150121 |
| **2003** | 0,00046 | 0,00002 | 0,148 | 0,004 | 0,194 | 0,0545 | 0,00000000 | 0,00062926 |
| **2004** | 0,00041 | 0,00002 | 0,149 | 0,004 | 0,240 | 0,0564 | 0,00000000 | 0,00067828 |
| **2005** | 0,00041 | 0,00002 | 0,141 | 0,004 | 0,025 | 0,0511 | 0,00000000 | 0,00059266 |
| **2006** | 0,00038 | 0,00002 | 0,140 | 0,003 | 0,000 | 0,0514 | 0,00000000 | 0,00055835 |
| **2007** | 0,00035 | 0,00002 | 0,142 | 0,003 | 0,000 | 0,0531 | 0,00000000 | 0,00062167 |
| **2008** | 0,00034 | 0,00002 | 0,142 | 0,003 | 0,000 | 0,0551 | 0,00000000 | 0,00061457 |
| **2009** | 0,00030 | 0,00001 | 0,147 | 0,003 | 0,069 | 0,0559 | 0,00000000 | 0,00043880 |
| **Males** | | | | | | | | |
| **Year** | $\widehat{a}(y)$ | s.e.$\widehat{a}(y)$ | $\widehat{b}(y)$ | s.e.$\widehat{b}(y)$ | $\widehat{\gamma}(y)$ | s.e.$\widehat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00166 | 0,00021 | 0,129 | 0,010 | 0,304 | 0,0685 | 0,00038148 | 0,00023158 |
| **2001** | 0,00153 | 0,00021 | 0,132 | 0,011 | 0,318 | 0,0741 | 0,00032669 | 0,00023132 |
| **2002** | 0,00143 | 0,00018 | 0,133 | 0,010 | 0,313 | 0,0695 | 0,00033574 | 0,00020061 |
| **2003** | 0,00163 | 0,00024 | 0,119 | 0,011 | 0,199 | 0,0775 | 0,00003769 | 0,00026078 |
| **2004** | 0,00126 | 0,00016 | 0,135 | 0,010 | 0,307 | 0,0744 | 0,00029444 | 0,00018104 |
| **2005** | 0,00144 | 0,00021 | 0,118 | 0,011 | 0,161 | 0,0762 | 0,00003605 | 0,00022348 |
| **2006** | 0,00103 | 0,00013 | 0,137 | 0,010 | 0,264 | 0,0743 | 0,00032515 | 0,00014361 |
| **2007** | 0,00094 | 0,00012 | 0,138 | 0,010 | 0,252 | 0,0789 | 0,00037635 | 0,00013731 |
| **2008** | 0,00097 | 0,00012 | 0,134 | 0,010 | 0,229 | 0,0779 | 0,00023323 | 0,00013826 |
| **2009** | 0,00093 | 0,00013 | 0,131 | 0,011 | 0,193 | 0,0908 | 0,00018693 | 0,00014998 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 21: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00052 | 0,00003 | 0,167 | 0,004 | 0,566 | 0,0526 | 0,00000000 | 0,00076115 |
| **2001** | 0,00050 | 0,00002 | 0,164 | 0,004 | 0,515 | 0,0517 | 0,00000000 | 0,00158793 |
| **2002** | 0,00049 | 0,00002 | 0,157 | 0,004 | 0,395 | 0,0520 | 0,00000000 | 0,00056283 |
| **2003** | 0,00049 | 0,00002 | 0,158 | 0,004 | 0,422 | 0,0511 | 0,00000000 | 0,00244776 |
| **2004** | 0,00046 | 0,00002 | 0,147 | 0,003 | 0,192 | 0,0485 | 0,00000000 | 0,00059179 |
| **2005** | 0,00045 | 0,00002 | 0,147 | 0,003 | 0,202 | 0,0482 | 0,00000000 | 0,00064959 |
| **2006** | 0,00044 | 0,00002 | 0,139 | 0,003 | 0,062 | 0,0477 | 0,00000000 | 0,00033267 |
| **2007** | 0,00042 | 0,00002 | 0,139 | 0,003 | 0,038 | 0,0496 | 0,00000000 | 0,00053441 |
| **2008** | 0,00042 | 0,00002 | 0,138 | 0,003 | 0,003 | 0,0501 | 0,00000000 | 0,00180081 |
| **2009** | 0,00040 | 0,00002 | 0,142 | 0,003 | 0,113 | 0,0514 | 0,00000000 | 0,00040110 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2000** | 0,00092 | 0,00011 | 0,153 | 0,010 | 0,361 | 0,0713 | 0,00003176 | 0,00012211 |
| **2001** | 0,00071 | 0,00008 | 0,170 | 0,010 | 0,470 | 0,0712 | 0,00023335 | 0,00009472 |
| **2002** | 0,00087 | 0,00009 | 0,148 | 0,009 | 0,329 | 0,0654 | 0,00000003 | 0,00046366 |
| **2003** | 0,00068 | 0,00008 | 0,173 | 0,010 | 0,541 | 0,0755 | 0,00017193 | 0,00009298 |
| **2004** | 0,00068 | 0,00009 | 0,157 | 0,011 | 0,404 | 0,0816 | 0,00008070 | 0,00010073 |
| **2005** | 0,00058 | 0,00007 | 0,167 | 0,011 | 0,450 | 0,0815 | 0,00016842 | 0,00008602 |
| **2006** | 0,00066 | 0,00008 | 0,150 | 0,010 | 0,335 | 0,0773 | 0,00000000 | 0,00234448 |
| **2007** | 0,00063 | 0,00008 | 0,148 | 0,010 | 0,300 | 0,0819 | 0,00000002 | 0,00049061 |
| **2008** | 0,00061 | 0,00007 | 0,149 | 0,010 | 0,342 | 0,0793 | 0,00000001 | 0,00077741 |
| **2009** | 0,00058 | 0,00007 | 0,148 | 0,010 | 0,305 | 0,0836 | 0,00000004 | 0,00026962 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 22: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00081 | 0,00003 | 0,166 | 0,003 | 0,196 | 0,0381 | 0,00000001 | 0,00031636 |
| **2001** | 0,00085 | 0,00003 | 0,157 | 0,003 | 0,044 | 0,0367 | 0,00000001 | 0,00038631 |
| **2002** | 0,00080 | 0,00003 | 0,159 | 0,003 | 0,059 | 0,0362 | 0,00000001 | 0,00029660 |
| **2003** | 0,00078 | 0,00003 | 0,161 | 0,003 | 0,058 | 0,0354 | 0,00000001 | 0,00029313 |
| **2004** | 0,00072 | 0,00003 | 0,158 | 0,003 | 0,037 | 0,0366 | 0,00000000 | 0,00076051 |
| **2005** | 0,00069 | 0,00002 | 0,159 | 0,002 | 0,000 | 0,0337 | 0,00000002 | 0,00019708 |
| **2006** | 0,00064 | 0,00002 | 0,161 | 0,002 | 0,000 | 0,0334 | 0,00002332 | 0,00003336 |
| **2007** | 0,00061 | 0,00002 | 0,162 | 0,002 | 0,000 | 0,0330 | 0,00000000 | 0,00115242 |
| **2008** | 0,00060 | 0,00002 | 0,163 | 0,002 | 0,000 | 0,0326 | 0,00000063 | 0,00002972 |
| **2009** | 0,00058 | 0,00002 | 0,163 | 0,002 | 0,000 | 0,0324 | 0,00000000 | 0,00069309 |

| Males | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2000** | 0,00157 | 0,00014 | 0,150 | 0,007 | 0,152 | 0,0509 | 0,00055500 | 0,00016117 |
| **2001** | 0,00132 | 0,00012 | 0,159 | 0,008 | 0,193 | 0,0528 | 0,00072400 | 0,00014169 |
| **2002** | 0,00123 | 0,00011 | 0,165 | 0,007 | 0,231 | 0,0528 | 0,00067536 | 0,00013074 |
| **2003** | 0,00114 | 0,00010 | 0,172 | 0,008 | 0,289 | 0,0552 | 0,00073426 | 0,00012358 |
| **2004** | 0,00138 | 0,00013 | 0,149 | 0,008 | 0,137 | 0,0572 | 0,00029340 | 0,00014913 |
| **2005** | 0,00155 | 0,00015 | 0,135 | 0,008 | 0,000 | 0,0546 | 0,00006366 | 0,00016343 |
| **2006** | 0,00120 | 0,00011 | 0,151 | 0,007 | 0,103 | 0,0555 | 0,00034825 | 0,00012516 |
| **2007** | 0,00130 | 0,00011 | 0,141 | 0,007 | 0,000 | 0,0545 | 0,00015376 | 0,00013278 |
| **2008** | 0,00118 | 0,00010 | 0,146 | 0,007 | 0,009 | 0,0547 | 0,00020645 | 0,00011730 |
| **2009** | 0,00071 | 0,00006 | 0,188 | 0,007 | 0,372 | 0,0567 | 0,00071539 | 0,00007549 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 23: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00034 | 0,00002 | 0,155 | 0,005 | 0,000 | 0,0639 | 0,00000002 | 0,00015892 |
| **2001** | 0,00028 | 0,00002 | 0,157 | 0,006 | 0,025 | 0,0686 | 0,00000001 | 0,00022633 |
| **2002** | 0,00029 | 0,00002 | 0,159 | 0,005 | 0,052 | 0,0620 | 0,00000000 | 0,00027683 |
| **2003** | 0,00031 | 0,00002 | 0,157 | 0,005 | 0,006 | 0,0601 | 0,00000001 | 0,00016709 |
| **2004** | 0,00026 | 0,00002 | 0,154 | 0,005 | 0,000 | 0,0714 | 0,00000002 | 0,00011959 |
| **2005** | 0,00027 | 0,00002 | 0,160 | 0,004 | 0,000 | 0,0555 | 0,00000001 | 0,00018315 |
| **2006** | 0,00023 | 0,00001 | 0,157 | 0,004 | 0,000 | 0,0589 | 0,00001584 | 0,00002091 |
| **2007** | 0,00025 | 0,00001 | 0,154 | 0,004 | 0,000 | 0,0570 | 0,00000003 | 0,00008816 |
| **2008** | 0,00025 | 0,00001 | 0,154 | 0,004 | 0,000 | 0,0572 | 0,00000001 | 0,00017465 |
| **2009** | 0,00025 | 0,00001 | 0,156 | 0,003 | 0,000 | 0,0551 | 0,00000000 | 0,00024022 |
| **Males** | | | | | | | | |
| **Year** | $\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2000** | 0,00084 | 0,00010 | 0,150 | 0,010 | 0,096 | 0,0673 | 0,00028466 | 0,00011548 |
| **2001** | 0,00094 | 0,00012 | 0,134 | 0,010 | 0,010 | 0,0705 | 0,00003062 | 0,00013488 |
| **2002** | 0,00089 | 0,00010 | 0,142 | 0,009 | 0,075 | 0,0639 | 0,00000398 | 0,00011263 |
| **2003** | 0,00092 | 0,00011 | 0,140 | 0,010 | 0,017 | 0,0712 | 0,00000819 | 0,00012709 |
| **2004** | 0,00075 | 0,00010 | 0,147 | 0,011 | 0,124 | 0,0779 | 0,00002426 | 0,00011092 |
| **2005** | 0,00087 | 0,00010 | 0,137 | 0,009 | 0,000 | 0,0686 | 0,00000006 | 0,00033604 |
| **2006** | 0,00076 | 0,00008 | 0,136 | 0,008 | 0,000 | 0,0638 | 0,00000001 | 0,00063962 |
| **2007** | 0,00076 | 0,00008 | 0,137 | 0,009 | 0,004 | 0,0665 | 0,00000004 | 0,00032824 |
| **2008** | 0,00073 | 0,00008 | 0,140 | 0,009 | 0,036 | 0,0709 | 0,00000030 | 0,00012100 |
| **2009** | 0,00072 | 0,00008 | 0,140 | 0,009 | 0,018 | 0,0717 | 0,00000001 | 0,00072643 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 24: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00028 | 0,00004 | 0,128 | 0,009 | 0,000 | 0,1042 | 0,00013912 | 0,00004403 |
| **2001** | 0,00026 | 0,00003 | 0,130 | 0,008 | 0,000 | 0,0984 | 0,00013270 | 0,00003797 |
| **2002** | 0,00031 | 0,00004 | 0,123 | 0,008 | 0,000 | 0,0996 | 0,00009801 | 0,00004409 |
| **2003** | 0,00028 | 0,00003 | 0,127 | 0,008 | 0,000 | 0,0988 | 0,00013658 | 0,00004049 |
| **2004** | 0,00028 | 0,00003 | 0,123 | 0,008 | 0,000 | 0,1004 | 0,00008346 | 0,00004075 |
| **2005** | 0,00027 | 0,00003 | 0,124 | 0,007 | 0,000 | 0,0866 | 0,00006564 | 0,00003606 |
| **2006** | 0,00025 | 0,00002 | 0,126 | 0,006 | 0,000 | 0,0842 | 0,00008405 | 0,00003217 |
| **2007** | 0,00024 | 0,00002 | 0,126 | 0,006 | 0,000 | 0,1060 | 0,00011576 | 0,00003181 |
| **2008** | 0,00027 | 0,00003 | 0,123 | 0,006 | 0,000 | 0,0862 | 0,00004408 | 0,00003280 |
| **2009** | 0,00028 | 0,00002 | 0,120 | 0,005 | 0,000 | 0,0832 | 0,00004417 | 0,00003176 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00019 | 0,00005 | 0,178 | 0,023 | 0,380 | 0,1541 | 0,00100588 | 0,00007056 |
| **2001** | 0,00020 | 0,00006 | 0,172 | 0,025 | 0,352 | 0,1695 | 0,00098813 | 0,00008340 |
| **2002** | 0,00025 | 0,00008 | 0,152 | 0,025 | 0,206 | 0,1689 | 0,00083523 | 0,00009732 |
| **2003** | 0,00024 | 0,00007 | 0,150 | 0,022 | 0,139 | 0,1532 | 0,00090958 | 0,00008208 |
| **2004** | 0,00044 | 0,00015 | 0,111 | 0,025 | 0,000 | 0,1672 | 0,00054571 | 0,00016759 |
| **2005** | 0,00030 | 0,00009 | 0,137 | 0,023 | 0,138 | 0,1605 | 0,00070284 | 0,00010355 |
| **2006** | 0,00034 | 0,00011 | 0,122 | 0,023 | 0,000 | 0,1629 | 0,00058625 | 0,00012225 |
| **2007** | 0,00052 | 0,00017 | 0,102 | 0,022 | 0,000 | 0,1542 | 0,00032313 | 0,00018546 |
| **2008** | 0,00038 | 0,00010 | 0,121 | 0,020 | 0,066 | 0,1481 | 0,00049782 | 0,00011588 |
| **2009** | 0,00037 | 0,00010 | 0,120 | 0,020 | 0,056 | 0,1501 | 0,00045487 | 0,00011341 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 25: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00028 | 0,00003 | 0,142 | 0,007 | 0,007 | 0,0866 | 0,00015735 | 0,00003692 |
| **2001** | 0,00028 | 0,00003 | 0,141 | 0,007 | 0,000 | 0,0847 | 0,00012469 | 0,00003508 |
| **2002** | 0,00025 | 0,00002 | 0,146 | 0,007 | 0,000 | 0,0826 | 0,00017037 | 0,00003113 |
| **2003** | 0,00029 | 0,00002 | 0,144 | 0,006 | 0,000 | 0,0768 | 0,00011745 | 0,00003187 |
| **2004** | 0,00024 | 0,00002 | 0,141 | 0,007 | 0,000 | 0,0856 | 0,00010934 | 0,00003016 |
| **2005** | 0,00021 | 0,00002 | 0,148 | 0,006 | 0,000 | 0,0769 | 0,00017174 | 0,00002550 |
| **2006** | 0,00019 | 0,00002 | 0,147 | 0,006 | 0,000 | 0,0760 | 0,00018698 | 0,00002465 |
| **2007** | 0,00019 | 0,00001 | 0,146 | 0,005 | 0,000 | 0,0748 | 0,00015922 | 0,00002350 |
| **2008** | 0,00019 | 0,00001 | 0,147 | 0,005 | 0,000 | 0,0740 | 0,00015295 | 0,00002238 |
| **2009** | 0,00020 | 0,00001 | 0,143 | 0,005 | 0,000 | 0,0728 | 0,00013540 | 0,00002273 |

| Males | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2000** | 0,00034 | 0,00006 | 0,161 | 0,016 | 0,187 | 0,1069 | 0,00076780 | 0,00008279 |
| **2001** | 0,00024 | 0,00005 | 0,184 | 0,017 | 0,323 | 0,1207 | 0,00082128 | 0,00006753 |
| **2002** | 0,00029 | 0,00006 | 0,168 | 0,017 | 0,209 | 0,1192 | 0,00073590 | 0,00007898 |
| **2003** | 0,00039 | 0,00008 | 0,148 | 0,017 | 0,082 | 0,1188 | 0,00064068 | 0,00009837 |
| **2004** | 0,00044 | 0,00010 | 0,130 | 0,019 | 0,000 | 0,1282 | 0,00048749 | 0,00011975 |
| **2005** | 0,00039 | 0,00008 | 0,144 | 0,016 | 0,104 | 0,1136 | 0,00054098 | 0,00009154 |
| **2006** | 0,00037 | 0,00008 | 0,136 | 0,017 | 0,000 | 0,1208 | 0,00056613 | 0,00009433 |
| **2007** | 0,00039 | 0,00008 | 0,134 | 0,016 | 0,000 | 0,1173 | 0,00046428 | 0,00009396 |
| **2008** | 0,00035 | 0,00007 | 0,143 | 0,015 | 0,079 | 0,1161 | 0,00052893 | 0,00008342 |
| **2009** | 0,00027 | 0,00005 | 0,167 | 0,014 | 0,274 | 0,1145 | 0,00057304 | 0,00006184 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 26: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in France**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **2000** | 0,00142 | 0,00006 | 0,148 | 0,003 | 0,035 | 0,0347 | 0,00005406 | 0,00007018 |
| **2001** | 0,00135 | 0,00005 | 0,152 | 0,003 | 0,063 | 0,0337 | 0,00006688 | 0,00006424 |
| **2002** | 0,00141 | 0,00005 | 0,151 | 0,003 | 0,050 | 0,0326 | 0,00003526 | 0,00006410 |
| **2003** | 0,00152 | 0,00005 | 0,151 | 0,002 | 0,047 | 0,0298 | 0,00000001 | 0,00036801 |
| **2004** | 0,00123 | 0,00004 | 0,151 | 0,002 | 0,041 | 0,0324 | 0,00005182 | 0,00005609 |
| **2005** | 0,00128 | 0,00004 | 0,150 | 0,002 | 0,000 | 0,0289 | 0,00001926 | 0,00005378 |
| **2006** | 0,00119 | 0,00003 | 0,151 | 0,002 | 0,000 | 0,0280 | 0,00007012 | 0,00005018 |
| **2007** | 0,00116 | 0,00003 | 0,153 | 0,002 | 0,000 | 0,0273 | 0,00003573 | 0,00004711 |
| **2008** | 0,00115 | 0,00003 | 0,155 | 0,002 | 0,000 | 0,0268 | 0,00011309 | 0,00004561 |
| **2009** | 0,00116 | 0,00003 | 0,154 | 0,002 | 0,000 | 0,0262 | 0,00007565 | 0,00004377 |
| **Males** | | | | | | | | |
| **Year** | $\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{a}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{b}}(\boldsymbol{y})$ | $\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\widehat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **2000** | 0,00119 | 0,00009 | 0,187 | 0,006 | 0,375 | 0,0447 | 0,00189770 | 0,00011822 |
| **2001** | 0,00161 | 0,00013 | 0,163 | 0,007 | 0,215 | 0,0462 | 0,00130290 | 0,00015417 |
| **2002** | 0,00158 | 0,00012 | 0,164 | 0,007 | 0,215 | 0,0472 | 0,00132320 | 0,00015328 |
| **2003** | 0,00143 | 0,00011 | 0,179 | 0,007 | 0,318 | 0,0476 | 0,00152906 | 0,00013764 |
| **2004** | 0,00147 | 0,00012 | 0,166 | 0,007 | 0,251 | 0,0521 | 0,00111307 | 0,00015028 |
| **2005** | 0,00152 | 0,00012 | 0,162 | 0,006 | 0,191 | 0,0475 | 0,00116753 | 0,00014243 |
| **2006** | 0,00172 | 0,00013 | 0,147 | 0,006 | 0,092 | 0,0465 | 0,00075524 | 0,00015342 |
| **2007** | 0,00154 | 0,00011 | 0,155 | 0,006 | 0,142 | 0,0462 | 0,00095672 | 0,00013496 |
| **2008** | 0,00170 | 0,00011 | 0,151 | 0,005 | 0,106 | 0,0423 | 0,00074451 | 0,00013330 |
| **2009** | 0,00124 | 0,00008 | 0,177 | 0,005 | 0,315 | 0,0461 | 0,00121650 | 0,00010631 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 27: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00944 | 0,00057 | 0,134 | 0,004 | 0,152 | 0,0416 | 0,00332719 | 0,00067055 |
| **1997** | 0,00969 | 0,00060 | 0,131 | 0,005 | 0,127 | 0,0429 | 0,00241294 | 0,00069633 |
| **1998** | 0,00904 | 0,00054 | 0,135 | 0,004 | 0,159 | 0,0425 | 0,00302259 | 0,00063621 |
| **1999** | 0,01025 | 0,00061 | 0,127 | 0,004 | 0,069 | 0,0399 | 0,00183904 | 0,00070251 |
| **2000** | 0,00975 | 0,00057 | 0,131 | 0,004 | 0,134 | 0,0409 | 0,00205020 | 0,00066431 |
| **2001** | 0,01061 | 0,00063 | 0,124 | 0,004 | 0,057 | 0,0412 | 0,00091658 | 0,00072047 |
| **2002** | 0,01135 | 0,00066 | 0,119 | 0,004 | 0,000 | 0,0395 | 0,00001168 | 0,00074408 |
| **2003** | 0,00939 | 0,00054 | 0,130 | 0,004 | 0,080 | 0,0407 | 0,00182153 | 0,00062902 |
| **2004** | 0,00977 | 0,00056 | 0,124 | 0,004 | 0,039 | 0,0401 | 0,00082191 | 0,00064552 |
| **2005** | 0,01000 | 0,00056 | 0,121 | 0,004 | 0,004 | 0,0392 | 0,00000015 | 0,00117763 |
| **2006** | 0,00925 | 0,00051 | 0,125 | 0,004 | 0,022 | 0,0398 | 0,00052871 | 0,00058130 |
| **2007** | 0,00862 | 0,00047 | 0,125 | 0,004 | 0,028 | 0,0400 | 0,00102452 | 0,00053893 |
| **2008** | 0,00843 | 0,00045 | 0,126 | 0,004 | 0,004 | 0,0399 | 0,00103496 | 0,00051835 |
| **2009** | 0,00746 | 0,00038 | 0,133 | 0,004 | 0,078 | 0,0411 | 0,00165147 | 0,00045476 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,02577 | 0,00225 | 0,110 | 0,007 | 0,154 | 0,0421 | 0,00008105 | 0,00237503 |
| **1997** | 0,02295 | 0,00228 | 0,115 | 0,008 | 0,169 | 0,0480 | 0,00203371 | 0,00241523 |
| **1998** | 0,02194 | 0,00224 | 0,115 | 0,008 | 0,143 | 0,0492 | 0,00305978 | 0,00237056 |
| **1999** | 0,02417 | 0,00230 | 0,107 | 0,007 | 0,079 | 0,0429 | 0,00000202 | 0,00242049 |
| **2000** | 0,02308 | 0,00209 | 0,112 | 0,007 | 0,132 | 0,0420 | 0,00002049 | 0,00221236 |
| **2001** | 0,02248 | 0,00207 | 0,109 | 0,007 | 0,095 | 0,0420 | 0,00003301 | 0,00219099 |
| **2002** | 0,02151 | 0,00185 | 0,114 | 0,007 | 0,133 | 0,0402 | 0,00025759 | 0,00196658 |
| **2003** | 0,02042 | 0,00188 | 0,116 | 0,007 | 0,110 | 0,0426 | 0,00021383 | 0,00200490 |
| **2004** | 0,01906 | 0,00179 | 0,115 | 0,007 | 0,112 | 0,0430 | 0,00072641 | 0,00191699 |
| **2005** | 0,01874 | 0,00153 | 0,116 | 0,006 | 0,108 | 0,0379 | 0,00000771 | 0,00163819 |
| **2006** | 0,01769 | 0,00151 | 0,116 | 0,006 | 0,096 | 0,0396 | 0,00000065 | 0,00162271 |
| **2007** | 0,01572 | 0,00128 | 0,122 | 0,006 | 0,119 | 0,0386 | 0,00140521 | 0,00138390 |
| **2008** | 0,01483 | 0,00119 | 0,123 | 0,006 | 0,114 | 0,0383 | 0,00142542 | 0,00129839 |
| **2009** | 0,01397 | 0,00113 | 0,126 | 0,006 | 0,148 | 0,0397 | 0,00217719 | 0,00123129 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 28: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00432 | 0,00164 | 0,071 | 0,020 | 0,120 | 0,1492 | 0,00132860 | 0,00169632 |
| **1997** | 0,00542 | 0,00154 | 0,062 | 0,014 | 0,084 | 0,1016 | 0,00000028 | 0,00213237 |
| **1998** | 0,00470 | 0,00148 | 0,068 | 0,016 | 0,090 | 0,1235 | 0,00064450 | 0,00152965 |
| **1999** | 0,00555 | 0,00135 | 0,059 | 0,011 | 0,048 | 0,0830 | 0,00000008 | 0,00348677 |
| **2000** | 0,00540 | 0,00127 | 0,060 | 0,011 | 0,046 | 0,0821 | 0,00001431 | 0,00130908 |
| **2001** | 0,00532 | 0,00172 | 0,064 | 0,016 | 0,155 | 0,1228 | 0,00006166 | 0,00176670 |
| **2002** | 0,00547 | 0,00160 | 0,062 | 0,014 | 0,147 | 0,1114 | 0,00000031 | 0,00210240 |
| **2003** | 0,00545 | 0,00120 | 0,062 | 0,011 | 0,145 | 0,0871 | 0,00000052 | 0,00124372 |
| **2004** | 0,00532 | 0,00167 | 0,066 | 0,016 | 0,217 | 0,1284 | 0,00000028 | 0,00232050 |
| **2005** | 0,00515 | 0,00116 | 0,067 | 0,011 | 0,187 | 0,0956 | 0,00002799 | 0,00120518 |
| **2006** | 0,00510 | 0,00115 | 0,071 | 0,012 | 0,295 | 0,1051 | 0,00013722 | 0,00119132 |
| **2007** | 0,00505 | 0,00142 | 0,071 | 0,014 | 0,336 | 0,1308 | 0,00000053 | 0,00146957 |
| **2008** | 0,00536 | 0,00148 | 0,064 | 0,013 | 0,210 | 0,1159 | 0,00000001 | 0,01499447 |
| **2009** | 0,00520 | 0,00183 | 0,065 | 0,017 | 0,213 | 0,1517 | 0,00000099 | 0,00188195 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,01050 | 0,00246 | 0,090 | 0,016 | 0,317 | 0,0964 | 0,00000175 | 0,00253729 |
| **1997** | 0,01033 | 0,00292 | 0,085 | 0,018 | 0,261 | 0,1078 | 0,00000936 | 0,00299963 |
| **1998** | 0,00848 | 0,00209 | 0,097 | 0,017 | 0,316 | 0,1061 | 0,00167729 | 0,00216552 |
| **1999** | 0,01008 | 0,00219 | 0,088 | 0,014 | 0,293 | 0,0861 | 0,00000819 | 0,00225524 |
| **2000** | 0,00982 | 0,00265 | 0,086 | 0,017 | 0,278 | 0,1030 | 0,00004947 | 0,00272928 |
| **2001** | 0,00961 | 0,00183 | 0,090 | 0,012 | 0,333 | 0,0772 | 0,00000130 | 0,00189915 |
| **2002** | 0,00939 | 0,00159 | 0,090 | 0,011 | 0,334 | 0,0709 | 0,00006048 | 0,00164742 |
| **2003** | 0,00897 | 0,00152 | 0,095 | 0,011 | 0,353 | 0,0719 | 0,00000029 | 0,00208144 |
| **2004** | 0,00893 | 0,00140 | 0,092 | 0,010 | 0,351 | 0,0661 | 0,00000035 | 0,00175385 |
| **2005** | 0,00862 | 0,00144 | 0,093 | 0,011 | 0,331 | 0,0698 | 0,00000030 | 0,00194925 |
| **2006** | 0,00835 | 0,00134 | 0,094 | 0,010 | 0,353 | 0,0685 | 0,00000022 | 0,00213296 |
| **2007** | 0,00825 | 0,00169 | 0,096 | 0,013 | 0,371 | 0,0870 | 0,00000004 | 0,00609331 |
| **2008** | 0,00816 | 0,00138 | 0,090 | 0,011 | 0,301 | 0,0684 | 0,00000046 | 0,00150237 |
| **2009** | 0,00817 | 0,00146 | 0,092 | 0,011 | 0,349 | 0,0755 | 0,00000018 | 0,00254784 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 29: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00192 | 0,00029 | 0,127 | 0,011 | 0,484 | 0,1047 | 0,00000000 | 0,00345778 |
| **1997** | 0,00169 | 0,00026 | 0,131 | 0,011 | 0,527 | 0,1117 | 0,00000014 | 0,00055591 |
| **1998** | 0,00156 | 0,00027 | 0,132 | 0,013 | 0,484 | 0,1251 | 0,00014787 | 0,00030960 |
| **1999** | 0,00146 | 0,00020 | 0,135 | 0,010 | 0,536 | 0,1031 | 0,00000002 | 0,00126566 |
| **2000** | 0,00143 | 0,00020 | 0,133 | 0,010 | 0,524 | 0,1042 | 0,00000006 | 0,00069752 |
| **2001** | 0,00125 | 0,00018 | 0,137 | 0,011 | 0,503 | 0,1115 | 0,00000002 | 0,00110353 |
| **2002** | 0,00121 | 0,00018 | 0,136 | 0,011 | 0,502 | 0,1153 | 0,00000004 | 0,00077249 |
| **2003** | 0,00104 | 0,00017 | 0,142 | 0,013 | 0,522 | 0,1283 | 0,00000002 | 0,00102695 |
| **2004** | 0,00092 | 0,00012 | 0,141 | 0,010 | 0,444 | 0,1066 | 0,00000001 | 0,00090915 |
| **2005** | 0,00084 | 0,00011 | 0,143 | 0,010 | 0,508 | 0,1066 | 0,00000000 | 0,00151225 |
| **2006** | 0,00096 | 0,00011 | 0,143 | 0,010 | 0,508 | 0,1066 | 0,00000000 | 0,00151225 |
| **2007** | 0,00074 | 0,00012 | 0,135 | 0,012 | 0,338 | 0,1306 | 0,00000004 | 0,00046225 |
| **2008** | 0,00063 | 0,00009 | 0,143 | 0,011 | 0,381 | 0,1221 | 0,00000001 | 0,00103893 |
| **2009** | 0,00051 | 0,00008 | 0,155 | 0,012 | 0,580 | 0,1409 | 0,00000001 | 0,00059201 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00514 | 0,00089 | 0,109 | 0,013 | 0,366 | 0,0863 | 0,00000003 | 0,00362339 |
| **1997** | 0,00474 | 0,00138 | 0,108 | 0,022 | 0,342 | 0,1371 | 0,00021958 | 0,00144095 |
| **1998** | 0,00462 | 0,00126 | 0,106 | 0,021 | 0,312 | 0,1274 | 0,00000027 | 0,00178738 |
| **1999** | 0,00433 | 0,00110 | 0,105 | 0,019 | 0,271 | 0,1153 | 0,00002991 | 0,00115709 |
| **2000** | 0,00390 | 0,00085 | 0,110 | 0,016 | 0,329 | 0,1039 | 0,00000035 | 0,00107953 |
| **2001** | 0,00346 | 0,00060 | 0,112 | 0,013 | 0,265 | 0,0854 | 0,00016129 | 0,00064711 |
| **2002** | 0,00296 | 0,00077 | 0,119 | 0,020 | 0,305 | 0,1261 | 0,00032859 | 0,00081470 |
| **2003** | 0,00305 | 0,00048 | 0,112 | 0,012 | 0,246 | 0,0785 | 0,00000001 | 0,00490967 |
| **2004** | 0,00190 | 0,00044 | 0,144 | 0,019 | 0,451 | 0,1246 | 0,00076906 | 0,00048575 |
| **2005** | 0,00178 | 0,00032 | 0,143 | 0,015 | 0,445 | 0,1014 | 0,00060477 | 0,00036001 |
| **2006** | 0,00174 | 0,00043 | 0,132 | 0,020 | 0,317 | 0,1263 | 0,00044363 | 0,00046790 |
| **2007** | 0,00137 | 0,00030 | 0,144 | 0,018 | 0,346 | 0,1173 | 0,00048144 | 0,00033427 |
| **2008** | 0,00126 | 0,00028 | 0,147 | 0,018 | 0,398 | 0,1210 | 0,00047859 | 0,00031371 |
| **2009** | 0,00157 | 0,00039 | 0,125 | 0,019 | 0,285 | 0,1272 | 0,00000011 | 0,00092229 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 30: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00084 | 0,00009 | 0,180 | 0,009 | 0,735 | 0,0962 | 0,00000005 | 0,00038196 |
| **1997** | 0,00083 | 0,00011 | 0,177 | 0,011 | 0,685 | 0,1107 | 0,00000000 | 0,00149387 |
| **1998** | 0,00084 | 0,00010 | 0,173 | 0,010 | 0,647 | 0,1007 | 0,00000001 | 0,00090975 |
| **1999** | 0,00089 | 0,00011 | 0,170 | 0,010 | 0,648 | 0,1010 | 0,00000001 | 0,00078845 |
| **2000** | 0,00082 | 0,00010 | 0,175 | 0,009 | 0,700 | 0,0998 | 0,00000000 | 0,00166318 |
| **2001** | 0,00078 | 0,00009 | 0,171 | 0,009 | 0,576 | 0,0986 | 0,00000000 | 0,00148398 |
| **2002** | 0,00075 | 0,00008 | 0,175 | 0,009 | 0,641 | 0,0960 | 0,00000000 | 0,00115377 |
| **2003** | 0,00065 | 0,00007 | 0,182 | 0,009 | 0,694 | 0,0963 | 0,00000000 | 0,00126467 |
| **2004** | 0,00063 | 0,00007 | 0,182 | 0,009 | 0,746 | 0,1021 | 0,00000003 | 0,00036782 |
| **2005** | 0,00061 | 0,00007 | 0,174 | 0,009 | 0,616 | 0,1041 | 0,00000000 | 0,00140005 |
| **2006** | 0,00058 | 0,00007 | 0,168 | 0,009 | 0,483 | 0,1067 | 0,00000001 | 0,00072091 |
| **2007** | 0,00054 | 0,00006 | 0,169 | 0,010 | 0,543 | 0,1110 | 0,00000001 | 0,00058129 |
| **2008** | 0,00047 | 0,00005 | 0,173 | 0,009 | 0,526 | 0,1052 | 0,00000000 | 0,00682799 |
| **2009** | 0,00046 | 0,00005 | 0,177 | 0,009 | 0,635 | 0,1118 | 0,00000000 | 0,00070201 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00104 | 0,00023 | 0,190 | 0,021 | 0,668 | 0,1465 | 0,00051529 | 0,00026529 |
| **1997** | 0,00116 | 0,00024 | 0,181 | 0,020 | 0,621 | 0,1371 | 0,00023513 | 0,00027579 |
| **1998** | 0,00128 | 0,00029 | 0,163 | 0,021 | 0,455 | 0,1419 | 0,00013940 | 0,00032537 |
| **1999** | 0,00132 | 0,00025 | 0,160 | 0,018 | 0,406 | 0,1178 | 0,00000005 | 0,00089800 |
| **2000** | 0,00125 | 0,00021 | 0,164 | 0,015 | 0,482 | 0,1050 | 0,00000000 | 0,00347701 |
| **2001** | 0,00122 | 0,00026 | 0,160 | 0,019 | 0,441 | 0,1284 | 0,00000017 | 0,00048943 |
| **2002** | 0,00111 | 0,00023 | 0,168 | 0,019 | 0,479 | 0,1281 | 0,00017698 | 0,00026722 |
| **2003** | 0,00109 | 0,00022 | 0,161 | 0,018 | 0,423 | 0,1176 | 0,00000001 | 0,00226828 |
| **2004** | 0,00092 | 0,00021 | 0,165 | 0,020 | 0,406 | 0,1315 | 0,00015082 | 0,00023547 |
| **2005** | 0,00086 | 0,00017 | 0,168 | 0,018 | 0,458 | 0,1207 | 0,00000004 | 0,00071348 |
| **2006** | 0,00082 | 0,00016 | 0,164 | 0,017 | 0,426 | 0,1191 | 0,00000000 | 0,00218245 |
| **2007** | 0,00068 | 0,00015 | 0,169 | 0,019 | 0,427 | 0,1323 | 0,00013321 | 0,00017702 |
| **2008** | 0,00067 | 0,00015 | 0,160 | 0,019 | 0,344 | 0,1290 | 0,00009296 | 0,00017552 |
| **2009** | 0,00062 | 0,00013 | 0,167 | 0,018 | 0,436 | 0,1284 | 0,00000001 | 0,00146705 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 31: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00132 | 0,00017 | 0,145 | 0,010 | 0,151 | 0,0929 | 0,00000006 | 0,00054802 |
| **1997** | 0,00126 | 0,00017 | 0,147 | 0,010 | 0,172 | 0,0987 | 0,00005074 | 0,00019894 |
| **1998** | 0,00121 | 0,00016 | 0,148 | 0,010 | 0,146 | 0,0986 | 0,00001372 | 0,00018747 |
| **1999** | 0,00125 | 0,00015 | 0,147 | 0,010 | 0,153 | 0,0929 | 0,00002080 | 0,00018385 |
| **2000** | 0,00118 | 0,00014 | 0,156 | 0,009 | 0,264 | 0,0922 | 0,00008297 | 0,00016949 |
| **2001** | 0,00122 | 0,00013 | 0,151 | 0,009 | 0,204 | 0,0882 | 0,00000001 | 0,00108480 |
| **2002** | 0,00117 | 0,00012 | 0,154 | 0,008 | 0,213 | 0,0845 | 0,00000001 | 0,00143822 |
| **2003** | 0,00112 | 0,00011 | 0,157 | 0,008 | 0,248 | 0,0810 | 0,00000000 | 0,00228273 |
| **2004** | 0,00110 | 0,00011 | 0,154 | 0,008 | 0,207 | 0,0833 | 0,00000002 | 0,00076547 |
| **2005** | 0,00106 | 0,00010 | 0,159 | 0,007 | 0,283 | 0,0796 | 0,00000000 | 0,00280564 |
| **2006** | 0,00093 | 0,00009 | 0,165 | 0,008 | 0,288 | 0,0830 | 0,00000001 | 0,00112212 |
| **2007** | 0,00096 | 0,00009 | 0,160 | 0,007 | 0,216 | 0,0825 | 0,00000002 | 0,00052777 |
| **2008** | 0,00087 | 0,00008 | 0,167 | 0,007 | 0,285 | 0,0835 | 0,00000000 | 0,00345226 |
| **2009** | 0,00080 | 0,00007 | 0,169 | 0,007 | 0,298 | 0,0793 | 0,00000000 | 0,00108478 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00298 | 0,00070 | 0,124 | 0,020 | 0,144 | 0,1222 | 0,00020138 | 0,00074572 |
| **1997** | 0,00280 | 0,00053 | 0,126 | 0,016 | 0,145 | 0,1005 | 0,00000001 | 0,00343837 |
| **1998** | 0,00236 | 0,00053 | 0,132 | 0,019 | 0,145 | 0,1178 | 0,00088483 | 0,00057964 |
| **1999** | 0,00259 | 0,00057 | 0,127 | 0,018 | 0,122 | 0,1125 | 0,00040931 | 0,00061571 |
| **2000** | 0,00280 | 0,00056 | 0,125 | 0,017 | 0,128 | 0,1015 | 0,00001158 | 0,00060785 |
| **2001** | 0,00268 | 0,00057 | 0,121 | 0,017 | 0,062 | 0,1048 | 0,00000018 | 0,00102742 |
| **2002** | 0,00263 | 0,00052 | 0,128 | 0,016 | 0,142 | 0,1004 | 0,00000103 | 0,00056281 |
| **2003** | 0,00228 | 0,00045 | 0,134 | 0,016 | 0,112 | 0,1015 | 0,00025620 | 0,00049696 |
| **2004** | 0,00232 | 0,00048 | 0,131 | 0,017 | 0,104 | 0,1035 | 0,00008506 | 0,00052401 |
| **2005** | 0,00229 | 0,00040 | 0,132 | 0,014 | 0,106 | 0,0883 | 0,00000044 | 0,00046434 |
| **2006** | 0,00202 | 0,00035 | 0,139 | 0,014 | 0,166 | 0,0909 | 0,00000710 | 0,00038620 |
| **2007** | 0,00189 | 0,00033 | 0,139 | 0,014 | 0,125 | 0,0919 | 0,00009246 | 0,00037125 |
| **2008** | 0,00171 | 0,00026 | 0,146 | 0,013 | 0,178 | 0,0829 | 0,00000002 | 0,00165012 |
| **2009** | 0,00139 | 0,00023 | 0,156 | 0,014 | 0,185 | 0,0922 | 0,00032924 | 0,00026645 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 32: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00053 | 0,00008 | 0,171 | 0,013 | 0,298 | 0,1232 | 0,00027188 | 0,00011079 |
| **1997** | 0,00064 | 0,00010 | 0,159 | 0,013 | 0,205 | 0,1240 | 0,00016660 | 0,00012656 |
| **1998** | 0,00066 | 0,00010 | 0,161 | 0,012 | 0,243 | 0,1227 | 0,00018575 | 0,00012963 |
| **1999** | 0,00069 | 0,00011 | 0,156 | 0,012 | 0,132 | 0,1183 | 0,00028918 | 0,00013980 |
| **2000** | 0,00081 | 0,00012 | 0,147 | 0,012 | 0,124 | 0,1143 | 0,00011077 | 0,00014999 |
| **2001** | 0,00082 | 0,00012 | 0,140 | 0,012 | 0,087 | 0,1154 | 0,00000001 | 0,00108577 |
| **2002** | 0,00086 | 0,00014 | 0,134 | 0,012 | 0,000 | 0,1203 | 0,00000001 | 0,00122956 |
| **2003** | 0,00089 | 0,00013 | 0,135 | 0,011 | 0,010 | 0,1100 | 0,00000909 | 0,00015822 |
| **2004** | 0,00077 | 0,00012 | 0,140 | 0,012 | 0,113 | 0,1223 | 0,00000048 | 0,00015142 |
| **2005** | 0,00083 | 0,00011 | 0,139 | 0,010 | 0,034 | 0,1059 | 0,00000002 | 0,00075935 |
| **2006** | 0,00080 | 0,00010 | 0,140 | 0,010 | 0,099 | 0,1031 | 0,00000001 | 0,00096377 |
| **2007** | 0,00078 | 0,00011 | 0,134 | 0,010 | 0,035 | 0,1068 | 0,00000000 | 0,00271565 |
| **2008** | 0,00077 | 0,00009 | 0,141 | 0,009 | 0,155 | 0,1015 | 0,00000001 | 0,00074483 |
| **2009** | 0,00072 | 0,00009 | 0,146 | 0,010 | 0,192 | 0,1092 | 0,00000000 | 0,00136579 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00192 | 0,00027 | 0,176 | 0,014 | 0,484 | 0,0940 | 0,00000005 | 0,00097122 |
| **1997** | 0,00192 | 0,00029 | 0,168 | 0,015 | 0,394 | 0,0977 | 0,00000010 | 0,00075537 |
| **1998** | 0,00199 | 0,00030 | 0,169 | 0,014 | 0,430 | 0,0958 | 0,00000008 | 0,00081754 |
| **1999** | 0,00175 | 0,00023 | 0,175 | 0,013 | 0,400 | 0,0852 | 0,00000012 | 0,00055197 |
| **2000** | 0,00175 | 0,00021 | 0,183 | 0,012 | 0,512 | 0,0799 | 0,00000004 | 0,00086046 |
| **2001** | 0,00144 | 0,00021 | 0,188 | 0,014 | 0,537 | 0,0964 | 0,00022093 | 0,00025479 |
| **2002** | 0,00153 | 0,00020 | 0,179 | 0,012 | 0,453 | 0,0818 | 0,00000000 | 0,00244445 |
| **2003** | 0,00123 | 0,00018 | 0,199 | 0,014 | 0,555 | 0,0920 | 0,00028398 | 0,00021666 |
| **2004** | 0,00128 | 0,00017 | 0,184 | 0,012 | 0,473 | 0,0845 | 0,00000000 | 0,00243048 |
| **2005** | 0,00142 | 0,00019 | 0,176 | 0,012 | 0,384 | 0,0814 | 0,00000001 | 0,00176044 |
| **2006** | 0,00121 | 0,00015 | 0,182 | 0,011 | 0,406 | 0,0771 | 0,00000000 | 0,00272135 |
| **2007** | 0,00122 | 0,00016 | 0,175 | 0,012 | 0,336 | 0,0792 | 0,00000003 | 0,00078659 |
| **2008** | 0,00108 | 0,00013 | 0,184 | 0,010 | 0,407 | 0,0722 | 0,00000001 | 0,00091371 |
| **2009** | 0,00116 | 0,00015 | 0,174 | 0,011 | 0,350 | 0,0787 | 0,00000010 | 0,00040129 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 33: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00032 | 0,00008 | 0,152 | 0,020 | 0,188 | 0,1860 | 0,00011879 | 0,00009976 |
| **1997** | 0,00032 | 0,00008 | 0,156 | 0,021 | 0,319 | 0,2023 | 0,00007921 | 0,00010277 |
| **1998** | 0,00040 | 0,00010 | 0,133 | 0,019 | 0,050 | 0,1812 | 0,00000000 | 0,00453155 |
| **1999** | 0,00029 | 0,00007 | 0,166 | 0,019 | 0,420 | 0,1856 | 0,00005439 | 0,00008397 |
| **2000** | 0,00039 | 0,00008 | 0,142 | 0,016 | 0,201 | 0,1642 | 0,00000000 | 0,00207128 |
| **2001** | 0,00038 | 0,00008 | 0,145 | 0,016 | 0,232 | 0,1662 | 0,00000002 | 0,00048580 |
| **2002** | 0,00039 | 0,00008 | 0,145 | 0,016 | 0,232 | 0,1662 | 0,00000002 | 0,00048580 |
| **2003** | 0,00031 | 0,00007 | 0,156 | 0,018 | 0,246 | 0,1821 | 0,00012971 | 0,00008926 |
| **2004** | 0,00038 | 0,00008 | 0,145 | 0,016 | 0,238 | 0,1670 | 0,00000000 | 0,00190752 |
| **2005** | 0,00035 | 0,00008 | 0,146 | 0,016 | 0,285 | 0,1714 | 0,00000000 | 0,00101589 |
| **2006** | 0,00031 | 0,00007 | 0,155 | 0,017 | 0,365 | 0,1832 | 0,00005878 | 0,00008236 |
| **2007** | 0,00036 | 0,00006 | 0,140 | 0,012 | 0,223 | 0,1405 | 0,00000001 | 0,00048152 |
| **2008** | 0,00032 | 0,00006 | 0,154 | 0,016 | 0,428 | 0,1786 | 0,00000000 | 0,00112785 |
| **2009** | 0,00029 | 0,00006 | 0,150 | 0,015 | 0,342 | 0,1740 | 0,00000000 | 0,00122869 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00071 | 0,00037 | 0,109 | 0,043 | 0,000 | 0,2564 | 0,00000001 | 0,00254221 |
| **1997** | 0,00037 | 0,00016 | 0,164 | 0,040 | 0,385 | 0,2630 | 0,00034616 | 0,00018983 |
| **1998** | 0,00059 | 0,00030 | 0,115 | 0,042 | 0,001 | 0,2486 | 0,00012085 | 0,00032457 |
| **1999** | 0,00053 | 0,00026 | 0,131 | 0,041 | 0,139 | 0,2509 | 0,00012655 | 0,00028025 |
| **2000** | 0,00048 | 0,00019 | 0,150 | 0,035 | 0,309 | 0,2260 | 0,00016212 | 0,00021293 |
| **2001** | 0,00041 | 0,00015 | 0,155 | 0,033 | 0,279 | 0,2147 | 0,00020688 | 0,00017416 |
| **2002** | 0,00043 | 0,00017 | 0,158 | 0,035 | 0,319 | 0,2229 | 0,00015659 | 0,00019669 |
| **2003** | 0,00054 | 0,00023 | 0,129 | 0,035 | 0,058 | 0,2148 | 0,00013940 | 0,00025319 |
| **2004** | 0,00040 | 0,00017 | 0,157 | 0,035 | 0,339 | 0,2263 | 0,00030253 | 0,00019153 |
| **2005** | 0,00019 | 0,00007 | 0,214 | 0,031 | 0,641 | 0,2097 | 0,00043765 | 0,00009364 |
| **2006** | 0,00028 | 0,00010 | 0,178 | 0,032 | 0,420 | 0,2102 | 0,00030105 | 0,00012508 |
| **2007** | 0,00051 | 0,00017 | 0,131 | 0,026 | 0,147 | 0,1660 | 0,00000003 | 0,00082363 |
| **2008** | 0,00026 | 0,00010 | 0,171 | 0,032 | 0,358 | 0,2113 | 0,00032945 | 0,00012096 |
| **2009** | 0,00025 | 0,00010 | 0,167 | 0,033 | 0,300 | 0,2178 | 0,00030169 | 0,00011967 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 34: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00015 | 0,00005 | 0,149 | 0,028 | 0,000 | 0,2594 | 0,00009582 | 0,00006758 |
| **1997** | 0,00012 | 0,00004 | 0,155 | 0,028 | 0,000 | 0,2719 | 0,00012999 | 0,00005670 |
| **1998** | 0,00011 | 0,00004 | 0,162 | 0,030 | 0,092 | 0,2869 | 0,00014328 | 0,00005441 |
| **1999** | 0,00008 | 0,00003 | 0,193 | 0,026 | 0,324 | 0,2541 | 0,00013961 | 0,00004106 |
| **2000** | 0,00012 | 0,00005 | 0,153 | 0,030 | 0,000 | 0,2853 | 0,00015115 | 0,00006056 |
| **2001** | 0,00015 | 0,00004 | 0,154 | 0,023 | 0,000 | 0,2292 | 0,00002511 | 0,00005523 |
| **2002** | 0,00015 | 0,00005 | 0,149 | 0,025 | 0,000 | 0,2526 | 0,00005362 | 0,00006037 |
| **2003** | 0,00012 | 0,00004 | 0,159 | 0,025 | 0,000 | 0,2491 | 0,00011373 | 0,00005043 |
| **2004** | 0,00012 | 0,00004 | 0,155 | 0,025 | 0,000 | 0,2485 | 0,00006864 | 0,00005160 |
| **2005** | 0,00013 | 0,00004 | 0,155 | 0,023 | 0,000 | 0,2379 | 0,00008073 | 0,00004996 |
| **2006** | 0,00009 | 0,00002 | 0,186 | 0,021 | 0,282 | 0,2301 | 0,00009680 | 0,00003585 |
| **2007** | 0,00014 | 0,00004 | 0,154 | 0,022 | 0,029 | 0,2330 | 0,00004582 | 0,00004862 |
| **2008** | 0,00013 | 0,00003 | 0,165 | 0,019 | 0,114 | 0,2156 | 0,00005539 | 0,00004201 |
| **2009** | 0,00013 | 0,00003 | 0,173 | 0,020 | 0,308 | 0,2255 | 0,00006701 | 0,00004216 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00029 | 0,00017 | 0,130 | 0,051 | 0,000 | 0,3154 | 0,00013839 | 0,00018941 |
| **1997** | 0,00006 | 0,00003 | 0,264 | 0,050 | 0,768 | 0,3303 | 0,00036736 | 0,00005540 |
| **1998** | 0,00008 | 0,00005 | 0,226 | 0,053 | 0,563 | 0,3518 | 0,00034401 | 0,00006839 |
| **1999** | 0,00012 | 0,00009 | 0,167 | 0,064 | 0,054 | 0,4007 | 0,00037092 | 0,00010669 |
| **2000** | 0,00010 | 0,00005 | 0,214 | 0,048 | 0,437 | 0,3116 | 0,00030656 | 0,00007451 |
| **2001** | 0,00010 | 0,00005 | 0,219 | 0,047 | 0,447 | 0,3030 | 0,00035245 | 0,00007117 |
| **2002** | 0,00019 | 0,00011 | 0,160 | 0,050 | 0,139 | 0,3124 | 0,00019933 | 0,00012739 |
| **2003** | 0,00012 | 0,00007 | 0,190 | 0,053 | 0,231 | 0,3282 | 0,00030461 | 0,00009487 |
| **2004** | 0,00006 | 0,00003 | 0,269 | 0,043 | 0,813 | 0,2829 | 0,00035901 | 0,00005167 |
| **2005** | 0,00018 | 0,00009 | 0,159 | 0,045 | 0,023 | 0,2775 | 0,00023713 | 0,00011361 |
| **2006** | 0,00013 | 0,00006 | 0,188 | 0,039 | 0,225 | 0,2512 | 0,00034539 | 0,00008157 |
| **2007** | 0,00018 | 0,00009 | 0,162 | 0,043 | 0,075 | 0,2737 | 0,00020580 | 0,00010895 |
| **2008** | 0,00013 | 0,00006 | 0,172 | 0,040 | 0,030 | 0,2496 | 0,00029959 | 0,00008537 |
| **2009** | 0,00009 | 0,00004 | 0,223 | 0,039 | 0,456 | 0,2559 | 0,00031079 | 0,00006348 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 35: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in Netherlands**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00130 | 0,00014 | 0,160 | 0,008 | 0,102 | 0,0811 | 0,00038308 | 0,00017468 |
| **1997** | 0,00140 | 0,00015 | 0,157 | 0,008 | 0,065 | 0,0810 | 0,00012638 | 0,00018009 |
| **1998** | 0,00131 | 0,00013 | 0,164 | 0,008 | 0,163 | 0,0806 | 0,00022843 | 0,00016749 |
| **1999** | 0,00161 | 0,00016 | 0,150 | 0,008 | 0,003 | 0,0732 | 0,00001653 | 0,00018956 |
| **2000** | 0,00121 | 0,00011 | 0,175 | 0,007 | 0,274 | 0,0745 | 0,00036773 | 0,00014526 |
| **2001** | 0,00152 | 0,00014 | 0,161 | 0,007 | 0,164 | 0,0741 | 0,00031023 | 0,00017719 |
| **2002** | 0,00173 | 0,00015 | 0,154 | 0,007 | 0,075 | 0,0681 | 0,00000003 | 0,00078368 |
| **2003** | 0,00138 | 0,00012 | 0,166 | 0,007 | 0,145 | 0,0710 | 0,00028417 | 0,00015637 |
| **2004** | 0,00133 | 0,00012 | 0,166 | 0,007 | 0,194 | 0,0725 | 0,00023270 | 0,00014981 |
| **2005** | 0,00134 | 0,00012 | 0,160 | 0,007 | 0,092 | 0,0715 | 0,00000005 | 0,00046233 |
| **2006** | 0,00140 | 0,00011 | 0,157 | 0,006 | 0,057 | 0,0660 | 0,00000001 | 0,00088225 |
| **2007** | 0,00121 | 0,00010 | 0,162 | 0,006 | 0,094 | 0,0709 | 0,00006698 | 0,00012710 |
| **2008** | 0,00122 | 0,00009 | 0,162 | 0,006 | 0,052 | 0,0678 | 0,00000003 | 0,00053529 |
| **2009** | 0,00103 | 0,00008 | 0,172 | 0,006 | 0,152 | 0,0717 | 0,00021551 | 0,00010692 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00224 | 0,00047 | 0,131 | 0,019 | 0,000 | 0,1156 | 0,00030341 | 0,00051703 |
| **1997** | 0,00236 | 0,00052 | 0,126 | 0,019 | 0,000 | 0,1148 | 0,00015789 | 0,00055916 |
| **1998** | 0,00196 | 0,00038 | 0,138 | 0,017 | 0,000 | 0,1085 | 0,00056931 | 0,00042780 |
| **1999** | 0,00202 | 0,00033 | 0,138 | 0,014 | 0,007 | 0,0895 | 0,00062301 | 0,00036941 |
| **2000** | 0,00182 | 0,00033 | 0,148 | 0,016 | 0,070 | 0,0988 | 0,00089805 | 0,00038137 |
| **2001** | 0,00147 | 0,00026 | 0,171 | 0,016 | 0,193 | 0,1018 | 0,00143937 | 0,00031343 |
| **2002** | 0,00211 | 0,00037 | 0,147 | 0,015 | 0,094 | 0,0940 | 0,00066948 | 0,00041592 |
| **2003** | 0,00162 | 0,00028 | 0,165 | 0,015 | 0,155 | 0,0952 | 0,00110020 | 0,00032641 |
| **2004** | 0,00156 | 0,00029 | 0,156 | 0,016 | 0,079 | 0,0985 | 0,00104565 | 0,00033757 |
| **2005** | 0,00131 | 0,00021 | 0,175 | 0,014 | 0,227 | 0,0892 | 0,00117162 | 0,00025764 |
| **2006** | 0,00184 | 0,00030 | 0,144 | 0,014 | 0,016 | 0,0865 | 0,00041385 | 0,00034560 |
| **2007** | 0,00129 | 0,00020 | 0,168 | 0,013 | 0,174 | 0,0870 | 0,00099393 | 0,00024938 |
| **2008** | 0,00114 | 0,00017 | 0,183 | 0,013 | 0,260 | 0,0823 | 0,00087773 | 0,00020951 |
| **2009** | 0,00122 | 0,00017 | 0,177 | 0,012 | 0,273 | 0,0821 | 0,00087505 | 0,00021553 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 36: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00881 | 0,00090 | 0,136 | 0,008 | 0,152 | 0,0679 | 0,00266912 | 0,00107351 |
| **1997** | 0,01093 | 0,00119 | 0,121 | 0,008 | 0,031 | 0,0691 | 0,00021404 | 0,00135892 |
| **1998** | 0,01025 | 0,00110 | 0,126 | 0,008 | 0,096 | 0,0722 | 0,00021249 | 0,00126362 |
| **1999** | 0,00864 | 0,00090 | 0,136 | 0,008 | 0,120 | 0,0726 | 0,00270497 | 0,00107508 |
| **2000** | 0,00886 | 0,00092 | 0,136 | 0,008 | 0,169 | 0,0716 | 0,00147772 | 0,00109593 |
| **2001** | 0,01022 | 0,00106 | 0,122 | 0,007 | 0,019 | 0,0679 | 0,00000698 | 0,00122757 |
| **2002** | 0,00951 | 0,00097 | 0,127 | 0,007 | 0,046 | 0,0682 | 0,00083136 | 0,00114481 |
| **2003** | 0,00880 | 0,00093 | 0,128 | 0,007 | 0,049 | 0,0706 | 0,00117644 | 0,00109508 |
| **2004** | 0,00927 | 0,00098 | 0,122 | 0,007 | 0,009 | 0,0705 | 0,00000076 | 0,00112480 |
| **2005** | 0,00812 | 0,00082 | 0,127 | 0,007 | 0,003 | 0,0695 | 0,00130307 | 0,00097432 |
| **2006** | 0,00876 | 0,00082 | 0,125 | 0,007 | 0,000 | 0,0657 | 0,00000004 | 0,00336644 |
| **2007** | 0,00754 | 0,00069 | 0,135 | 0,007 | 0,111 | 0,0682 | 0,00169783 | 0,00084635 |
| **2008** | 0,00804 | 0,00074 | 0,127 | 0,006 | 0,018 | 0,0677 | 0,00126808 | 0,00087570 |
| **2009** | 0,00688 | 0,00059 | 0,139 | 0,006 | 0,150 | 0,0692 | 0,00201003 | 0,00072970 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,02334 | 0,00335 | 0,108 | 0,011 | 0,111 | 0,0664 | 0,00000196 | 0,00358126 |
| **1997** | 0,02262 | 0,00354 | 0,109 | 0,012 | 0,094 | 0,0721 | 0,00001162 | 0,00378977 |
| **1998** | 0,02194 | 0,00354 | 0,112 | 0,012 | 0,145 | 0,0756 | 0,00000726 | 0,00379367 |
| **1999** | 0,01865 | 0,00282 | 0,123 | 0,012 | 0,161 | 0,0738 | 0,00337257 | 0,00308416 |
| **2000** | 0,01983 | 0,00320 | 0,115 | 0,012 | 0,119 | 0,0761 | 0,00034607 | 0,00343662 |
| **2001** | 0,01813 | 0,00280 | 0,122 | 0,012 | 0,152 | 0,0747 | 0,00151361 | 0,00305356 |
| **2002** | 0,01647 | 0,00250 | 0,124 | 0,012 | 0,136 | 0,0732 | 0,00354592 | 0,00275653 |
| **2003** | 0,01228 | 0,00186 | 0,141 | 0,012 | 0,216 | 0,0774 | 0,00671989 | 0,00213895 |
| **2004** | 0,01194 | 0,00181 | 0,141 | 0,012 | 0,230 | 0,0758 | 0,00589189 | 0,00208293 |
| **2005** | 0,01485 | 0,00217 | 0,125 | 0,011 | 0,144 | 0,0681 | 0,00172692 | 0,00239970 |
| **2006** | 0,01010 | 0,00136 | 0,148 | 0,011 | 0,253 | 0,0687 | 0,00624682 | 0,00160502 |
| **2007** | 0,01104 | 0,00152 | 0,142 | 0,011 | 0,202 | 0,0695 | 0,00551579 | 0,00175577 |
| **2008** | 0,01275 | 0,00179 | 0,130 | 0,011 | 0,122 | 0,0687 | 0,00299523 | 0,00200193 |
| **2009** | 0,00895 | 0,00127 | 0,153 | 0,011 | 0,289 | 0,0751 | 0,00649733 | 0,00149327 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 37: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00357 | 0,00250 | 0,075 | 0,037 | 0,163 | 0,2734 | 0,00205167 | 0,00262826 |
| **1997** | 0,00540 | 0,00260 | 0,059 | 0,022 | 0,186 | 0,1723 | 0,00000335 | 0,00267287 |
| **1998** | 0,00485 | 0,00203 | 0,068 | 0,021 | 0,312 | 0,1808 | 0,00000001 | 0,01507222 |
| **1999** | 0,00532 | 0,00276 | 0,054 | 0,022 | 0,093 | 0,1585 | 0,00000009 | 0,00686251 |
| **2000** | 0,00499 | 0,00247 | 0,068 | 0,024 | 0,256 | 0,1989 | 0,00000039 | 0,00291336 |
| **2001** | 0,00538 | 0,00252 | 0,056 | 0,021 | 0,068 | 0,1504 | 0,00000044 | 0,00277177 |
| **2002** | 0,00533 | 0,00264 | 0,059 | 0,022 | 0,141 | 0,1670 | 0,00000010 | 0,00617627 |
| **2003** | 0,00512 | 0,00198 | 0,063 | 0,018 | 0,227 | 0,1486 | 0,00000001 | 0,01378304 |
| **2004** | 0,00528 | 0,00182 | 0,055 | 0,015 | 0,063 | 0,1197 | 0,00000780 | 0,00189434 |
| **2005** | 0,00390 | 0,00200 | 0,077 | 0,027 | 0,323 | 0,2359 | 0,00109989 | 0,00211585 |
| **2006** | 0,00469 | 0,00154 | 0,072 | 0,017 | 0,308 | 0,1562 | 0,00000020 | 0,00260413 |
| **2007** | 0,00517 | 0,00215 | 0,062 | 0,019 | 0,234 | 0,1703 | 0,00000007 | 0,00591698 |
| **2008** | 0,00503 | 0,00188 | 0,071 | 0,019 | 0,517 | 0,1956 | 0,00002979 | 0,00196097 |
| **2009** | 0,00475 | 0,00294 | 0,073 | 0,031 | 0,421 | 0,3006 | 0,00000027 | 0,00418784 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00855 | 0,00250 | 0,092 | 0,019 | 0,381 | 0,1284 | 0,00000030 | 0,00339779 |
| **1997** | 0,00795 | 0,00364 | 0,092 | 0,030 | 0,312 | 0,1872 | 0,00033521 | 0,00378042 |
| **1998** | 0,00682 | 0,00295 | 0,101 | 0,030 | 0,377 | 0,1921 | 0,00141205 | 0,00310012 |
| **1999** | 0,00855 | 0,00310 | 0,079 | 0,022 | 0,188 | 0,1261 | 0,00000042 | 0,00351660 |
| **2000** | 0,00783 | 0,00303 | 0,090 | 0,025 | 0,342 | 0,1577 | 0,00000010 | 0,00715058 |
| **2001** | 0,00767 | 0,00217 | 0,095 | 0,019 | 0,364 | 0,1236 | 0,00000104 | 0,00228682 |
| **2002** | 0,00665 | 0,00309 | 0,099 | 0,031 | 0,325 | 0,1936 | 0,00122956 | 0,00324779 |
| **2003** | 0,00761 | 0,00361 | 0,084 | 0,029 | 0,188 | 0,1702 | 0,00000041 | 0,00415424 |
| **2004** | 0,00757 | 0,00221 | 0,090 | 0,018 | 0,298 | 0,1162 | 0,00000015 | 0,00421201 |
| **2005** | 0,00701 | 0,00199 | 0,100 | 0,019 | 0,393 | 0,1234 | 0,00000008 | 0,00515188 |
| **2006** | 0,00558 | 0,00241 | 0,101 | 0,028 | 0,306 | 0,1747 | 0,00163995 | 0,00256015 |
| **2007** | 0,00519 | 0,00180 | 0,113 | 0,024 | 0,419 | 0,1586 | 0,00191295 | 0,00194080 |
| **2008** | 0,00669 | 0,00214 | 0,096 | 0,020 | 0,311 | 0,1335 | 0,00000065 | 0,00225292 |
| **2009** | 0,00611 | 0,00200 | 0,100 | 0,021 | 0,351 | 0,1440 | 0,00048974 | 0,00211288 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 38: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00191 | 0,00035 | 0,140 | 0,014 | 0,345 | 0,1295 | 0,00000001 | 0,00365558 |
| **1997** | 0,00189 | 0,00032 | 0,142 | 0,013 | 0,358 | 0,1240 | 0,00000003 | 0,00167856 |
| **1998** | 0,00157 | 0,00024 | 0,157 | 0,012 | 0,569 | 0,1240 | 0,00005106 | 0,00030190 |
| **1999** | 0,00153 | 0,00031 | 0,156 | 0,016 | 0,472 | 0,1589 | 0,00012714 | 0,00037679 |
| **2000** | 0,00149 | 0,00028 | 0,157 | 0,014 | 0,532 | 0,1441 | 0,00000840 | 0,00034963 |
| **2001** | 0,00132 | 0,00021 | 0,156 | 0,012 | 0,432 | 0,1275 | 0,00000000 | 0,00522747 |
| **2002** | 0,00124 | 0,00022 | 0,157 | 0,013 | 0,376 | 0,1371 | 0,00000001 | 0,00191549 |
| **2003** | 0,00111 | 0,00019 | 0,161 | 0,013 | 0,403 | 0,1404 | 0,00000000 | 0,00546314 |
| **2004** | 0,00088 | 0,00014 | 0,177 | 0,013 | 0,589 | 0,1399 | 0,00000001 | 0,00181345 |
| **2005** | 0,00082 | 0,00015 | 0,162 | 0,014 | 0,368 | 0,1522 | 0,00000000 | 0,00494946 |
| **2006** | 0,00089 | 0,00017 | 0,149 | 0,014 | 0,166 | 0,1530 | 0,00000001 | 0,00199818 |
| **2007** | 0,00074 | 0,00013 | 0,166 | 0,013 | 0,396 | 0,1496 | 0,00000002 | 0,00094838 |
| **2008** | 0,00078 | 0,00015 | 0,154 | 0,015 | 0,240 | 0,1671 | 0,00000001 | 0,00112860 |
| **2009** | 0,00071 | 0,00014 | 0,162 | 0,015 | 0,395 | 0,1800 | 0,00000002 | 0,00086937 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00522 | 0,00181 | 0,118 | 0,027 | 0,296 | 0,1721 | 0,00134471 | 0,00195342 |
| **1997** | 0,00596 | 0,00139 | 0,114 | 0,018 | 0,288 | 0,1166 | 0,00002024 | 0,00150503 |
| **1998** | 0,00543 | 0,00163 | 0,122 | 0,024 | 0,369 | 0,1535 | 0,00002560 | 0,00175857 |
| **1999** | 0,00442 | 0,00131 | 0,130 | 0,024 | 0,358 | 0,1546 | 0,00089792 | 0,00143846 |
| **2000** | 0,00322 | 0,00093 | 0,147 | 0,024 | 0,402 | 0,1611 | 0,00131787 | 0,00106086 |
| **2001** | 0,00387 | 0,00119 | 0,129 | 0,025 | 0,262 | 0,1587 | 0,00026668 | 0,00129810 |
| **2002** | 0,00320 | 0,00106 | 0,135 | 0,027 | 0,254 | 0,1683 | 0,00102412 | 0,00118862 |
| **2003** | 0,00219 | 0,00063 | 0,164 | 0,024 | 0,461 | 0,1619 | 0,00152608 | 0,00074995 |
| **2004** | 0,00178 | 0,00055 | 0,168 | 0,026 | 0,457 | 0,1720 | 0,00151214 | 0,00067596 |
| **2005** | 0,00151 | 0,00043 | 0,177 | 0,024 | 0,525 | 0,1591 | 0,00114104 | 0,00053224 |
| **2006** | 0,00242 | 0,00084 | 0,117 | 0,025 | 0,032 | 0,1567 | 0,00000024 | 0,00131867 |
| **2007** | 0,00162 | 0,00056 | 0,145 | 0,027 | 0,163 | 0,1767 | 0,00090387 | 0,00065425 |
| **2008** | 0,00114 | 0,00036 | 0,175 | 0,026 | 0,416 | 0,1776 | 0,00130908 | 0,00045753 |
| **2009** | 0,00092 | 0,00030 | 0,186 | 0,027 | 0,501 | 0,1899 | 0,00135731 | 0,00039791 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 39: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00094 | 0,00018 | 0,185 | 0,016 | 0,742 | 0,1551 | 0,00000002 | 0,00106875 |
| **1997** | 0,00081 | 0,00014 | 0,195 | 0,015 | 0,827 | 0,1487 | 0,00000000 | 0,00773824 |
| **1998** | 0,00090 | 0,00016 | 0,183 | 0,014 | 0,738 | 0,1502 | 0,00000001 | 0,00175296 |
| **1999** | 0,00075 | 0,00014 | 0,188 | 0,015 | 0,717 | 0,1612 | 0,00000001 | 0,00108672 |
| **2000** | 0,00063 | 0,00012 | 0,202 | 0,016 | 0,906 | 0,1661 | 0,00000001 | 0,00137626 |
| **2001** | 0,00063 | 0,00011 | 0,193 | 0,014 | 0,808 | 0,1522 | 0,00000000 | 0,00197153 |
| **2002** | 0,00071 | 0,00013 | 0,182 | 0,015 | 0,688 | 0,1571 | 0,00000001 | 0,00114349 |
| **2003** | 0,00066 | 0,00014 | 0,180 | 0,017 | 0,608 | 0,1767 | 0,00000000 | 0,00183835 |
| **2004** | 0,00073 | 0,00016 | 0,160 | 0,017 | 0,383 | 0,1784 | 0,00000000 | 0,00275198 |
| **2005** | 0,00054 | 0,00011 | 0,183 | 0,016 | 0,651 | 0,1732 | 0,00000001 | 0,00138988 |
| **2006** | 0,00059 | 0,00010 | 0,167 | 0,014 | 0,373 | 0,1565 | 0,00000000 | 0,01766902 |
| **2007** | 0,00052 | 0,00010 | 0,179 | 0,015 | 0,638 | 0,1773 | 0,00000000 | 0,00145810 |
| **2008** | 0,00050 | 0,00009 | 0,178 | 0,014 | 0,572 | 0,1666 | 0,00000000 | 0,00245288 |
| **2009** | 0,00040 | 0,00007 | 0,197 | 0,015 | 0,882 | 0,1849 | 0,00000000 | 0,00257300 |
| **Males** | | | | | | | | |
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00161 | 0,00038 | 0,167 | 0,022 | 0,461 | 0,1510 | 0,00000000 | 0,00513146 |
| **1997** | 0,00128 | 0,00033 | 0,189 | 0,024 | 0,645 | 0,1727 | 0,00000009 | 0,00091268 |
| **1998** | 0,00116 | 0,00031 | 0,203 | 0,025 | 0,794 | 0,1836 | 0,00020797 | 0,00037498 |
| **1999** | 0,00127 | 0,00036 | 0,177 | 0,026 | 0,504 | 0,1782 | 0,00000001 | 0,00276678 |
| **2000** | 0,00104 | 0,00033 | 0,186 | 0,029 | 0,575 | 0,2041 | 0,00030185 | 0,00040316 |
| **2001** | 0,00118 | 0,00032 | 0,169 | 0,024 | 0,477 | 0,1688 | 0,00000001 | 0,00314833 |
| **2002** | 0,00089 | 0,00033 | 0,185 | 0,032 | 0,508 | 0,2182 | 0,00032183 | 0,00040470 |
| **2003** | 0,00088 | 0,00034 | 0,176 | 0,033 | 0,454 | 0,2254 | 0,00013039 | 0,00040106 |
| **2004** | 0,00077 | 0,00027 | 0,190 | 0,030 | 0,615 | 0,2080 | 0,00021582 | 0,00033008 |
| **2005** | 0,00073 | 0,00026 | 0,178 | 0,030 | 0,427 | 0,2030 | 0,00037863 | 0,00032318 |
| **2006** | 0,00068 | 0,00018 | 0,181 | 0,023 | 0,467 | 0,1628 | 0,00000001 | 0,00178996 |
| **2007** | 0,00079 | 0,00027 | 0,164 | 0,028 | 0,381 | 0,1967 | 0,00000001 | 0,00183314 |
| **2008** | 0,00052 | 0,00017 | 0,202 | 0,028 | 0,635 | 0,2007 | 0,00026176 | 0,00021259 |
| **2009** | 0,00073 | 0,00030 | 0,158 | 0,033 | 0,282 | 0,2262 | 0,00021048 | 0,00034711 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 40: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00080 | 0,00014 | 0,175 | 0,014 | 0,321 | 0,1413 | 0,00000000 | 0,00316404 |
| **1997** | 0,00072 | 0,00013 | 0,183 | 0,015 | 0,377 | 0,1460 | 0,00000000 | 0,00355302 |
| **1998** | 0,00078 | 0,00014 | 0,179 | 0,014 | 0,381 | 0,1457 | 0,00000000 | 0,00252353 |
| **1999** | 0,00087 | 0,00016 | 0,166 | 0,015 | 0,165 | 0,1503 | 0,00000000 | 0,00218243 |
| **2000** | 0,00073 | 0,00023 | 0,175 | 0,024 | 0,251 | 0,2332 | 0,00010651 | 0,00029735 |
| **2001** | 0,00065 | 0,00011 | 0,195 | 0,013 | 0,545 | 0,1409 | 0,00001782 | 0,00015777 |
| **2002** | 0,00067 | 0,00011 | 0,186 | 0,013 | 0,432 | 0,1415 | 0,00000000 | 0,00172665 |
| **2003** | 0,00078 | 0,00014 | 0,162 | 0,014 | 0,121 | 0,1459 | 0,00000000 | 0,00222883 |
| **2004** | 0,00068 | 0,00012 | 0,175 | 0,014 | 0,255 | 0,1474 | 0,00000001 | 0,00130596 |
| **2005** | 0,00068 | 0,00014 | 0,158 | 0,016 | 0,040 | 0,1677 | 0,00000003 | 0,00072659 |
| **2006** | 0,00056 | 0,00008 | 0,186 | 0,012 | 0,359 | 0,1364 | 0,00000000 | 0,00281942 |
| **2007** | 0,00059 | 0,00010 | 0,183 | 0,013 | 0,380 | 0,1463 | 0,00000001 | 0,00121742 |
| **2008** | 0,00050 | 0,00008 | 0,179 | 0,013 | 0,229 | 0,1547 | 0,00000001 | 0,00072565 |
| **2009** | 0,00049 | 0,00008 | 0,183 | 0,013 | 0,315 | 0,1594 | 0,00000003 | 0,00049224 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00198 | 0,00062 | 0,135 | 0,026 | 0,126 | 0,1701 | 0,00000000 | 0,01122930 |
| **1997** | 0,00194 | 0,00063 | 0,136 | 0,028 | 0,117 | 0,1753 | 0,00000005 | 0,00233384 |
| **1998** | 0,00196 | 0,00051 | 0,138 | 0,022 | 0,161 | 0,1452 | 0,00000001 | 0,00568806 |
| **1999** | 0,00144 | 0,00042 | 0,172 | 0,026 | 0,399 | 0,1753 | 0,00036778 | 0,00050585 |
| **2000** | 0,00133 | 0,00041 | 0,173 | 0,028 | 0,360 | 0,1851 | 0,00032429 | 0,00049710 |
| **2001** | 0,00100 | 0,00029 | 0,200 | 0,027 | 0,563 | 0,1834 | 0,00077302 | 0,00037846 |
| **2002** | 0,00169 | 0,00049 | 0,140 | 0,024 | 0,097 | 0,1549 | 0,00000000 | 0,00842673 |
| **2003** | 0,00097 | 0,00032 | 0,179 | 0,029 | 0,302 | 0,1906 | 0,00055048 | 0,00040590 |
| **2004** | 0,00092 | 0,00029 | 0,183 | 0,027 | 0,361 | 0,1777 | 0,00046747 | 0,00036482 |
| **2005** | 0,00078 | 0,00026 | 0,186 | 0,028 | 0,360 | 0,1854 | 0,00062902 | 0,00033801 |
| **2006** | 0,00062 | 0,00019 | 0,209 | 0,026 | 0,519 | 0,1783 | 0,00084245 | 0,00026628 |
| **2007** | 0,00055 | 0,00017 | 0,215 | 0,026 | 0,503 | 0,1798 | 0,00112097 | 0,00025726 |
| **2008** | 0,00093 | 0,00031 | 0,163 | 0,028 | 0,148 | 0,1850 | 0,00035095 | 0,00037759 |
| **2009** | 0,00105 | 0,00038 | 0,143 | 0,028 | 0,000 | 0,1887 | 0,00003602 | 0,00042626 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 41: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00060 | 0,00017 | 0,156 | 0,021 | 0,050 | 0,1994 | 0,00008277 | 0,00021154 |
| **1997** | 0,00051 | 0,00015 | 0,160 | 0,022 | 0,000 | 0,2069 | 0,00046124 | 0,00020818 |
| **1998** | 0,00024 | 0,00007 | 0,222 | 0,022 | 0,616 | 0,2255 | 0,00070459 | 0,00012706 |
| **1999** | 0,00057 | 0,00016 | 0,160 | 0,022 | 0,081 | 0,2105 | 0,00044846 | 0,00022693 |
| **2000** | 0,00078 | 0,00022 | 0,142 | 0,021 | 0,000 | 0,1985 | 0,00013853 | 0,00027297 |
| **2001** | 0,00057 | 0,00018 | 0,153 | 0,023 | 0,000 | 0,2173 | 0,00047668 | 0,00024843 |
| **2002** | 0,00068 | 0,00017 | 0,156 | 0,019 | 0,109 | 0,1827 | 0,00032753 | 0,00023054 |
| **2003** | 0,00064 | 0,00019 | 0,141 | 0,022 | 0,005 | 0,2084 | 0,00026537 | 0,00025286 |
| **2004** | 0,00065 | 0,00020 | 0,145 | 0,022 | 0,258 | 0,2189 | 0,00008357 | 0,00024675 |
| **2005** | 0,00064 | 0,00019 | 0,141 | 0,021 | 0,025 | 0,2109 | 0,00030264 | 0,00025203 |
| **2006** | 0,00088 | 0,00028 | 0,124 | 0,021 | 0,000 | 0,2086 | 0,00004730 | 0,00033120 |
| **2007** | 0,00053 | 0,00013 | 0,175 | 0,018 | 0,605 | 0,2022 | 0,00032972 | 0,00018912 |
| **2008** | 0,00065 | 0,00019 | 0,138 | 0,020 | 0,091 | 0,2103 | 0,00044235 | 0,00024776 |
| **2009** | 0,00066 | 0,00017 | 0,146 | 0,019 | 0,272 | 0,2116 | 0,00037194 | 0,00022489 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00128 | 0,00037 | 0,163 | 0,026 | 0,288 | 0,1753 | 0,00000002 | 0,00215298 |
| **1997** | 0,00099 | 0,00033 | 0,174 | 0,030 | 0,259 | 0,2008 | 0,00044000 | 0,00040412 |
| **1998** | 0,00125 | 0,00037 | 0,156 | 0,027 | 0,215 | 0,1771 | 0,00000002 | 0,00205878 |
| **1999** | 0,00140 | 0,00042 | 0,151 | 0,026 | 0,116 | 0,1709 | 0,00000009 | 0,00116467 |
| **2000** | 0,00129 | 0,00046 | 0,156 | 0,031 | 0,169 | 0,2026 | 0,00024674 | 0,00053737 |
| **2001** | 0,00118 | 0,00028 | 0,171 | 0,021 | 0,286 | 0,1457 | 0,00000001 | 0,00242312 |
| **2002** | 0,00118 | 0,00029 | 0,174 | 0,022 | 0,330 | 0,1504 | 0,00005174 | 0,00035875 |
| **2003** | 0,00101 | 0,00034 | 0,165 | 0,029 | 0,205 | 0,1881 | 0,00029218 | 0,00041315 |
| **2004** | 0,00078 | 0,00029 | 0,169 | 0,031 | 0,204 | 0,2010 | 0,00042634 | 0,00036017 |
| **2005** | 0,00128 | 0,00037 | 0,154 | 0,023 | 0,206 | 0,1529 | 0,00000000 | 0,00560658 |
| **2006** | 0,00096 | 0,00030 | 0,175 | 0,026 | 0,384 | 0,1760 | 0,00027996 | 0,00036160 |
| **2007** | 0,00117 | 0,00025 | 0,163 | 0,018 | 0,320 | 0,1253 | 0,00000000 | 0,00571945 |
| **2008** | 0,00124 | 0,00029 | 0,155 | 0,019 | 0,246 | 0,1331 | 0,00000001 | 0,00242056 |
| **2009** | 0,00102 | 0,00032 | 0,163 | 0,025 | 0,305 | 0,1773 | 0,00010242 | 0,00037562 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 42: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00016 | 0,00007 | 0,203 | 0,038 | 0,968 | 0,3803 | 0,00010024 | 0,00010378 |
| **1997** | 0,00014 | 0,00007 | 0,193 | 0,040 | 0,643 | 0,3924 | 0,00023580 | 0,00010541 |
| **1998** | 0,00018 | 0,00009 | 0,177 | 0,041 | 0,566 | 0,4081 | 0,00014838 | 0,00012447 |
| **1999** | 0,00025 | 0,00011 | 0,173 | 0,038 | 0,759 | 0,3886 | 0,00008380 | 0,00014331 |
| **2000** | 0,00036 | 0,00014 | 0,128 | 0,029 | 0,179 | 0,2873 | 0,00001805 | 0,00016442 |
| **2001** | 0,00029 | 0,00013 | 0,147 | 0,033 | 0,386 | 0,3279 | 0,00000001 | 0,00129238 |
| **2002** | 0,00035 | 0,00020 | 0,121 | 0,039 | 0,000 | 0,3635 | 0,00000000 | 0,00413969 |
| **2003** | 0,00028 | 0,00015 | 0,136 | 0,041 | 0,123 | 0,3995 | 0,00001615 | 0,00017888 |
| **2004** | 0,00033 | 0,00017 | 0,127 | 0,038 | 0,052 | 0,3691 | 0,00000002 | 0,00115130 |
| **2005** | 0,00032 | 0,00017 | 0,119 | 0,038 | 0,000 | 0,3751 | 0,00000000 | 0,01225809 |
| **2006** | 0,00023 | 0,00012 | 0,146 | 0,037 | 0,260 | 0,3834 | 0,00007149 | 0,00014631 |
| **2007** | 0,00028 | 0,00014 | 0,131 | 0,036 | 0,251 | 0,3706 | 0,00000001 | 0,00101036 |
| **2008** | 0,00026 | 0,00013 | 0,130 | 0,036 | 0,077 | 0,3852 | 0,00005017 | 0,00015754 |
| **2009** | 0,00030 | 0,00012 | 0,125 | 0,027 | 0,080 | 0,3108 | 0,00000000 | 0,00155251 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00056 | 0,00043 | 0,114 | 0,061 | 0,051 | 0,3726 | 0,00000856 | 0,00047244 |
| **1997** | 0,00055 | 0,00047 | 0,114 | 0,066 | 0,071 | 0,4083 | 0,00000001 | 0,00312223 |
| **1998** | 0,00032 | 0,00031 | 0,156 | 0,082 | 0,375 | 0,5332 | 0,00035987 | 0,00035762 |
| **1999** | 0,00026 | 0,00022 | 0,178 | 0,074 | 0,446 | 0,4789 | 0,00024623 | 0,00028337 |
| **2000** | 0,00039 | 0,00031 | 0,143 | 0,067 | 0,264 | 0,4330 | 0,00013494 | 0,00035738 |
| **2001** | 0,00050 | 0,00032 | 0,124 | 0,050 | 0,102 | 0,3161 | 0,00000001 | 0,00220681 |
| **2002** | 0,00038 | 0,00041 | 0,124 | 0,084 | 0,000 | 0,5047 | 0,00012612 | 0,00045252 |
| **2003** | 0,00030 | 0,00034 | 0,118 | 0,085 | 0,000 | 0,5046 | 0,00034147 | 0,00038395 |
| **2004** | 0,00008 | 0,00006 | 0,274 | 0,066 | 1,164 | 0,4587 | 0,00049293 | 0,00011819 |
| **2005** | 0,00011 | 0,00009 | 0,214 | 0,072 | 0,616 | 0,4762 | 0,00040190 | 0,00014694 |
| **2006** | 0,00046 | 0,00086 | 0,107 | 0,131 | 0,000 | 0,7653 | 0,00003485 | 0,00091538 |
| **2007** | 0,00027 | 0,00026 | 0,137 | 0,073 | 0,144 | 0,4661 | 0,00019675 | 0,00029897 |
| **2008** | 0,00025 | 0,00027 | 0,133 | 0,081 | 0,075 | 0,5195 | 0,00035754 | 0,00031233 |
| **2009** | 0,00018 | 0,00017 | 0,169 | 0,075 | 0,338 | 0,5042 | 0,00025386 | 0,00021562 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 43: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00015 | 0,00007 | 0,171 | 0,038 | 0,112 | 0,3599 | 0,00014647 | 0,00010198 |
| **1997** | 0,00025 | 0,00014 | 0,141 | 0,040 | 0,000 | 0,3680 | 0,00006718 | 0,00016988 |
| **1998** | 0,00013 | 0,00006 | 0,183 | 0,039 | 0,258 | 0,3836 | 0,00017387 | 0,00009419 |
| **1999** | 0,00007 | 0,00003 | 0,241 | 0,034 | 0,815 | 0,3605 | 0,00022586 | 0,00006054 |
| **2000** | 0,00017 | 0,00008 | 0,167 | 0,040 | 0,181 | 0,3858 | 0,00009503 | 0,00011496 |
| **2001** | 0,00023 | 0,00011 | 0,145 | 0,038 | 0,000 | 0,7001 | 0,00000224 | 0,00014359 |
| **2002** | 0,00011 | 0,00005 | 0,197 | 0,040 | 0,518 | 0,4053 | 0,00016507 | 0,00009028 |
| **2003** | 0,00011 | 0,00005 | 0,202 | 0,036 | 0,667 | 0,3778 | 0,00007051 | 0,00007619 |
| **2004** | 0,00012 | 0,00006 | 0,168 | 0,041 | 0,135 | 0,4190 | 0,00017488 | 0,00009124 |
| **2005** | 0,00017 | 0,00007 | 0,155 | 0,034 | 0,000 | 0,3519 | 0,00000715 | 0,00009255 |
| **2006** | 0,00021 | 0,00009 | 0,142 | 0,033 | 0,000 | 0,3484 | 0,00000560 | 0,00010986 |
| **2007** | 0,00013 | 0,00006 | 0,178 | 0,032 | 0,345 | 0,3583 | 0,00015444 | 0,00008110 |
| **2008** | 0,00019 | 0,00008 | 0,149 | 0,031 | 0,029 | 0,3420 | 0,00000000 | 0,00223189 |
| **2009** | 0,00018 | 0,00007 | 0,155 | 0,029 | 0,058 | 0,3334 | 0,00005485 | 0,00009331 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **0,00023** | 0,00020 | 0,187 | 0,079 | 0,361 | 0,5051 | 0,00061977 | 0,00027060 | 0,00023 |
| **0,00036** | 0,00030 | 0,141 | 0,070 | 0,000 | 0,4293 | 0,00040208 | 0,00036446 | 0,00036 |
| **0,00028** | 0,00028 | 0,147 | 0,086 | 0,006 | 0,5261 | 0,00043949 | 0,00034444 | 0,00028 |
| **0,00021** | 0,00017 | 0,168 | 0,067 | 0,023 | 0,4242 | 0,00069011 | 0,00022840 | 0,00021 |
| **0,00014** | 0,00013 | 0,198 | 0,086 | 0,250 | 0,5497 | 0,00064127 | 0,00019725 | 0,00014 |
| **0,00024** | 0,00020 | 0,159 | 0,072 | 0,017 | 0,4588 | 0,00043195 | 0,00024418 | 0,00024 |
| **0,00013** | 0,00012 | 0,226 | 0,079 | 0,615 | 0,5085 | 0,00060922 | 0,00019997 | 0,00013 |
| **0,00017** | 0,00014 | 0,174 | 0,072 | 0,094 | 0,4519 | 0,00060080 | 0,00020301 | 0,00017 |
| **0,00017** | 0,00017 | 0,165 | 0,083 | 0,000 | 0,5127 | 0,00064171 | 0,00022936 | 0,00017 |
| **0,00027** | 0,00022 | 0,150 | 0,066 | 0,043 | 0,4135 | 0,00020864 | 0,00026467 | 0,00027 |
| **0,00020** | 0,00014 | 0,184 | 0,057 | 0,322 | 0,3760 | 0,00036340 | 0,00018174 | 0,00020 |
| **0,00007** | 0,00004 | 0,265 | 0,049 | 0,757 | 0,3389 | 0,00054189 | 0,00008930 | 0,00007 |
| **0,00009** | 0,00007 | 0,241 | 0,058 | 0,571 | 0,3940 | 0,00045003 | 0,00011988 | 0,00009 |
| **0,00007** | 0,00005 | 0,266 | 0,065 | 0,776 | 0,4436 | 0,00058366 | 0,00010966 | 0,00007 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 44: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in Norway**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1996** | 0,00084 | 0,00021 | 0,153 | 0,019 | 0,045 | 0,1732 | 0,00047893 | 0,00027001 |
| **1997** | 0,00126 | 0,00027 | 0,137 | 0,016 | 0,000 | 0,1513 | 0,00000000 | 0,00506873 |
| **1998** | 0,00126 | 0,00085 | 0,140 | 0,050 | 0,002 | 0,4408 | 0,00004273 | 0,00099069 |
| **1999** | 0,00116 | 0,00027 | 0,142 | 0,018 | 0,000 | 0,1661 | 0,00027033 | 0,00034709 |
| **2000** | 0,00102 | 0,00023 | 0,149 | 0,017 | 0,012 | 0,1620 | 0,00027450 | 0,00028879 |
| **2001** | 0,00096 | 0,00020 | 0,161 | 0,016 | 0,183 | 0,1566 | 0,00049614 | 0,00027183 |
| **2002** | 0,00110 | 0,00022 | 0,154 | 0,015 | 0,095 | 0,1482 | 0,00028138 | 0,00028057 |
| **2003** | 0,00095 | 0,00019 | 0,165 | 0,015 | 0,187 | 0,1481 | 0,00051843 | 0,00026017 |
| **2004** | 0,00101 | 0,00018 | 0,164 | 0,013 | 0,235 | 0,1393 | 0,00000000 | 0,00979626 |
| **2005** | 0,00131 | 0,00023 | 0,146 | 0,013 | 0,000 | 0,1323 | 0,00000008 | 0,00072929 |
| **2006** | 0,00115 | 0,00018 | 0,162 | 0,012 | 0,190 | 0,1286 | 0,00000004 | 0,00086014 |
| **2007** | 0,00124 | 0,00019 | 0,151 | 0,011 | 0,000 | 0,1219 | 0,00000004 | 0,00086297 |
| **2008** | 0,00131 | 0,00019 | 0,152 | 0,011 | 0,084 | 0,1227 | 0,00000007 | 0,00064062 |
| **2009** | 0,00125 | 0,00017 | 0,153 | 0,010 | 0,033 | 0,1196 | 0,00000012 | 0,00044464 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1996** | 0,00144 | 0,00063 | 0,132 | 0,036 | 0,000 | 0,2220 | 0,00078289 | 0,00071740 |
| **1997** | 0,00136 | 0,00061 | 0,140 | 0,038 | 0,035 | 0,2360 | 0,00128729 | 0,00071552 |
| **1998** | 0,00158 | 0,00068 | 0,131 | 0,035 | 0,000 | 0,2129 | 0,00096524 | 0,00077903 |
| **1999** | 0,00109 | 0,00037 | 0,177 | 0,030 | 0,365 | 0,1972 | 0,00146525 | 0,00047284 |
| **2000** | 0,00226 | 0,00085 | 0,118 | 0,029 | 0,021 | 0,1803 | 0,00000001 | 0,00602204 |
| **2001** | 0,00053 | 0,00023 | 0,223 | 0,038 | 0,572 | 0,2482 | 0,00251095 | 0,00037139 |
| **2002** | 0,00178 | 0,00081 | 0,129 | 0,036 | 0,005 | 0,2199 | 0,00091118 | 0,00091028 |
| **2003** | 0,00111 | 0,00038 | 0,175 | 0,029 | 0,313 | 0,1915 | 0,00136686 | 0,00049262 |
| **2004** | 0,00090 | 0,00029 | 0,190 | 0,028 | 0,374 | 0,1820 | 0,00130286 | 0,00039699 |
| **2005** | 0,00212 | 0,00077 | 0,128 | 0,028 | 0,000 | 0,1695 | 0,00029261 | 0,00086453 |
| **2006** | 0,00160 | 0,00050 | 0,148 | 0,025 | 0,116 | 0,1602 | 0,00061053 | 0,00058444 |
| **2007** | 0,00131 | 0,00037 | 0,168 | 0,023 | 0,225 | 0,1531 | 0,00108556 | 0,00046489 |
| **2008** | 0,00157 | 0,00048 | 0,150 | 0,024 | 0,085 | 0,1593 | 0,00083993 | 0,00056665 |
| **2009** | 0,00120 | 0,00034 | 0,178 | 0,023 | 0,322 | 0,1607 | 0,00108952 | 0,00042789 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 45: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for overall mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00854 | 0,00065 | 0,133 | 0,005 | 0,120 | 0,0506 | 0,00203255 | 0,00076384 |
| **1998** | 0,00887 | 0,00063 | 0,131 | 0,005 | 0,118 | 0,0489 | 0,00145373 | 0,00074356 |
| **1999** | 0,00883 | 0,00056 | 0,132 | 0,005 | 0,120 | 0,0452 | 0,00147394 | 0,00066438 |
| **2000** | 0,00853 | 0,00057 | 0,133 | 0,005 | 0,118 | 0,0473 | 0,00151881 | 0,00067522 |
| **2001** | 0,00908 | 0,00061 | 0,126 | 0,005 | 0,035 | 0,0464 | 0,00115910 | 0,00071294 |
| **2002** | 0,00922 | 0,00060 | 0,125 | 0,005 | 0,000 | 0,0453 | 0,00088076 | 0,00070169 |
| **2003** | 0,00824 | 0,00054 | 0,130 | 0,005 | 0,048 | 0,0474 | 0,00158176 | 0,00064729 |
| **2004** | 0,00872 | 0,00057 | 0,125 | 0,005 | 0,014 | 0,0463 | 0,00070247 | 0,00067169 |
| **2005** | 0,00825 | 0,00051 | 0,126 | 0,004 | 0,000 | 0,0444 | 0,00136907 | 0,00060330 |
| **2006** | 0,00807 | 0,00047 | 0,127 | 0,004 | 0,000 | 0,0438 | 0,00105595 | 0,00056878 |
| **2007** | 0,00772 | 0,00045 | 0,130 | 0,004 | 0,017 | 0,0452 | 0,00165860 | 0,00054007 |
| **2008** | 0,00734 | 0,00040 | 0,131 | 0,004 | 0,001 | 0,0436 | 0,00168082 | 0,00049024 |
| **2009** | 0,00749 | 0,00041 | 0,129 | 0,004 | 0,002 | 0,0438 | 0,00138124 | 0,00050104 |
| **2010** | 0,00744 | 0,00039 | 0,129 | 0,004 | 0,000 | 0,0434 | 0,00137350 | 0,00047486 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,01686 | 0,00176 | 0,121 | 0,0079 | 0,122 | 0,0481 | 0,00353164 | 0,00193730 |
| **1998** | 0,01524 | 0,00154 | 0,129 | 0,0078 | 0,169 | 0,0485 | 0,00497918 | 0,00171954 |
| **1999** | 0,01713 | 0,00169 | 0,120 | 0,0074 | 0,117 | 0,0453 | 0,00219142 | 0,00186046 |
| **2000** | 0,01631 | 0,00160 | 0,120 | 0,0073 | 0,096 | 0,0449 | 0,00216924 | 0,00177240 |
| **2001** | 0,01498 | 0,00154 | 0,122 | 0,0076 | 0,082 | 0,0469 | 0,00307946 | 0,00170842 |
| **2002** | 0,01395 | 0,00135 | 0,128 | 0,0072 | 0,118 | 0,0449 | 0,00393242 | 0,00152715 |
| **2003** | 0,01297 | 0,00121 | 0,133 | 0,0070 | 0,174 | 0,0440 | 0,00470033 | 0,00138862 |
| **2004** | 0,01154 | 0,00121 | 0,137 | 0,0079 | 0,181 | 0,0502 | 0,00542591 | 0,00139552 |
| **2005** | 0,01245 | 0,00114 | 0,132 | 0,0068 | 0,147 | 0,0440 | 0,00416955 | 0,00128912 |
| **2006** | 0,01176 | 0,00107 | 0,134 | 0,0068 | 0,164 | 0,0450 | 0,00411610 | 0,00122413 |
| **2007** | 0,01096 | 0,00096 | 0,136 | 0,0065 | 0,145 | 0,0441 | 0,00426993 | 0,00109383 |
| **2008** | 0,00960 | 0,00082 | 0,146 | 0,0065 | 0,227 | 0,0447 | 0,00546084 | 0,00096351 |
| **2009** | 0,00980 | 0,00083 | 0,142 | 0,0063 | 0,190 | 0,0447 | 0,00444081 | 0,00095449 |
| **2010** | 0,01042 | 0,00090 | 0,137 | 0,0064 | 0,164 | 0,0458 | 0,00359561 | 0,00101660 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 46: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for neoplasms mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00518 | 0,00161 | 0,063 | 0,015 | 0,293 | 0,1240 | 0,00000788 | 0,00166624 |
| **1998** | 0,00504 | 0,00199 | 0,063 | 0,018 | 0,319 | 0,1576 | 0,00000003 | 0,00828110 |
| **1999** | 0,00505 | 0,00218 | 0,066 | 0,021 | 0,405 | 0,1888 | 0,00000057 | 0,00224966 |
| **2000** | 0,00483 | 0,00132 | 0,071 | 0,014 | 0,458 | 0,1306 | 0,00005149 | 0,00138133 |
| **2001** | 0,00534 | 0,00135 | 0,066 | 0,012 | 0,373 | 0,1126 | 0,00000002 | 0,00664475 |
| **2002** | 0,00520 | 0,00191 | 0,064 | 0,017 | 0,343 | 0,1522 | 0,00000008 | 0,00483858 |
| **2003** | 0,00506 | 0,00161 | 0,066 | 0,015 | 0,386 | 0,1417 | 0,00000020 | 0,00267317 |
| **2004** | 0,00503 | 0,00145 | 0,069 | 0,014 | 0,449 | 0,1387 | 0,00000019 | 0,00247821 |
| **2005** | 0,00516 | 0,00154 | 0,066 | 0,014 | 0,463 | 0,1425 | 0,00000008 | 0,00397783 |
| **2006** | 0,00511 | 0,00136 | 0,067 | 0,013 | 0,405 | 0,1271 | 0,00000105 | 0,00141407 |
| **2007** | 0,00516 | 0,00111 | 0,068 | 0,011 | 0,438 | 0,1130 | 0,00002738 | 0,00116364 |
| **2008** | 0,00497 | 0,00138 | 0,065 | 0,013 | 0,326 | 0,1320 | 0,00006674 | 0,00142314 |
| **2009** | 0,00498 | 0,00128 | 0,067 | 0,012 | 0,430 | 0,1310 | 0,00000002 | 0,00764316 |
| **2010** | 0,00481 | 0,00103 | 0,070 | 0,011 | 0,476 | 0,1212 | 0,00000002 | 0,00496152 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00723 | 0,00200 | 0,089 | 0,017 | 0,324 | 0,1090 | 0,00000558 | 0,00208448 |
| **1998** | 0,00712 | 0,00195 | 0,088 | 0,017 | 0,274 | 0,1049 | 0,00004003 | 0,00204144 |
| **1999** | 0,00708 | 0,00287 | 0,088 | 0,025 | 0,298 | 0,1502 | 0,00000859 | 0,00299230 |
| **2000** | 0,00660 | 0,00145 | 0,095 | 0,014 | 0,350 | 0,0909 | 0,00000004 | 0,00571131 |
| **2001** | 0,00678 | 0,00165 | 0,089 | 0,015 | 0,285 | 0,0937 | 0,00000053 | 0,00173595 |
| **2002** | 0,00673 | 0,00155 | 0,089 | 0,014 | 0,293 | 0,0880 | 0,00000002 | 0,00791282 |
| **2003** | 0,00674 | 0,00129 | 0,094 | 0,012 | 0,353 | 0,0791 | 0,00000347 | 0,00137358 |
| **2004** | 0,00664 | 0,00145 | 0,093 | 0,013 | 0,346 | 0,0887 | 0,00000018 | 0,00254747 |
| **2005** | 0,00685 | 0,00188 | 0,085 | 0,016 | 0,257 | 0,1005 | 0,00000104 | 0,00196418 |
| **2006** | 0,00619 | 0,00135 | 0,100 | 0,014 | 0,416 | 0,0966 | 0,00000002 | 0,00773164 |
| **2007** | 0,00427 | 0,00092 | 0,122 | 0,015 | 0,571 | 0,1117 | 0,00185159 | 0,00100980 |
| **2008** | 0,00584 | 0,00125 | 0,097 | 0,014 | 0,365 | 0,0945 | 0,00007262 | 0,00131930 |
| **2009** | 0,00565 | 0,00121 | 0,101 | 0,014 | 0,420 | 0,1000 | 0,00001886 | 0,00128222 |
| **2010** | 0,00582 | 0,00086 | 0,093 | 0,009 | 0,310 | 0,0695 | 0,00000002 | 0,00469778 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 47: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for ischaemic heart diseases mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00192 | 0,00026 | 0,144 | 0,010 | 0,304 | 0,0966 | 0,00000004 | 0,00109399 |
| **1998** | 0,00176 | 0,00021 | 0,151 | 0,009 | 0,401 | 0,0898 | 0,00000004 | 0,00087019 |
| **1999** | 0,00167 | 0,00019 | 0,148 | 0,009 | 0,321 | 0,0897 | 0,00000169 | 0,00023556 |
| **2000** | 0,00155 | 0,00017 | 0,150 | 0,008 | 0,327 | 0,0888 | 0,00000003 | 0,00081846 |
| **2001** | 0,00155 | 0,00019 | 0,146 | 0,009 | 0,264 | 0,0963 | 0,00000001 | 0,00202730 |
| **2002** | 0,00143 | 0,00016 | 0,152 | 0,008 | 0,311 | 0,0908 | 0,00000003 | 0,00076167 |
| **2003** | 0,00140 | 0,00016 | 0,148 | 0,009 | 0,249 | 0,0951 | 0,00000005 | 0,00063965 |
| **2004** | 0,00133 | 0,00014 | 0,149 | 0,008 | 0,283 | 0,0899 | 0,00000001 | 0,00171419 |
| **2005** | 0,00115 | 0,00012 | 0,151 | 0,008 | 0,212 | 0,0868 | 0,00000001 | 0,00087869 |
| **2006** | 0,00117 | 0,00011 | 0,148 | 0,007 | 0,129 | 0,0846 | 0,00000001 | 0,00097217 |
| **2007** | 0,00104 | 0,00011 | 0,153 | 0,008 | 0,189 | 0,0943 | 0,00000157 | 0,00014098 |
| **2008** | 0,00104 | 0,00010 | 0,147 | 0,007 | 0,080 | 0,0890 | 0,00000004 | 0,00045654 |
| **2009** | 0,00094 | 0,00010 | 0,148 | 0,008 | 0,068 | 0,0938 | 0,00000002 | 0,00067277 |
| **2010** | 0,00090 | 0,00009 | 0,144 | 0,007 | 0,000 | 0,0940 | 0,00000000 | 0,00135948 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00610 | 0,00142 | 0,106 | 0,017 | 0,145 | 0,0982 | 0,00000204 | 0,00151729 |
| **1998** | 0,00422 | 0,00080 | 0,132 | 0,015 | 0,263 | 0,0939 | 0,00149286 | 0,00089767 |
| **1999** | 0,00483 | 0,00099 | 0,120 | 0,015 | 0,203 | 0,0942 | 0,00060272 | 0,00108764 |
| **2000** | 0,00364 | 0,00073 | 0,130 | 0,015 | 0,194 | 0,0953 | 0,00133448 | 0,00082342 |
| **2001** | 0,00321 | 0,00065 | 0,133 | 0,016 | 0,164 | 0,0976 | 0,00154217 | 0,00074896 |
| **2002** | 0,00255 | 0,00043 | 0,155 | 0,013 | 0,327 | 0,0880 | 0,00200684 | 0,00052681 |
| **2003** | 0,00275 | 0,00050 | 0,146 | 0,014 | 0,270 | 0,0895 | 0,00156509 | 0,00058364 |
| **2004** | 0,00279 | 0,00052 | 0,138 | 0,014 | 0,217 | 0,0910 | 0,00102001 | 0,00059272 |
| **2005** | 0,00273 | 0,00049 | 0,138 | 0,014 | 0,210 | 0,0901 | 0,00088541 | 0,00056531 |
| **2006** | 0,00288 | 0,00056 | 0,130 | 0,014 | 0,134 | 0,0947 | 0,00042559 | 0,00062603 |
| **2007** | 0,00196 | 0,00036 | 0,150 | 0,014 | 0,239 | 0,0972 | 0,00130386 | 0,00042705 |
| **2008** | 0,00165 | 0,00029 | 0,162 | 0,014 | 0,314 | 0,0952 | 0,00145971 | 0,00035141 |
| **2009** | 0,00204 | 0,00041 | 0,137 | 0,015 | 0,100 | 0,1034 | 0,00073720 | 0,00046616 |
| **2010** | 0,00183 | 0,00033 | 0,147 | 0,014 | 0,201 | 0,0992 | 0,00057550 | 0,00037671 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 48: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for cerebrovascular diseases mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00076 | 0,00010 | 0,187 | 0,011 | 0,772 | 0,1112 | 0,00000000 | 0,00225641 |
| **1998** | 0,00081 | 0,00010 | 0,181 | 0,010 | 0,706 | 0,1104 | 0,00000002 | 0,00064822 |
| **1999** | 0,00076 | 0,00009 | 0,187 | 0,010 | 0,798 | 0,1093 | 0,00000000 | 0,00249302 |
| **2000** | 0,00072 | 0,00009 | 0,187 | 0,010 | 0,788 | 0,1077 | 0,00000000 | 0,00212608 |
| **2001** | 0,00074 | 0,00009 | 0,176 | 0,010 | 0,595 | 0,1080 | 0,00000023 | 0,00017883 |
| **2002** | 0,00082 | 0,00010 | 0,167 | 0,009 | 0,499 | 0,1059 | 0,00000000 | 0,00188845 |
| **2003** | 0,00070 | 0,00008 | 0,177 | 0,010 | 0,641 | 0,1102 | 0,00000000 | 0,00206098 |
| **2004** | 0,00064 | 0,00007 | 0,177 | 0,009 | 0,608 | 0,1069 | 0,00000000 | 0,00642890 |
| **2005** | 0,00062 | 0,00007 | 0,168 | 0,009 | 0,497 | 0,1103 | 0,00000000 | 0,00180448 |
| **2006** | 0,00060 | 0,00007 | 0,169 | 0,009 | 0,507 | 0,1060 | 0,00000000 | 0,00138609 |
| **2007** | 0,00057 | 0,00007 | 0,166 | 0,010 | 0,437 | 0,1190 | 0,00000001 | 0,00080683 |
| **2008** | 0,00057 | 0,00006 | 0,166 | 0,008 | 0,360 | 0,1051 | 0,00000000 | 0,01297483 |
| **2009** | 0,00057 | 0,00008 | 0,160 | 0,011 | 0,313 | 0,1295 | 0,00000034 | 0,00013076 |
| **2010** | 0,00047 | 0,00005 | 0,174 | 0,008 | 0,460 | 0,1078 | 0,00000000 | 0,00230813 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00108 | 0,00022 | 0,182 | 0,018 | 0,564 | 0,1251 | 0,00042825 | 0,00027542 |
| **1998** | 0,00112 | 0,00024 | 0,175 | 0,019 | 0,511 | 0,1281 | 0,00040227 | 0,00029415 |
| **1999** | 0,00130 | 0,00026 | 0,161 | 0,017 | 0,446 | 0,1146 | 0,00000000 | 0,00470864 |
| **2000** | 0,00120 | 0,00027 | 0,165 | 0,019 | 0,456 | 0,1267 | 0,00015357 | 0,00031513 |
| **2001** | 0,00087 | 0,00018 | 0,188 | 0,018 | 0,585 | 0,1236 | 0,00031409 | 0,00022495 |
| **2002** | 0,00074 | 0,00017 | 0,193 | 0,019 | 0,601 | 0,1298 | 0,00060169 | 0,00022009 |
| **2003** | 0,00104 | 0,00022 | 0,170 | 0,017 | 0,492 | 0,1180 | 0,00000041 | 0,00028129 |
| **2004** | 0,00098 | 0,00020 | 0,164 | 0,017 | 0,444 | 0,1184 | 0,00000002 | 0,00119448 |
| **2005** | 0,00083 | 0,00018 | 0,172 | 0,018 | 0,469 | 0,1262 | 0,00012483 | 0,00021770 |
| **2006** | 0,00079 | 0,00018 | 0,167 | 0,018 | 0,415 | 0,1312 | 0,00009911 | 0,00021313 |
| **2007** | 0,00088 | 0,00018 | 0,151 | 0,016 | 0,282 | 0,1185 | 0,00000001 | 0,00136088 |
| **2008** | 0,00076 | 0,00016 | 0,172 | 0,017 | 0,476 | 0,1227 | 0,00000015 | 0,00033789 |
| **2009** | 0,00072 | 0,00013 | 0,171 | 0,015 | 0,438 | 0,1163 | 0,00000001 | 0,00106374 |
| **2010** | 0,00073 | 0,00015 | 0,157 | 0,017 | 0,297 | 0,1270 | 0,00000001 | 0,00138260 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 49: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for remaining circulatory system diseases mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00073 | 0,00009 | 0,180 | 0,010 | 0,300 | 0,1045 | 0,00000001 | 0,00077146 |
| **1998** | 0,00076 | 0,00009 | 0,178 | 0,010 | 0,350 | 0,1006 | 0,00000000 | 0,00193938 |
| **1999** | 0,00076 | 0,00008 | 0,178 | 0,009 | 0,319 | 0,0932 | 0,00000000 | 0,00125606 |
| **2000** | 0,00075 | 0,00008 | 0,179 | 0,009 | 0,358 | 0,0966 | 0,00000001 | 0,00074627 |
| **2001** | 0,00076 | 0,00008 | 0,171 | 0,009 | 0,224 | 0,0945 | 0,00000001 | 0,00108377 |
| **2002** | 0,00074 | 0,00008 | 0,168 | 0,008 | 0,143 | 0,0909 | 0,00000001 | 0,00098987 |
| **2003** | 0,00072 | 0,00008 | 0,166 | 0,009 | 0,091 | 0,0963 | 0,00000000 | 0,00115224 |
| **2004** | 0,00059 | 0,00006 | 0,180 | 0,009 | 0,261 | 0,0975 | 0,00000001 | 0,00053287 |
| **2005** | 0,00061 | 0,00005 | 0,182 | 0,007 | 0,348 | 0,0834 | 0,00000001 | 0,00071468 |
| **2006** | 0,00055 | 0,00005 | 0,189 | 0,008 | 0,402 | 0,0937 | 0,00000000 | 0,00278632 |
| **2007** | 0,00057 | 0,00005 | 0,187 | 0,007 | 0,304 | 0,0918 | 0,00000000 | 0,00162733 |
| **2008** | 0,00051 | 0,00005 | 0,188 | 0,007 | 0,277 | 0,0907 | 0,00000000 | 0,00088083 |
| **2009** | 0,00057 | 0,00005 | 0,180 | 0,007 | 0,258 | 0,0915 | 0,00000000 | 0,00097773 |
| **2010** | 0,00060 | 0,00005 | 0,176 | 0,007 | 0,139 | 0,0860 | 0,00000001 | 0,00058636 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00155 | 0,00031 | 0,153 | 0,017 | 0,150 | 0,1074 | 0,00000129 | 0,00035912 |
| **1998** | 0,00180 | 0,00042 | 0,139 | 0,019 | 0,093 | 0,1194 | 0,00002579 | 0,00047548 |
| **1999** | 0,00150 | 0,00027 | 0,156 | 0,015 | 0,188 | 0,1009 | 0,00000010 | 0,00071226 |
| **2000** | 0,00125 | 0,00025 | 0,162 | 0,016 | 0,165 | 0,1068 | 0,00045020 | 0,00030189 |
| **2001** | 0,00153 | 0,00033 | 0,146 | 0,017 | 0,097 | 0,1105 | 0,00000001 | 0,00222550 |
| **2002** | 0,00083 | 0,00016 | 0,192 | 0,016 | 0,367 | 0,1052 | 0,00061042 | 0,00020846 |
| **2003** | 0,00123 | 0,00025 | 0,155 | 0,016 | 0,126 | 0,1063 | 0,00022616 | 0,00030371 |
| **2004** | 0,00057 | 0,00011 | 0,215 | 0,016 | 0,498 | 0,1102 | 0,00076248 | 0,00016484 |
| **2005** | 0,00081 | 0,00015 | 0,192 | 0,015 | 0,375 | 0,1038 | 0,00043944 | 0,00019526 |
| **2006** | 0,00059 | 0,00011 | 0,212 | 0,015 | 0,478 | 0,1074 | 0,00073920 | 0,00016083 |
| **2007** | 0,00079 | 0,00014 | 0,191 | 0,015 | 0,358 | 0,1058 | 0,00044142 | 0,00018691 |
| **2008** | 0,00061 | 0,00011 | 0,205 | 0,015 | 0,437 | 0,1063 | 0,00059461 | 0,00015310 |
| **2009** | 0,00046 | 0,00008 | 0,226 | 0,015 | 0,565 | 0,1092 | 0,00077547 | 0,00012844 |
| **2010** | 0,00063 | 0,00011 | 0,199 | 0,015 | 0,349 | 0,1098 | 0,00056424 | 0,00015241 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 50: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for respiratory system diseases mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00050 | 0,00012 | 0,147 | 0,017 | 0,000 | 0,1648 | 0,00009300 | 0,00014396 |
| **1998** | 0,00043 | 0,00011 | 0,148 | 0,018 | 0,066 | 0,1751 | 0,00025472 | 0,00013869 |
| **1999** | 0,00062 | 0,00015 | 0,133 | 0,017 | 0,000 | 0,1638 | 0,00004444 | 0,00017435 |
| **2000** | 0,00044 | 0,00010 | 0,146 | 0,017 | 0,046 | 0,1692 | 0,00032778 | 0,00013265 |
| **2001** | 0,00054 | 0,00014 | 0,130 | 0,018 | 0,000 | 0,1784 | 0,00006418 | 0,00016617 |
| **2002** | 0,00052 | 0,00012 | 0,135 | 0,017 | 0,001 | 0,1676 | 0,00022960 | 0,00015382 |
| **2003** | 0,00054 | 0,00013 | 0,130 | 0,017 | 0,002 | 0,1689 | 0,00013474 | 0,00015896 |
| **2004** | 0,00055 | 0,00015 | 0,125 | 0,019 | 0,000 | 0,2026 | 0,00011531 | 0,00018089 |
| **2005** | 0,00054 | 0,00012 | 0,130 | 0,016 | 0,000 | 0,1612 | 0,00014807 | 0,00014715 |
| **2006** | 0,00048 | 0,00011 | 0,131 | 0,016 | 0,034 | 0,1711 | 0,00016600 | 0,00013970 |
| **2007** | 0,00060 | 0,00014 | 0,122 | 0,016 | 0,030 | 0,1694 | 0,00003596 | 0,00016603 |
| **2008** | 0,00061 | 0,00013 | 0,120 | 0,015 | 0,000 | 0,1594 | 0,00000002 | 0,00083922 |
| **2009** | 0,00058 | 0,00012 | 0,129 | 0,015 | 0,184 | 0,1674 | 0,00000001 | 0,00098546 |
| **2010** | 0,00055 | 0,00014 | 0,114 | 0,017 | 0,057 | 0,1890 | 0,00010906 | 0,00016558 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00093 | 0,00021 | 0,159 | 0,019 | 0,175 | 0,1225 | 0,00000001 | 0,00176281 |
| **1998** | 0,00083 | 0,00018 | 0,160 | 0,018 | 0,178 | 0,1199 | 0,00000000 | 0,00383856 |
| **1999** | 0,00078 | 0,00018 | 0,170 | 0,020 | 0,253 | 0,1312 | 0,00016225 | 0,00022316 |
| **2000** | 0,00093 | 0,00022 | 0,151 | 0,019 | 0,155 | 0,1272 | 0,00000006 | 0,00075420 |
| **2001** | 0,00073 | 0,00021 | 0,154 | 0,023 | 0,128 | 0,1481 | 0,00016172 | 0,00024345 |
| **2002** | 0,00092 | 0,00020 | 0,144 | 0,018 | 0,090 | 0,1146 | 0,00000003 | 0,00097733 |
| **2003** | 0,00076 | 0,00019 | 0,162 | 0,020 | 0,276 | 0,1337 | 0,00007491 | 0,00023142 |
| **2004** | 0,00060 | 0,00016 | 0,170 | 0,021 | 0,308 | 0,1413 | 0,00015502 | 0,00019339 |
| **2005** | 0,00076 | 0,00019 | 0,152 | 0,020 | 0,165 | 0,1340 | 0,00001993 | 0,00022370 |
| **2006** | 0,00070 | 0,00016 | 0,151 | 0,018 | 0,180 | 0,1253 | 0,00000001 | 0,00111914 |
| **2007** | 0,00067 | 0,00015 | 0,149 | 0,017 | 0,127 | 0,1200 | 0,00000012 | 0,00035396 |
| **2008** | 0,00072 | 0,00018 | 0,149 | 0,020 | 0,173 | 0,1395 | 0,00000009 | 0,00049946 |
| **2009** | 0,00063 | 0,00016 | 0,159 | 0,020 | 0,279 | 0,1446 | 0,00000114 | 0,00018085 |
| **2010** | 0,00064 | 0,00017 | 0,152 | 0,020 | 0,304 | 0,1510 | 0,00000000 | 0,00221421 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 51: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for digestive system diseases of mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00032 | 0,00014 | 0,120 | 0,031 | 0,003 | 0,2779 | 0,00000002 | 0,00084000 |
| **1998** | 0,00032 | 0,00011 | 0,122 | 0,025 | 0,020 | 0,2400 | 0,00000000 | 0,00133828 |
| **1999** | 0,00018 | 0,00007 | 0,162 | 0,028 | 0,386 | 0,2845 | 0,00016157 | 0,00008707 |
| **2000** | 0,00026 | 0,00010 | 0,136 | 0,029 | 0,173 | 0,2930 | 0,00009215 | 0,00012271 |
| **2001** | 0,00025 | 0,00010 | 0,128 | 0,029 | 0,000 | 0,2814 | 0,00013288 | 0,00012304 |
| **2002** | 0,00021 | 0,00007 | 0,155 | 0,024 | 0,296 | 0,2545 | 0,00014153 | 0,00009028 |
| **2003** | 0,00026 | 0,00009 | 0,133 | 0,025 | 0,107 | 0,2577 | 0,00007552 | 0,00011279 |
| **2004** | 0,00024 | 0,00009 | 0,134 | 0,026 | 0,084 | 0,2635 | 0,00011656 | 0,00010549 |
| **2005** | 0,00020 | 0,00008 | 0,144 | 0,028 | 0,358 | 0,2976 | 0,00016957 | 0,00009610 |
| **2006** | 0,00032 | 0,00011 | 0,115 | 0,023 | 0,000 | 0,2463 | 0,00000000 | 0,00303479 |
| **2007** | 0,00026 | 0,00010 | 0,122 | 0,026 | 0,000 | 0,2844 | 0,00015604 | 0,00011462 |
| **2008** | 0,00025 | 0,00008 | 0,137 | 0,022 | 0,260 | 0,2530 | 0,00004411 | 0,00009171 |
| **2009** | 0,00028 | 0,00010 | 0,117 | 0,024 | 0,010 | 0,2615 | 0,00009364 | 0,00011684 |
| **2010** | 0,00023 | 0,00008 | 0,119 | 0,025 | 0,000 | 0,2825 | 0,00011166 | 0,00010095 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00011 | 0,00006 | 0,239 | 0,049 | 0,750 | 0,3199 | 0,00052932 | 0,00009927 |
| **1998** | 0,00019 | 0,00011 | 0,175 | 0,047 | 0,295 | 0,3013 | 0,00044851 | 0,00014086 |
| **1999** | 0,00039 | 0,00027 | 0,123 | 0,053 | 0,019 | 0,3212 | 0,00021822 | 0,00029652 |
| **2000** | 0,00051 | 0,00039 | 0,103 | 0,054 | 0,000 | 0,3133 | 0,00009838 | 0,00041592 |
| **2001** | 0,00023 | 0,00013 | 0,160 | 0,044 | 0,274 | 0,2846 | 0,00037027 | 0,00016204 |
| **2002** | 0,00031 | 0,00021 | 0,132 | 0,050 | 0,000 | 0,3042 | 0,00033525 | 0,00024609 |
| **2003** | 0,00008 | 0,00005 | 0,234 | 0,054 | 0,648 | 0,3476 | 0,00069066 | 0,00009799 |
| **2004** | 0,00007 | 0,00005 | 0,231 | 0,059 | 0,622 | 0,3846 | 0,00060698 | 0,00009586 |
| **2005** | 0,00026 | 0,00015 | 0,155 | 0,044 | 0,336 | 0,2904 | 0,00029099 | 0,00017787 |
| **2006** | 0,00021 | 0,00015 | 0,149 | 0,055 | 0,173 | 0,3557 | 0,00053979 | 0,00018416 |
| **2007** | 0,00008 | 0,00005 | 0,215 | 0,050 | 0,559 | 0,3457 | 0,00056229 | 0,00008641 |
| **2008** | 0,00019 | 0,00011 | 0,161 | 0,044 | 0,286 | 0,3054 | 0,00049007 | 0,00014234 |
| **2009** | 0,00010 | 0,00006 | 0,201 | 0,045 | 0,514 | 0,3232 | 0,00047785 | 0,00008803 |
| **2010** | 0,00021 | 0,00017 | 0,130 | 0,059 | 0,000 | 0,3990 | 0,00040409 | 0,00019989 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 52: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for external causes of mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00017 | 0,00008 | 0,144 | 0,034 | 0,084 | 0,3176 | 0,00006227 | 0,00009956 |
| **1998** | 0,00013 | 0,00006 | 0,159 | 0,038 | 0,235 | 0,3661 | 0,00017756 | 0,00008532 |
| **1999** | 0,00015 | 0,00006 | 0,147 | 0,032 | 0,111 | 0,3160 | 0,00014358 | 0,00008277 |
| **2000** | 0,00009 | 0,00004 | 0,173 | 0,031 | 0,222 | 0,3239 | 0,00020415 | 0,00005696 |
| **2001** | 0,00017 | 0,00007 | 0,139 | 0,030 | 0,000 | 0,3001 | 0,00007726 | 0,00009105 |
| **2002** | 0,00015 | 0,00006 | 0,146 | 0,028 | 0,000 | 0,2845 | 0,00010848 | 0,00007750 |
| **2003** | 0,00016 | 0,00006 | 0,147 | 0,026 | 0,000 | 0,2756 | 0,00005621 | 0,00007249 |
| **2004** | 0,00015 | 0,00006 | 0,153 | 0,027 | 0,210 | 0,2834 | 0,00012888 | 0,00007647 |
| **2005** | 0,00013 | 0,00004 | 0,152 | 0,023 | 0,000 | 0,2508 | 0,00020788 | 0,00006134 |
| **2006** | 0,00012 | 0,00004 | 0,153 | 0,026 | 0,000 | 0,2834 | 0,00014793 | 0,00005874 |
| **2007** | 0,00013 | 0,00004 | 0,156 | 0,024 | 0,081 | 0,2747 | 0,00012209 | 0,00005630 |
| **2008** | 0,00013 | 0,00004 | 0,152 | 0,022 | 0,001 | 0,2571 | 0,00013984 | 0,00005694 |
| **2009** | 0,00011 | 0,00003 | 0,157 | 0,022 | 0,000 | 0,2656 | 0,00018479 | 0,00005020 |
| **2010** | 0,00015 | 0,00004 | 0,145 | 0,022 | 0,000 | 0,2581 | 0,00014612 | 0,00006132 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00016 | 0,00010 | 0,176 | 0,052 | 0,172 | 0,3293 | 0,00063507 | 0,00013843 |
| **1998** | 0,00005 | 0,00003 | 0,288 | 0,055 | 1,046 | 0,3617 | 0,00082908 | 0,00008109 |
| **1999** | 0,00009 | 0,00005 | 0,229 | 0,050 | 0,626 | 0,3277 | 0,00069289 | 0,00009863 |
| **2000** | 0,00017 | 0,00012 | 0,164 | 0,059 | 0,106 | 0,3578 | 0,00066547 | 0,00017055 |
| **2001** | 0,00011 | 0,00006 | 0,207 | 0,049 | 0,406 | 0,3192 | 0,00071146 | 0,00010671 |
| **2002** | 0,00019 | 0,00012 | 0,161 | 0,050 | 0,000 | 0,3080 | 0,00059874 | 0,00016602 |
| **2003** | 0,00005 | 0,00003 | 0,259 | 0,048 | 0,641 | 0,3075 | 0,00078696 | 0,00007772 |
| **2004** | 0,00006 | 0,00004 | 0,249 | 0,049 | 0,554 | 0,3180 | 0,00080355 | 0,00008388 |
| **2005** | 0,00008 | 0,00004 | 0,230 | 0,039 | 0,504 | 0,2627 | 0,00082061 | 0,00007616 |
| **2006** | 0,00013 | 0,00007 | 0,197 | 0,044 | 0,354 | 0,2937 | 0,00070317 | 0,00010966 |
| **2007** | 0,00014 | 0,00007 | 0,193 | 0,040 | 0,316 | 0,2735 | 0,00057452 | 0,00010404 |
| **2008** | 0,00007 | 0,00004 | 0,229 | 0,044 | 0,460 | 0,2992 | 0,00073549 | 0,00008525 |
| **2009** | 0,00004 | 0,00002 | 0,272 | 0,049 | 0,728 | 0,3389 | 0,00070509 | 0,00006363 |
| **2010** | 0,00005 | 0,00003 | 0,267 | 0,042 | 0,835 | 0,3047 | 0,00072181 | 0,00006505 |

**Source:** WHOMD and HMD 2014, own elaboration

**Table A. 53: Gamma-Gompertz-Makeham parameter estimates with associated standard errors for the remaining causes of death of mortality in Sweden**

| Females | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | $\hat{a}(y)$ | s.e.$\hat{a}(y)$ | $\hat{b}(y)$ | s.e.$\hat{b}(y)$ | $\hat{\gamma}(y)$ | s.e.$\hat{\gamma}(y)$ | $\hat{c}(y)$ | s.e.$\hat{c}(y)$ |
| **1997** | 0,00078 | 0,00013 | 0,157 | 0,013 | 0,042 | 0,1192 | 0,00028107 | 0,00016807 |
| **1998** | 0,00078 | 0,00012 | 0,162 | 0,011 | 0,080 | 0,1129 | 0,00024454 | 0,00015341 |
| **1999** | 0,00090 | 0,00012 | 0,161 | 0,010 | 0,071 | 0,1031 | 0,00021362 | 0,00015544 |
| **2000** | 0,00084 | 0,00011 | 0,163 | 0,010 | 0,074 | 0,1023 | 0,00028163 | 0,00014563 |
| **2001** | 0,00078 | 0,00009 | 0,177 | 0,009 | 0,240 | 0,0971 | 0,00029554 | 0,00012961 |
| **2002** | 0,00105 | 0,00012 | 0,159 | 0,009 | 0,062 | 0,0925 | 0,00003501 | 0,00015595 |
| **2003** | 0,00081 | 0,00009 | 0,174 | 0,009 | 0,227 | 0,0969 | 0,00026725 | 0,00013174 |
| **2004** | 0,00091 | 0,00010 | 0,165 | 0,009 | 0,144 | 0,0936 | 0,00010794 | 0,00014004 |
| **2005** | 0,00105 | 0,00011 | 0,155 | 0,008 | 0,000 | 0,0864 | 0,00014268 | 0,00014741 |
| **2006** | 0,00105 | 0,00010 | 0,155 | 0,007 | 0,000 | 0,8395 | 0,00000000 | 0,00156225 |
| **2007** | 0,00111 | 0,00011 | 0,159 | 0,007 | 0,102 | 0,0862 | 0,00000000 | 0,00218333 |
| **2008** | 0,00107 | 0,00010 | 0,162 | 0,007 | 0,136 | 0,0833 | 0,00008245 | 0,00013244 |
| **2009** | 0,00106 | 0,00009 | 0,163 | 0,006 | 0,158 | 0,0792 | 0,00000001 | 0,00113051 |
| **2010** | 0,00126 | 0,00011 | 0,155 | 0,006 | 0,096 | 0,0792 | 0,00000013 | 0,00027490 |
| **Males** | | | | | | | | |
| **Year** | $\hat{\boldsymbol{a}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{a}}(\boldsymbol{y})$ | $\hat{\boldsymbol{b}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{b}}(\boldsymbol{y})$ | $\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{\gamma}}(\boldsymbol{y})$ | $\hat{\boldsymbol{c}}(\boldsymbol{y})$ | s.e.$\hat{\boldsymbol{c}}(\boldsymbol{y})$ |
| **1997** | 0,00096 | 0,00028 | 0,151 | 0,024 | 0,036 | 0,1460 | 0,00071413 | 0,00033666 |
| **1998** | 0,00087 | 0,00020 | 0,176 | 0,020 | 0,255 | 0,1282 | 0,00086268 | 0,00026212 |
| **1999** | 0,00143 | 0,00036 | 0,138 | 0,020 | 0,000 | 0,1231 | 0,00034128 | 0,00041719 |
| **2000** | 0,00078 | 0,00017 | 0,191 | 0,018 | 0,351 | 0,1188 | 0,00097608 | 0,00023771 |
| **2001** | 0,00097 | 0,00020 | 0,172 | 0,017 | 0,199 | 0,1126 | 0,00075870 | 0,00026661 |
| **2002** | 0,00168 | 0,00036 | 0,136 | 0,017 | 0,000 | 0,1053 | 0,00000017 | 0,00070695 |
| **2003** | 0,00091 | 0,00020 | 0,177 | 0,017 | 0,240 | 0,1131 | 0,00089307 | 0,00026252 |
| **2004** | 0,00099 | 0,00022 | 0,168 | 0,018 | 0,170 | 0,1163 | 0,00104872 | 0,00028367 |
| **2005** | 0,00174 | 0,00038 | 0,134 | 0,017 | 0,000 | 0,1066 | 0,00000006 | 0,00122316 |
| **2006** | 0,00118 | 0,00023 | 0,161 | 0,016 | 0,162 | 0,1054 | 0,00076226 | 0,00028583 |
| **2007** | 0,00138 | 0,00029 | 0,150 | 0,016 | 0,034 | 0,1098 | 0,00045407 | 0,00034617 |
| **2008** | 0,00108 | 0,00020 | 0,173 | 0,014 | 0,257 | 0,1009 | 0,00084288 | 0,00024867 |
| **2009** | 0,00151 | 0,00027 | 0,151 | 0,014 | 0,117 | 0,0966 | 0,00038284 | 0,00031194 |
| **2010** | 0,00185 | 0,00032 | 0,142 | 0,013 | 0,101 | 0,0961 | 0,00020524 | 0,00036772 |

**Source:** WHOMD and HMD 2014, own elaboration