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Mestrado em Estatística e Gestão de Informação
Master Program in Statistics and Information Management

EVOLUTION OF CARDIOVASCULAR DISEASES IN PORTUGAL AND JAPAN AND ITS IMPACT ON MORTALITY RISK

Sofia Gaspar de Oliveira

Dissertation presented as partial requirement for obtaining the Master's degree in Statistics and Information Management

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Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

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Dissertation presented as partial requirement for obtaining the Master's degree in Statistics and Information Management, with a specialization in Risk Analysis and Management

Advisor: Jorge Morais Mendes

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RESUMO

As doenças cardiovasculares (DCV) são a causa de morte dominante nas últimas décadas em Portugal e em vários países desenvolvidos. Apesar de o número de mortes ter vindo a diminuir, é crucial prever com precisão as taxas de mortalidade, de forma a garantir as estabilidades económica e social futuras. Tendo isto em conta, este estudo foca-se nas duas causas de mortalidade mais comuns dentro do grupo das DCV – doenças isquémicas do coração, DIC, (códigos Classificação Internacional de Doenças 10ª edição, CID-10: I20-I25) e doenças cerebrovasculares, DCBV, (códigos CID-10: I60-I69) –, tendo como objetivo principal investigar as suas evoluções em Portugal e compará-lo com o Japão, um país conhecido pela sua elevada longevidade. Neste contexto, usando dados de 1995 a 2016, agrupados em grupos etários de 5 anos, género e causa de morte, calculam-se os anos de vida perdidos devido a DIC e DCBV durante este período, e as tendências temporais nas taxas de mortalidade são descritas através da aplicação do modelo de Lee-Carter e do modelo bayesiano Idade-Período-Coorte. Posteriormente, as taxas de mortalidade futuras são projetadas até 2035 com base nas tendências passadas, recorrendo ao modelo com melhor desempenho – o modelo de Lee-Carter. Para determinar se a incidência das doenças em estudo pode ser afetada por possíveis alterações futuras na estrutura demográfica portuguesa, a influência que os fatores demográficos e o risco de morte por DCV independente da idade exercem no número correspondente de mortes é quantificada.

No geral, os resultados mostram que é expectável que o decréscimo que se tem vindo a verificar nas taxas de mortalidade continue nos próximos anos, sendo que a probabilidade futura de morte devido a estas doenças aparenta ser mais elevada para o sexo masculino. Apesar de, atualmente, Portugal apresentar uma situação mais desfavorável em termos de DIC e DCBV, é esperado que esta se reverta no futuro.

PALAVRAS-CHAVE

Doenças cardiovasculares| Modelo BAPC | Modelo de Lee-Carter | *Risk-Diff tool* | Rácios de mortalidade padronizados | Anos de vida perdidos

ABSTRACT

Cardiovascular diseases (CVD) have been the dominant cause of death in the last decades in Portugal and in several developed countries. Although the number of deaths has been declining, it is crucial to accurately forecast death rates to guarantee future economic and social stability. With that in mind, this study focuses on the two most common causes of death within CVD – ischaemic heart diseases, IHD, (International Classification of Diseases 10th edition, ICD-10, codes: I20-I25) and cerebrovascular diseases, CBVD, (ICD-10 codes: I60-I69) –, aiming to investigate their evolution in Portugal and compare it with Japan, a well-known country for its high longevity. In this context, using data from 1995 to 2016, grouped by 5-year age groups, gender and cause of death, years of life lost from IHD and CBVD during this period are calculated and time trends in death rates are described through the application of the Lee-Carter (LC) and the Bayesian Age-Period-Cohort (BAPC) models. Future mortality rates are projected until 2035 based on past trends using the best performing model – the LC model. To determine if the incidence of the diseases under study can be affected by possible future changes in the Portuguese demographic structure, the influence of demographic factors and age-independent risk of death by CVD on the change in the corresponding number of deaths is quantified.

Overall, findings show that the current decrease in mortality rates is likely to continue in the following years, with men being more prone to decease due to these diseases than women. Although Portugal currently presents a worse situation in terms of IHD and CBVD, this is expected to be reverted in the future.

KEYWORDS

Cardiovascular diseases | BAPC model | Lee-Carter model | *Risk-Diff* tool | Standardised mortality ratios | Years of life lost

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LIST OF ABBREVIATIONS AND ACRONYMS

APC	Age-Period-Cohort
ARIMA	Autoregressive Integrated Moving Average
BAPC	Bayesian Age-Period-Cohort Model
BRICS	Brazil, Russia, India, China and South Africa
CVD	Cardiovascular Diseases
CBVD	Cerebrovascular Diseases
CMR	Crude Mortality Rate
DSMR	Directly Standardised Mortality Rate
GBD	Global Burden of Disease
HDI	Human Development Index
HCD	Human Cause-of-Death Database
HMD	Human Mortality Database
ICD-10	International Classification of Diseases 10^{th} edition
IHD	Ischaemic Heart Diseases
INE	Instituto Nacional de Estatística
ISMR	Indirectly Standardised Mortality Rate
LC	Lee-Carter Model
MAPE	Mean Absolute Percentage Error
MIR	Mortality-to-Incidence Ratio
MSE	Mean Squared Error
RW1	Random Walk Prior Order 1
RW2	Random Walk Prior Order 2
SMR	Standardised Mortality Ratio
SRR	Standardised Rate Ratio
SVD	Singular Value Decomposition
YLL	Years of Life Lost

1. INTRODUCTION

1.1. BACKGROUND AND PROBLEM IDENTIFICATION

Nowadays, it is no secret that life expectancy has been increasing over the past years all over the world and therefore, people are surviving in more significant proportions to older ages. Portugal is no exception, going from estimates of life expectancy at birth of 73.10 years for men and 79.84 for women in 1999-2001 to 78.07 for men and 83.67 for women in 2017-2019. (Instituto Nacional de Estatística [INE], 2021a)

The increase in the average life expectancy, especially in advanced countries, goes hand in hand with a decrease in mortality rates at all ages but particularly at younger ages, and a reduction in the variability of the age of death. The lower mortality rates can be highly associated, not only in Portugal, but in several areas of the world, with the notorious decline in mortality caused by diseases of the circulatory system, commonly referred to as cardiovascular diseases (CVD), since they comprise specific diseases that affect the heart and blood vessels.

Nevertheless, several developed countries are recently experiencing a slower mortality improvement compared to earlier decades, which is more evident among elders and women. Cause-of-death statistics suggest that a stagnation in new medical treatments for diseases such as CVD can partly explain this. Continuous poor lifestyle choices concerning smoking, excessive alcohol consumption, unhealthy food and lack of regular physical exercise also play a key role. (Rischatsch et al., 2018)

Worldwide, CVD have remained the leading cause of death for the last decades which still remains the truth. Citing data from INE (2021c), about 33,000 people die each year due to CVD, which continue to be the leading cause of death in Portugal, representing about one-third of all deaths.

Considering the whole Portuguese population (both residents and non-residents in Portugal), although there has been a reduction in the proportion of CVD in total deaths in Portugal, from 31.9% in 2009 to 29.9% in 2019, mortality rates were 324.9 per 100 thousand inhabitants in 2019, which represents the highest value since 2009. In the last decade, there has been a stagnation in mortality rates due to CVD, although with some trend towards a slow increase since 2013. (INE, 2021b)

In light of the above, although mortality from CVD has been declining, these diseases are still widely recognized as a major risk factor to death.

Recently, studies related to human mortality have been extensively conducted to improve the future well-being of individuals. Current mortality improvements are leading people to live longer.

Though being a crowning accomplishment of this century, it also brings significant challenges, such as financial encounters and health complications, to individuals, governments, and private organizations.

Thus, today, more than ever, understanding mortality is fundamental to guaranteeing future stability in social and economic terms. Proper management and measurement of mortality risk can be the key to that, since overestimating mortality rates lies at the bottom of health insurance, long-term care systems and/or defined benefit pension schemes being mispriced. The contrary, that is, underestimating mortality rates, is no better because it could trigger the insolvency of these schemes. Unfortunately, even small changes to mortality assumptions can bring dramatic financial effects.

1.2. OBJECTIVES OF THE STUDY

Since CVD ranked first in terms of the cause of death in Portugal, the main objective of this study is to analyse their evolution and its impact on mortality within the Portuguese population. To provide a deeper insight of the incidence of these diseases in the country, a comparison with Japan, which is one of the countries with the highest average life expectancy, will be made. Comparing both populations will allow a better understanding of how Portugal stands in terms of the evolution of CVD relative to other countries, namely a well-known country for its high longevity.

This study aims to derive mortality rates for Portugal and Japan, with particular relevance for two types of CVD – ischaemic heart diseases (IHD) and cerebrovascular diseases (CBVD). At a first stage, it is aimed to understand the historical data for both countries, followed by the description of time trends in death rates and years of life lost (YLL) due to these diseases so that the incidence of CVD and its influence on mortality rates in both countries can be compared.

Subsequently, it is intended to measure the contribution of changes in the demographic structure of both countries and the variation in the risk of death from CVD in their corresponding number of deaths.

Finally, stochastic mortality models will be applied to the populations under study, and their performance will be evaluated. The best performing one will be used to project mortality rates due to IHD and CBVD for each country for 24 years.

Overall, the main research questions of this dissertation project are:

1. How does Portugal stand in mortality evolution due to IHD and CBVD relative to one of the countries with the highest life expectancy, Japan?
2. How do the YLL due to IHD and CBVD have been evolving during the past years in Portugal?
3. Does the study of the demographic structure allow to understand and project future CVD mortality?

1.3. STUDY RELEVANCE AND EXPECTED CONTRIBUTIONS

A proper mortality measure is essential for multiple areas that go beyond assessing the effectiveness of health policies and the assessment of living and development conditions of a population. This is also relevant for aiding in the indexation of the retirement age by old age (Ayuso et al., 2020), to determine the access conditions to public and private social benefits (Bravo, 2019), to serve as a basis for the design and negotiation of capital market solutions to cover the risk of longevity (Bravo, 2021b) and for the development of new risk-sharing insurance products (Bravo, 2021a).

This study intends to predict future CVD mortality, allowing for changes in the age structure of the Portuguese population, in the population size and in the age-independent risk of dying from it. Doing so is expected to lessen the unforeseen changes in mortality rates.

All these variations seem relevant to making proper projections and limiting the uncertainty over future mortality trends that bring several challenges for insurers and governments. Both need to consider the changes either in longevity or mortality risk since these entities are responsible for providing sufficient financial resources to retirees for a longer period than expected in case of improved longevity and families who suffer the premature death of one of its members. Regarding insurance companies, their pricing and reserving must be adjusted accordingly to the variations in a population's mortality dynamics to avoid either overpriced annuities or insolvency cases. (Rischatsch et al., 2018)

Understanding a temporary or a permanent change in the trends is essential because neither mortality nor longevity risks can be totally diversified away or completely hedged. (Rischatsch et al., 2018)

2. LITERATURE REVIEW

2.1. CARDIOVASCULAR DISEASES: DEFINITIONS AND TRENDS

CVD can be defined as abnormal conditions that affect the heart or blood vessels. These include six main groups, as portrayed in Table 2.1.

Table 2.1. Types of CVD (World Health Organization, 2021; Ekong, 2021)

TYPE OF CVD	EXPLANATION OF THE DISORDER
Coronary heart disease	Commonly known as ischaemic heart disease, is a disorder in which the coronary arteries are narrowed and blocked, not delivering enough oxygenated blood to the heart.
Cerebrovascular disease	The condition prevents the blood flow to the brain due to the narrowing or rupture of the blood vessels, blockage of an artery, or, most commonly, thromboembolism.
Peripheral arterial disease	The blood vessels that link the heart to arms and/or legs become too narrow and cannot supply enough blood to these body parts. This is usually caused by atherosclerosis.
Rheumatic heart disease	It occurs after an individual is affected by rheumatic fever, common in developing countries, in which the heart muscle and heart valves become damaged.
Congenital heart disease	Involves a birth malformation in the heart's structure, leading to cases of disability or, in more severe cases, death.
Deep vein thrombosis and pulmonary embolism	Involve the formation of blood clots, often in the legs or arms, that move to the blood vessels of the heart, in case of deep vein thrombosis, or to the lung, in case of pulmonary embolism.

High blood pressure, high cholesterol, diabetes, air pollution and unhealthy lifestyles, including poor eating habits, smoking, alcohol consumption, physical inactivity, mental illnesses, and stress, are major risk factors for developing these diseases. Moreover, some factors beyond control make some individuals more susceptible than others, namely gender, age, heredity, and ethnic background. (Ekong, 2021)

Given the variety of types of CVD and the actual number of contributors to developing these, it is not surprising that CVD rank first in terms of responsibility for the total number of deaths worldwide. Giving attention to the latest data available, more than 30% of all deaths around the world

were caused by CVD, from which more than 75% occurred in low- and middle-income nations. (World Health Organization, 2021)

Early detection of these disorders is crucial to managing and preventing the effects and could be the key to saving many lives. Hence, this notion has motivated the building of several prediction models for the risk of developing CVD. Unfortunately, despite the ambitious motivation, a lot still fails. Damen et al. (2016) reviewed 9965 references and identified 363 prediction models. It was concluded that there is an excess of these models, though most of them are meagrely reported and have not been externally validated and, therefore, are of little use for clinical practice and policy makers.

Nevertheless, several studies have been carried out in the last decades concerning the analysis of past trends and the modelling and forecasting of CVD mortality trends.

Recent work by Amini et al. (2021) deals with the lack of documentation regarding time trends of CVD incidence and mortality across the whole world, not focusing on a specific region of the globe, hence allowing them to become the pioneers in publishing an assessment of the CVD mortality-to-incidence ratio (MIR) worldwide. Under the available ways to measure the burden of CVD, three techniques were used: age-standardised CVD incidence, mortality, and MIR from 1990 to 2017 to identify mean trends between those. Besides, using the marginal modelling approach, the authors studied the longitudinal relationship between those rates and the Human Development Index (HDI) of the countries in the study, splitting them between 'developed' and 'developing', to incorporate the effects of their human development, progress, and living conditions, as well as the disparities between them. Overall, the estimated parameters showed a declining global trend, with only MIR presenting a relatively stable behaviour. Developing countries had a shallower decline in CVD MIR, whilst the developed ones had a faster and more pronounced decline in CVD incidence.

Most research focuses on specific regions worldwide rather than conducting a global analysis as Amini et al. (2021) did. An example of that is the study of Zou et al. (2020) which provides a general review of the CVD trend between 1992 and 2016 across the BRICS - a term used to designate a group of five emerging economies formed by Brazil, Russia, India, China and South Africa. Findings show that although CVD age-standardised mortality rates have decreased more significantly in North America, BRICS also reflected the same tendency, with Brazil having the highest decreases and only South Africa experiencing an increase. These results reflect the higher CVD mortality in low- and middle-income countries compared to high-income ones, thus being in accordance with Amini et al. (2021). The authors also restricted their analysis to subtypes of CVD, finding that age-standardised mortality rates from IHD have increased, on average, 2% across the BRICS. More encouraging news come with the decrease in deaths caused by stroke and hypertensive heart diseases. Through age-period-cohort

modelling, an exponential distribution for the age effects was observed, with the steepest increases for Russia and India. Across the period studied, improvements for the population – period effects – were evident for Brazil and China, but not for India. Besides, Brazil presented the most remarkable improvements across birth cohorts.

Joinpoint regression analysis are commonly used to identify significant annual changes in standardised mortality rates. Siqueira and Souza (2020) published a study regarding the main CVD mortality trends specifically in Brazil - acute myocardial infarction, stroke, and heart failure -, using standardised mortality rates and, with a joinpoint regression analysis, the annual percentage change was calculated to analyse significant variations in the trend curve. Results revealed general decreasing trends, though varying according to the Brazilian geographic region, and predictions also indicated men were more liable to be affected than the female gender. Wilson et al. (2017) applied the same methods, but for the UK population and with the intent to investigate changes from CVD to cancer as the leading cause of death. Their findings show that both diseases have been decreasing, though the downtrends in cancer mortality rates have slowed down since the 1990s and therefore, in 2011, death rates from cancer surpassed CVD death rates in both sexes.

Boumezoued et al. (2019) examined the interaction of several causes of death on granular US mortality rates. The study included CVD, dementia, diabetes, and neoplasms. The authors used the Lee-Carter (LC) model to forecast 15 years of death rates, with the calibration period being 1999 to 2016, and compared the results for a by-cause model and an all-causes model. Results have shown that the by-cause projection is a more pessimistic one for both gender and all age groups. The model projected a decrease in death rates relative to CVD which is in line with Siqueira and Souza (2020). However, in the case of males, the fast decline observed during the beginning of the century would not persist in the future.

Still regarding the US mortality, Pearson-Stuttard et al. (2016) also explored CVD mortality from 1979 to 2012, separating the results between coronary heart diseases and strokes, stratified by age, sex, and race/ethnicity. Using a hierarchical Bayesian Age-Period-Cohort (BAPC) model, the authors forecasted rates under two scenarios: firstly, considering a conventional model which assumes constant age, period, and cohort effects at 2012 values, and then a trend-based model incorporating expected trends in the same effects. According to the first model, both coronary and stroke deaths will increase by 2030. On the contrary, the second model contrasted the conventional projections, and it predicted a decrease in coronary mortality and unchanging stroke mortality, counteracting the ageing and growing population. The authors also expect that ethnicity will remain to cause disparities in mortality.

2.1.1. The case of Japan

It is a well-known fact that Japan is among the countries that present a highest life expectancy, even having a city being part of the so-called Blue Zones – a term coined to designate the home of an uncommonly high number of centenarians, and which includes Loma Linda, US; Nicoya, Costa Rica; Sardinia, Italy; Ikaria, Greece; and Okinawa, Japan.

Be that as it may, this was not always the case. Tsugane (2021) depicted that Japan had the lowest life expectancy in the group of the seven most industrialized countries during the sixties. Still, needless to say, the situation reverted, turning into the one with the highest life expectancy. Changes in the diet, which led to notable decreases in mortality from CBVD and stomach cancer, coupled with the already existent low rates for IHD and cancer, were identified by the author as being amongst the main reasons for the current longest life expectancy and healthy life expectancy, for both genders, and the high longevity, especially for females.

The downtrend of mortality rates from stroke and IHD which have been evident since 1960s was also portrayed in a recent study conducted by Iso (2021). Once more, the increase of longevity was ascribed to the mortality dynamics experienced in Japan. Compared with western countries - namely France, UK, and US -, Japan has shown steeper reductions in stroke death rates than the others and, despite the same cannot be said about IHD, the Asian country has also demonstrated substantial decreases in these rates. Improvements in socioeconomic and medical conditions can be credited for these trends. Still, the author also notes that these have not been equally prominent in all regions, with Tokyo and Osaka verifying the lower reductions, especially the middle-aged male population. Thus, the increase of mortality from IHD in the coming years is not ruled out unless earlier preventions and controls start to occur.

The critical analysis and comparison between the different Japanese municipalities is also registered by Okui (2020), who highlights that disparities in mortality rates and life expectancy have increased over the last few years. Knowing that there are much fewer deaths for various diseases than some years ago does not seem sufficient. This is where the author comes in, covering the lack of recent available information regarding the relationship between socioeconomic status and the change in the mortality rate for each cause of death. By grouping the regions according to their socioeconomic status, differences in all-cause and cause-specific standardised mortality rates were calculated using data from 1999 and 2019. On CVD, results have portrayed that mortality rates from stroke, heart disease and IHD were higher in wealthier regions in 1999. In 2019, this remained the truth for IHD, but the situation reverted for stroke and heart disease, with the higher rates being verified in the poorer municipalities. This is consistent with the common idea that low socioeconomic conditions are usually

responsible for people being more susceptible to develop cardiovascular risk factors and having less possibility to attend medical centres and thus, receive treatment for hypertension. The fact that mortality rates from IHD had a different behaviour from the others is also in accordance with previous studies. It is shown that this type of disease is becoming more prominent in Japanese urban areas mainly due to the increase in fat intake on these grounds. Thankfully, the scenario is not so doomed because of the accompanying decrease in blood pressure and smoking rates.

Nonetheless, more important than recognizing the longevity increases is understanding an individual's level of wellness and illness. Martin et al. (2019) focused on this matter by comparing Georgia and Tokyo centenarians' cardiovascular condition and mental abilities. As reported by the authors, the difference in lifestyles and diets between the two countries might explain the differences of the incidence of the diseases, with stroke being more prevalent in Japan, and the majority of CVD, including hypertension, heart disease and myocardial infarction, being more frequently registered in Georgia. Yet, controversially to what would be expected, Japan showed a lower performance of the mental processes, drawing a negative relationship between stroke and cognitive function, whilst blood pressure and hypertension could be positively associated with cognitive function.

2.1.2. The case of Portugal

Portugal is not unfortunate in terms of life expectancy, but it comes on after Japan. According to The World Bank (2019), Portugal revealed an average life expectancy at birth in 2019 of approximately 80.7, ranking 38 in 266 countries, while Japan presented nearly 84.4 for the same indicator.

In the last annual statistics report published by INE (2021b), it was stated that of the 111,834 deaths of residents in Portugal in 2019, 29.9% were from CVD, a 2.1%-increase compared to prior year. In numbers, these correspond to 33,421 deaths attributable to CVD. CBVD and IHD were still responsible for most of them, maintaining the scenario of prior years. Deceased individuals were mostly over the age of 65, corresponding to 91.5% of total deaths, and 54.6% were women. General statistics from 2019 are presented in Table 2.2. for different types of CVD.

Table 2.2. Statistics of different types of CVD in Portugal in 2019. Adapted from INE (2021b).

	CBVD	IHD	Myocardial infarction
Number of deaths	10,975	7,151	4,275
% of total mortality	9.8% (-2.3% than prior year)	6.4% (-1.2% than prior year)	3.8% (-7.5% than prior year)
Mortality rate per 100,000 inhabitants	106.5	68.3	40.7
YLL (on average)	9.3	11.0	11.3
Mainly affected gender	Women (78 deaths of men per 100 women)	Men (137.8 deaths of men per 100 men)	Men (133.2 deaths of women per 100 men)
Average age at death	84.0, for women 79.9, for men	82.1, for women 74.1, for men	81.2, for women 73.2, for men

Recently, Ramalheira et al. (2020) provided an insight into the trends of the Portuguese mortality due to CBVD, resorting to a joinpoint analysis to detect significant temporal variations in the calculated standardised mortality rates. Identically to what was reported by INE (2021b), the author argued that mortality rates increase exponentially with age and, when comparing both sexes, the number of CVD deaths was higher for women. However, the age-standardised death rates have been higher for men at least since 1913. One innovative analysis conducted by the authors was regarding the contribution of different factors to the number of deaths due to this disease. As argued, changes in Portuguese population size were responsible for modest increases in the number of CVD deaths, namely increases of 1.19% and 0.89% per year in the periods 1913-1933 and 1933-1955, respectively. The fact that the population has been getting older and older was also assigned to be the cause of increases in these deaths, mainly after the fifties, going from contributions of 1.61% per year between 1955 and 1974 to 2.96% between 1996 and 2012. Besides these, the contribution of unmeasured risk factors was more fluctuating, presenting either a positive or negative contribution to the change in the number of deaths. Yet, since 1974 and with a tendency to increase in absolute value, the risk has been diminishing, contrasting with the pressure exerted by the population ageing. A word of caution is necessary because findings demonstrated that these diseases are particularly evident in Portugal if comparisons are to be made with other European nations. However, it has been decreasing in the last decades. Unfortunately, the authors failed to perform any forecasts of death rates, which would be helpful to have a general understanding of the panorama that the Portuguese population should expect.

2.2. MAIN CONCEPTS INVOLVED: LIFE EXPECTANCY, MORTALITY AND LONGEVITY RISK

Life expectancy, much-discussed above, can be defined as a statistical measure of the average length of an individual's life, based on their year of birth, current age, and other demographic factors, including their gender. This measure aims to assess and establish many important policies associated with longevity risk. It can be analysed from two different perspectives: cohort and period.

A cohort life expectancy shows the probability that a person in a given cohort will die at each age throughout their life. Calculated using mortality data for each specific cohort, it considers any observed and projected improvements in its mortality over its lifetime. On the other hand, period life expectancies use mortality rates for a single year (or group of years) and assume that these rates apply throughout the individual's life, meaning that any future changes to mortality rates will not be taken into account.

More often than not, the concept of mortality risk is confused with longevity risk despite their noticeable differences. Mortality risk refers to the probability of actual mortality differing from the expected. On the contrary, longevity risk consists of the phenomenon of people living longer than expected. Life insurers, government pensions systems and defined-benefit pension schemes are more concerned with the latter, though also need to watch over mortality risk.

2.3. CHALLENGES OF LONGEVITY FOR ALL SOCIETAL INSTITUTIONS

As Amini et al. (2021) stated, “Today, CVD is responsible for a remarkable reduction in quality of life and life expectancy” (p. 2). Nonetheless, despite the negative contribution of these diseases to the increase in average life expectancy, the total number of deaths attributable to CVD has been falling, so everything indicates that societies will continue to face an increase in longevity.

More worrisome than the fact that individuals will live until an older age is the imminent demographic transition to an aged population where the active working population is relatively modest, hence passing the burden of supporting the elderly onto themselves. To be able to do so, they require assistance from social security and health care, which subsequently, need financial help from the governments. (Harper, 2019) Considering the huge financial needs of elders, especially for medical treatments for disorders such as CVD, and the imperative necessity for liquidity to face those, this generation is seen most of the time as a burden to society.

Keeping in mind the common desire to neither let the elderly run out of resources, possibly foregoing an acceptable standard of living, nor burden the national economies and the new generations, all societal institutions fear how the increase in longevity will impact their retirement

finances. If longevity estimates were accurate, there would be no significant issue. However, lately, these have been anything but precise, usually underestimating it. (Aon Hewitt, 2016)

Estimating longevity is not plain and simple as recent mortality trends have been quite volatile and it cannot be precisely known if past trends will persist or if there will be a major event changing them. Factors such as demographic structures and socio-economic profiles, for instance, also need to be considered for the estimations. (Aon Hewitt, 2016)

Longevity risk affects pension funds, governments who provide defined retirement benefits, and life insurers who might end up having a higher net present value of their annuity payments than initially expected due to the increase of the length of the payment period. (Antolin, 2007) The fact that pensions will be paid for a more extended period means this will cost more money. According to the Organization for Economic Cooperation and Development, each additional year of life expectancy not considered in a model could lead to a 3% to 5% increase in liabilities. (Rischatsch et al., 2018)

In light of the fact the state is finding difficulty in ensuring the required amount to provide individuals with a way to deal with those needs and guarantee them a comfortable standard of living, and also to avoid underfunded pension funds, private pension schemes have appeared as part of the answer. Not all is rosy, however, with this alternative. (Weinert & Gründl, 2020)

It is well-known there are already major concerns with the persistent fall of discount rates and, consequently, the increase of liabilities, so dodging additional concerns regarding an ageing crisis and its financial impact would be appreciated. On this basis, actuaries have been looking, in the last decades, for solutions to deal with the challenges of an ageing population.

3. METHODOLOGY

3.1. DATA SOURCES

Population Demographics

Mortality data for Portugal and Japan, specifically deaths and exposure-to-risk information, is available from 1940 to 2020 and from 1947 to 2019, respectively, in Human Mortality Database (HMD), which is a resource, first published in 2002, that provides mortality and population data for 41 developed countries. The data was then narrowed from 1995 to 2016 for each sex and 5-year age group.

CVD Mortality

Information relative to mortality from CVD was extracted from INE and Human Cause-of-Death Database (HCD) for Portugal and Japan, respectively.

INE is a Portuguese institution created in 1935 responsible for collecting and sharing all kind of official statistical data. HCD, developed by the French Institute for Demographic Studies in France and the Max Planck Institute for Demographic Research in Germany, consists of a database that groups mortality data of 16 countries classified into three fixed lists: short, intermediate, and full causes of death.

For this study, concerning Portugal, the following indicator was used: "Deaths (No.) by Place of residence (NUTS-2013), Sex, Age group and Death cause (European short-list)", which has data available from 1991 to 2019. The list of death causes is made up of a set of causes selected from International Classification of Diseases 9th edition and 10th edition (ICD-10). It has been chosen only the leading two death causes from the group of CVD - IHD and CBVD.

Concerning Japan, the HCD provides death counts and several types of death rates by gender, 5-year age groups and cause of death - from 1995 to 2016. Using the complete list of causes, in which data is split according to the ICD-10, age-specific death rates were extracted for IHD (codes I20-I25) and CBVD (codes I60-I69).

To have the same data available for both countries, and as less data was presented for Japan, the Portuguese indicator mentioned above was selected for these same dimensions, using 1995 to 2016 as the data reference period and selecting only Portugal for the place of residence, thus excluding foreigners since these might be subject to different external factors and have some different lifestyles.

The indicator was later divided by the exposure-to-risk information previously extracted from the HMD, to obtain the respective death rates for each age group.

3.2. METHODS

3.2.1. Measures of quantitative mortality

General notation

Two measures commonly used to quantify mortality are the probability of death (also known as initial rate of mortality), $q_{x,t}$, and the central rate of mortality, $m_{x,t}$. The difference between the two relies on the fact that $q_{x,t}$ is the probability of an individual aged x dying within the next year, and it is calculated by dividing the number of individuals with age x that deceased during time t, $d_{x,t}$, by the number of individuals alive at age x, $l_{x,t}$, whereas $m_{x,t}$ is the probability of someone aged between x and x + 1 dying before attaining age x + 1, being obtained by dividing $d_{x,t}$ by the expected number of individuals living between ages x and x + 1, $\int_0^1 l_{x+t}\, dt$, that is, the number of individuals with age x that are exposed to risk at time t, $E_{x,t}$. The first measure is inconvenient since it assumes that individuals at age x remain alive until age x + 1, thus not considering possible deaths during the year and not disregarding those members who will not be exposed to risk during the whole year. Hence, for population studies, $m_{x,t}$ is usually more suitable to use.

Regarding notation being used in the following sections, a superscript "s" is always added on the right of the variable in study every time the standard population is mentioned.

3.2.1.1. Crude mortality rate

The crude central mortality rate of a population is computed by dividing total deaths observed during time t by the total number of individuals exposed to risk during that time. If data is split into N age groups $(i = 1, \dots, N)$, the calculation is similar. Still, it starts by calculating a crude central mortality rate (CMR) for each age group and then, summing it all up to obtain the total crude central mortality rate for the population in the study.

$$CMR = \sum_{i=1}^{N} CMR_i = \frac{\sum_{i=1}^{N} E_i m_i}{\sum_{i=1}^{N} E_i}$$

It is tempting to compare crude mortality rates when comparing two or more populations. However, this can be misleading because these are overall average disease rates and disregard the cases in which the populations being compared have different distributions of other determinants of

disease, such as the age structure. Since age is associated with the risk of mortality, comparing crude rates seems unfair because of unequal age distributions between populations. An example of a confounding situation is demonstrated below in Table 3.1.

Table 3.1. Example of a confounding situation using crude mortality rates to compare two populations.

	POPULATION A			POPULATION B		
Age group (i)	**Number of People**	**Number of Deaths**	$\boldsymbol{CMR_i}$	**Number of People**	**Number of Deaths**	$\boldsymbol{CMR_i}$
30-39	15,000	150	0.010	10,000	100	0.010
40-49	15,000	300	0.020	12,000	240	0.020
50-59	15,000	500	0.033	15,000	500	0.033
60-69	15,000	1,050	0.070	25,000	1,750	0.070
Total	**60,000**	**2,000**	**0.033**	**62,000**	**2,590**	**0.042**

As illustrated, although population B appears to have a greater risk of death, the higher crude rate it presents is because a more significant proportion of older people in this population have an inherently more substantial risk of dying. Therefore, the overall crude rate is more heavily weighted by the age-specific rate among the older people of this population.

3.2.1.2. Standardised rates

In order to have a less distorted comparison, a technique known as standardisation is commonly used on the grounds that it allows the computation of summary rates that are adjusted to take into account differences in confounding factors.

There are two types of standardisations: direct and indirect. Directly standardised mortality rates (DSMR) are obtained by applying a standard population distribution to the populations being studied. This way, it is assumed that both have the same age distribution.

$$DSMR = \frac{\sum_{i=1}^{N} E_i^s m_i}{\sum_{i=1}^{N} E_i^s}$$

In other words, this measure consists of a weighted average of the mortality rates of each age group of the population under study, with the weights being the proportions of each age group in the standard population, $w_i^s = \frac{E_i^s}{\sum_{i=1}^{N} E_i^s}$

$$DSMR = \sum_{i=1}^{N} w_i^s m_i$$

If age-specific rates for the populations being compared are known, this is generally the measure chosen.

When this information is unavailable, indirectly standardised mortality rates (ISMR) arise as an alternative. The crude mortality rate for the standard population is multiplied by the ratio of actual to expected deaths in each age group.

$$ISMR = \frac{\sum_{i=1}^{N} E_i^s m_i^s}{\sum_{i=1}^{N} E_i^s} \times \frac{\sum_{i=1}^{N} E_i m_i}{\sum_{i=1}^{N} E_i m_i^s}$$

Defining the ratio of the actual number of deaths to the expected number of deaths as the standardised mortality ratio (SMR), it follows that:

$$ISMR = CMR^s \times SMR$$

Thereby, a SMR higher than 1 means that the risk of death in the study population is higher than that in the standard population and the opposite is true when the SMR is lower than 1.

The idea behind the indirect standardisation relies on taking the observed number of deaths in the study population and comparing it to the expected number if its mortality experience was the same as for the standard population.

In short, the study population provides the rates in direct standardisation, and the standard population provides the weights. In opposition, the roles are inverted in indirect standardisation, with the study population providing the weights and the standard population providing the rates. Because of that, in the indirect method, the study population can only be compared to the standard population, since the rates are both based on weights from the study population, whereas DSMR can be compared to each other and to the standard population, because these are all based on weights of the standard population.

For this study, as age-specific rates are available for both countries, a direct standardisation was employed, using the European Standard Population as of 2013 as the standard population. To compare the two populations under study, a standardised rate ratio (SRR) was obtained by dividing the DSMR of one population by that of the other.

3.2.2. Stochastic mortality models

Two methods were implemented and applied both to Portuguese and Japanese data to evaluate the mortality dynamics of the populations under study. CVD mortality was analysed separately for both sexes and grouped by 5-year age groups, from 30-34 to 80-84 years old, using data from 1995 to 2016, as aforementioned. This narrowing of age groups aims to exclude children, generally little affected by this type of disease, and older people, since the older they are, the more is the development of health complications which can also affect the onset of cardiovascular diseases and lead to biased results.

As death is an intrinsically unpredictable event, stochastic models seem to be the most appropriate in modelling mortality from a statistical point of view. With these, observed mortality rates in the past result from a random variable, and predicted rates are no more than estimates of random variables that represent future mortality.

3.2.2.1. Lee-Carter model

Firstly, an extrapolative method, namely the Lee-Carter (LC) model, was used. The choice of this method relies on the fact that this is the model most widely used by demographers. It combines a demographic model with time-series forecasting methods, but it only takes age and period effects into account.

Considering that α_x represents the average level of mortality over time for each age, β_x describes the standard deviation of mortality rates by age, k_t is the time trend of mortality and $\varepsilon_{x,t}$ is the residual, that is, the effects not captured by the model, with mean 0 and variance σ_ε^2, the methodology is given by

$$ln(m_{x,t}) = \alpha_x + \beta_x k_t + \varepsilon_{x,t}$$

As the parameterization is not unique, it is necessary to impose two constraints to obtain single solutions in the parameter estimation: 1) $\sum_{x=x_{min}}^{x_{max}} \beta_x = 1$ and 2) $\sum_{t=t_{min}}^{t_{max}} k_t = 0$.

The model assumes no interactions between age and time, meaning that β_x is fixed over the years for each age x and k_t is fixed by age groups for all years. Moreover, no assumptions are made regarding the nature of the trend of k_t.

The sign and magnitude of β_x dictate which mortality rates will be more affected by a change in k_t. Besides, the fact that β_x are monitored so that the sum is unitary, and these are all different, prevents mortality rates from varying in the same proportion. If the parameter is particularly high for

some age x, it would mean that the mortality rate improves quicker at this age than in general. On the contrary, if it is negative at some ages, it would mean that mortality is getting worse at those ages.

To estimate the parameters, the optimization problem is solved in order to minimize $\sum_{x,t}\left[ln(m_{x,t}) - \alpha_x - \beta_x k_t\right]^2$, applying the singular value decomposition (SVD) method to obtain the least squares solution.

In a first stage, the estimation of the parameters $\hat{\alpha}_x$ is carried out which is based on the logarithm of the geometric mean of the central mortality rates over time, for each age x:

$$\hat{\alpha}_x = \frac{1}{T}\sum_{t_1}^{t_n} ln(m_{x,t})$$

After that, the SVD is applied to the matrix $Z_{x,t} = ln(m_{x,t}) - \hat{\alpha}_x = \beta_x k_t$, decomposing it into a product of 3 matrixes:

$$Z_{x,t}^{SDV} = ULV' = L_1 U_{x_1} V_{t_1} + \ldots + L_X U_{x_X} V_{t_X}$$

Where U represents the age component, V represents the time component, that is, the year, and L the respective singular values.

The parameters k_t and β_x can then be determined, defining β_x as the first normalized column, U_{x_1}, and k_t as the multiplication of the first eigenvalue with the first normalized column of the matrix V', $L_1 V_{t_1}$.

Given the fact that the first estimation of k_t is based on the logarithms of the central mortality rates rather than the mortality rates themselves, notable differences can occur between the actual death numbers and the predicted ones. In these cases, k_t should be re-estimated, considering the values already estimated of α_x and β_x.

The model's projection can be based on the standard approach in which there is the application of the autoregressive integrated moving average (ARIMA) methodology, developed by Box and Jenkins in 1976, to the time series corresponding to the level of mortality. According to Lee & Carter (1992), the most suitable ARIMA model is the random walk with the inclusion of a constant (drift). Considering that $\hat{k}_t$ consists of the estimate of k_t and θ is the drift, this model is given by:

$$\hat{k}_t = \theta + k_{t-1} + \epsilon_t\,, \qquad \epsilon_t \sim N(0, \sigma_{rw}^2)$$

Lastly, after modelling the period indexes using time series techniques, forecasts of mortality rates can be derived, considering:

$${}_t q_x = 1 - exp\left(-\mu_x(t)\right), \text{ with } \mu_x(t) = exp(\alpha_x + \beta_x k_t^*)$$

3.2.2.2. Bayesian Age-Period-Cohort Model

As mortality trends from CVD are not marked mostly by period component effects and since cohort effects seem to play an important role, a hierarchical Bayesian Age-Period-Cohort (BAPC) model was also implemented, which uses efficient Markov Chain Monte Carlo methods for estimating the model (Castillo et al., 2014).

Although this model is usually defined as a log-linear Poisson, it can also be regarded as a binomial logit model, considering that the number of deaths from CVD in age group i at time j follows a binomial distribution with parameters $n_{i,j}$, number of individuals of the population that belong to age group i at time j, and $q_{i,j}$, the unknown mortality probability. The logit of the probability of death from CVD in age group i at time j is given by

$$log\left(\frac{q_{i,j}}{1-q_{i,j}}\right) = \mu + \theta_i + \varphi_j + \psi_k, \quad i = 1, \dots I, j = 1, \dots, J, k = 1, \dots, K$$

where $\theta_i, \varphi_j, \psi_k$ are the age, period, and cohort effects, respectively.

In order to ensure the identifiability of the model, that is, even after limitless linear transformations it is still possible to obtain a unique parameter set, some constraints need to be imposed, namely $\sum \theta_i = \sum \varphi_j = \sum \psi_k = 0$. Nonetheless, the problem remains in the case of linear trends. Therefore, and in order to interpret the three age-period-cohort (APC) effects, these must be restricted to non-linear trends because there is no issue regarding non-identifiability whenever there are change points or non-linear trends.

Since APC effects tend to be similar to their adjacent ones, random walk priors of order one (RW1) and two (RW2) are often used to describe that relationship. The difference relies on the fact that the first one assumes a constant time trend and thus, each effect comes from the immediate antecedent. In contrast, the latter presumes a linear time trend, with each of the effects being influenced by the two predecessors.

Although the first- and second-order differences in RW1 and RW2, respectively, are stochastically restricted to zero, this measure only ensures identifiability in the case of RW1, as it keeps the APC effects as constant as possible, not being effective in RW2, due to its linear trend.

As an illustration, in the case of the age effect, the difference priors are given by

$$[RW1] \qquad \theta_i = N(\theta_{i-1}, k^{-1}), i = 2, \dots, I$$

$$q(\theta_1) \propto constant$$

$$[RW2] \quad \theta_i = N(2\theta_{i-1} - \theta_{i-2}, k^{-1}), i = 2, \dots, I$$

$$q(\theta_1) = p(\theta_2) \propto constant$$

where k is a smoothing parameter that follows a gamma distribution, $k \sim G(\alpha, \beta)$, with common initial values $\alpha = 1$ and $\beta = 10^{-3}$, in a RW1, or $\beta = 10^{-5}$, in a RW2.

For the other two effects, the priors are similar, but instead of k, the hyperparameters need to be changed to λ, for the period effect, and v, for the cohort.

To calculate future mortality probabilities for the following n years, $q_{i,J+n}$, future APC effects can be projected, though this is usually not done for age because age groups of interest are already considered. For the first projection, the calculation is done as follows:

$$log\left(\frac{q_{i,J+1}}{1 - q_{i,J+1}}\right) = \mu + \theta_i + \varphi_{J+1} + \psi_{k(i,J+1)}$$

where

$$q_{i,J+1} = \frac{exp\left(log\left(\frac{q_{i,J+1}}{1 - q_{i,J+1}}\right)\right)}{1 + exp\left(log\left(\frac{q_{i,J+1}}{1 - q_{i,J+1}}\right)\right)}.$$

Given the non-identifiability of the model, it is not possible to interpret the parameters of a RW2. Therefore, considering that interpolation should not differ too much when using a RW1 or RW2, a RW1 was estimated to understand the APC effects.

Considering the data used, I, the total number of age groups, and J, the total number of periods, are 11 and 22, respectively. Each cohort is defined by $k = C(I - i) + j$, with C, the width of age bands, equal to 5. Thus, the total number of cohorts is given by $K = C(I - 1) + J = 72$.

3.2.2.3. Goodness-of-fit

As a means to assess the performance of the models in terms of in-sample goodness-of-fit to predict long-term mortality rates, data from 1995 to 2011 (train data) was used to generate forecasts of mortality rates from 2012 to 2016 (test data).

So that both models could be comparable, the probabilities of death, used by BAPC model, had to be converted into mortality rates, which the LC model uses. The conversion can be done using the formula:

$$m_{i,j} = \frac{q_{i,j}}{1 - \frac{q_{i,j}}{2}}$$

The predictive power of each model was evaluated by computing the mean absolute percentage error for each age group i for J periods, $MAPE_i$, between the projections obtained, f_{ij}, and the observed death rates, y_{ij}, and the mean squared error, MSE_i. These are calculated as follows:

$$MAPE_i = \left(\frac{1}{J} \times \sum_{j=1}^{J} \left| \frac{y_{ij} - f_{ij}}{y_{ij}} \right| \right)$$

$$MSE_i = \left(\frac{1}{J} \times \sum_{j=1}^{J} \sqrt{(f_{ij} - y_{ij})^2} \right)$$

The MAPE is an average of the absolute values of all errors, that is, the deviations of the observations whereas the MSE indicates the average of the squares of the errors, allowing one to reduce the effect of errors associated with high values of $f_{i,j}$, generally associated with more advanced age groups. Evidently, the lowest these statistic measures, the better the model's performance.

Once the best performing model was chosen, this was used to produce mortality forecasts from 2017 to 2035.

R software was used to compute the previously described methods, namely the packages *StMoMo* and *bamp* for the LC and for the BAPC models, respectively.

3.2.3. Factors of change in the incidence/mortality from CVD

Afterwards, to quantify the percentage of change in the Portuguese incidence or mortality from CVD attributable both to demographic factors (age structure and population size) and to changes in the risk of developing or dying from the disease, the method proposed by Bashir and Estève (2000) was implemented. Mortality data from CVD in Portugal from 1995 was used as the baseline group to compare the same data from 2016.

Let $\lambda_{i,j}$ be the crude mortality rate for age group i in year j, and $\omega_{i,j}$ the proportion of the population in age group i in year j, with $j \in \{1995, 2016\}$, i.e.,

$$\lambda_{i,j} = \frac{number\ of\ deaths\ from\ CVD\ in\ year\ j\ for\ age\ group\ i}{total\ population\ in\ year\ j}$$

$$\omega_{i,j} = \frac{number\ of\ individuals\ in\ age\ group\ i\ in\ year\ j}{total\ population\ in\ year\ j}$$

Hence, the crude mortality rates from CVD in Portugal in year j can be expressed as

$$S_j = \sum_i \lambda_{i,j}\ \omega_{i,j}$$

Finally, the relative difference in the crude rates between 1995 and 2016 can be split into the two components below.

$$\frac{S_{2016} - S_{1995}}{S_{1995}} = \frac{S_{2016} - S_{1995,2016}}{S_{1995}} + \frac{S_{1995,2016} - S_{1995}}{S_{1995}},$$

where $S_{1995,2016} = \sum_i \lambda_{i,1995}\ \omega_{i,2016}$ is the expected number of deaths in 2016 for a total population if the risk was the same than for the population of 1995.

The first parcel on the right-hand of the equation represents the differences in the risk and the second one, the differences in the population structure.

This method is particularly useful since, besides measuring the contribution of changes on the risk of dying from the disease itself, it also considers demographic factors, which cannot be done by simply using standardised mortality rates.

3.2.4. Years of life lost

The total number of deaths from CVD does not provide a good measure of overall mortality forasmuch as it attributes the same weight to all deaths, be it at age 80 or 30. Hence, the years of life lost (YLL) arises as an alternative measure as it determines premature mortality caused by CVD, considering the frequency of deaths and the age at which it occurs.

Given the vastness of different approaches available to estimate the YLL, the Global Burden of Disease (GBD) method was chosen. This indicator is calculated by multiplying the number of deaths at each age group by the life expectancy at which death occurs, e_x. In that way, it can be defined as follows:

$$YLL\ =\ (d_x)(e_x^s)$$

Since the data used was organized into 5-year age groups, the average age at death was considered the mid-point of each age group. Life expectancy at each age was extracted from the life tables for each country available in HMD for each year under analysis.

Further extensions to the basic formula were designed in order to incorporate time discounting and age weighting. The appliance of a discount rate aims to assign less weight to future mortality than to the current mortality outcomes. Moreover, the use of age weighting targets to consider the productive years of life as more valuable than the very young or the very old, which are therefore assigned less weight. Nonetheless, to avoid the introduction of these age-weights alters the total number of YLL, a correction constant should also be applied. To account for all these adjustments, the following formula is used:

$$YLL = d_x\left[\frac{KCe^r(n^a x)}{(r+\beta)^2}(e^z[-(r+\beta)(e_x^s+a_x)-1]-e^{-(r+\beta)a_x}[-(r+\beta)a_x-1]])+\frac{1-K}{r}(1-e^{r(e_x^s)})\right]$$

where

a = age of death (in years)

r = discount rate

β = age weighting constant

K = age weighting modulation constant

C = adjustment constant for age-weights

e = standard life expectancy at age of death

The values of the parameters were set equal to those defined in the 1990 GBD study, meaning that $r = 3\%$, $\beta = 0.04$, $K = 1$, and $C = 0.1658$.

Finally, to find the total YLL for each cause and gender, the YLL of all age groups were summed up.

4. RESULTS AND DISCUSSION

4.1. STATISTICAL MORTALITY ANALYSIS

4.1.1. General mortality

The mortality evolution in Portugal and Japan is consistent with the dynamics verified for the developed countries worldwide.

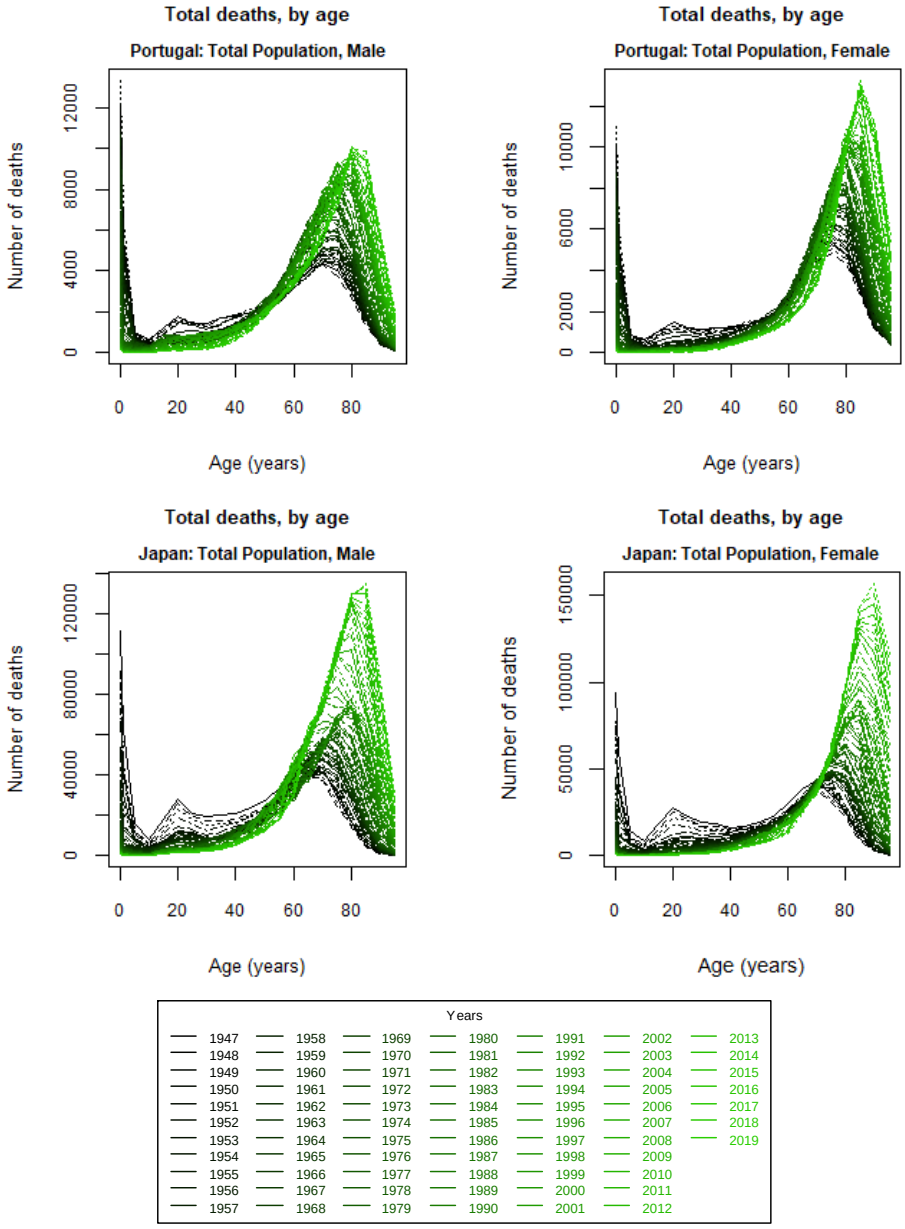

Figure 4.1. Total deaths by age and sex, from 1947 to 2019 for Portugal (upper panel) and Japan (lower panel).

On the surface, Figure 4.1 shows similar trends in the total number of deaths for both sexes and both countries in the study. The calendar years are represented by a palette of green colours, the

darkest ones correspondent to the older years of the dataset and the lightest correspondent to the most recent years. A sharp decrease in the proportion of infant mortality and a compression of the mortality derived from the reduction of variability in the age at death are quite noticeable. This has led to a concentration of deaths in more advanced ages, shifting the curves of total deaths to the right. This phenomenon is also known as rectangularization of the survival curve since this gets a more rectangular shape over time, with the function going up and to the right.

The case of Portugal

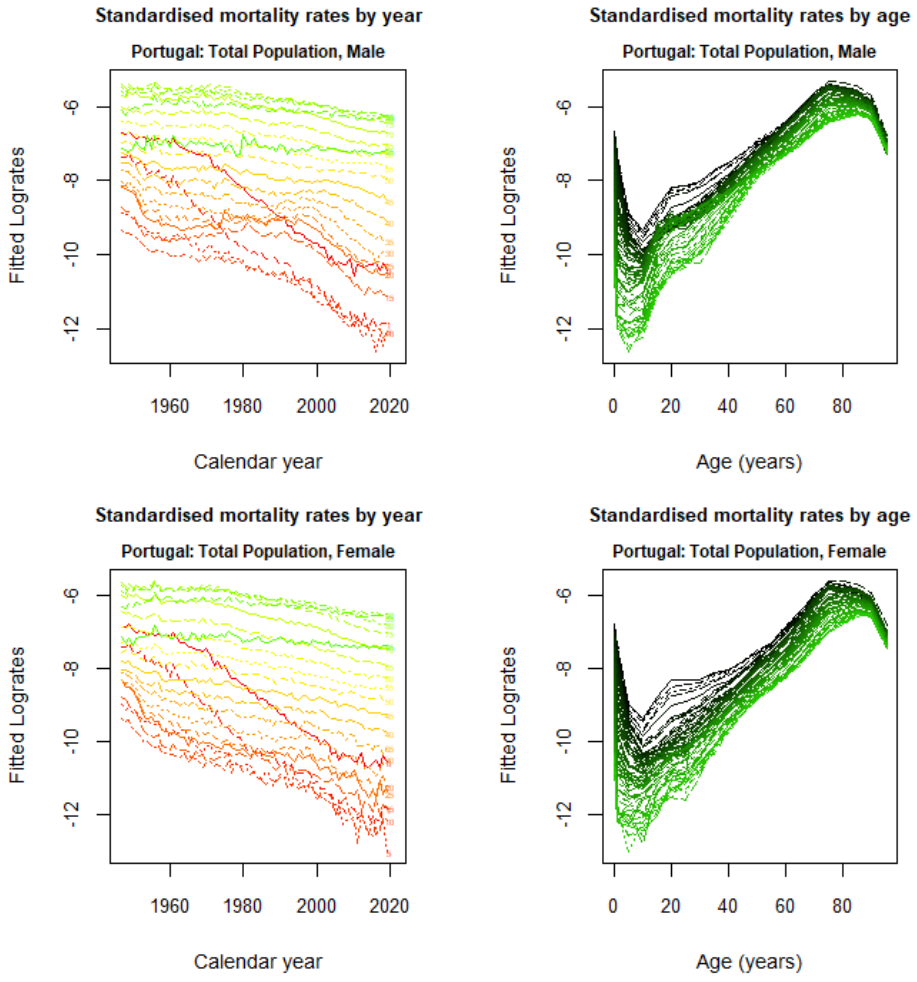

Figure 4.2. Logarithm of Portuguese standardised mortality rates (European standard population 2013) for the period 1947-2019, by age (upper panel) and by calendar year (lower panel).

In the right panel of Figure 4.2, Portuguese standardised mortality rates are portrayed by age for each sex. Looking at the graphs, these illustrate, once again, high neonatal mortality rates, followed by an accentuated decline still in the first years of life. A local maximum is reached between 15 and 30 years old which is thought to reflect accidents and maternal mortality for women (Heligman & Pollard,

1980). The rates increase again at older ages, reaching then a peak and evidencing the typical high mortality for elders.

Mortality has been declining over the years for all ages, despite not being similarly. There is a faster decline at younger ages and a slightly significant decline at older ages, for both sexes.

From the left graphs of Figure 4.2, a similar conclusion can be taken: mortality rates have been declining over the years, at all ages, for both females and males. However, this decrease is more significant in the younger population (warm colour lines) when compared to the older population (green lines). Again, there are slight differences between sexes, but these can be considered insignificant, as both sexes' mortality rates are moving in the same direction, at the same pace.

The case of Japan

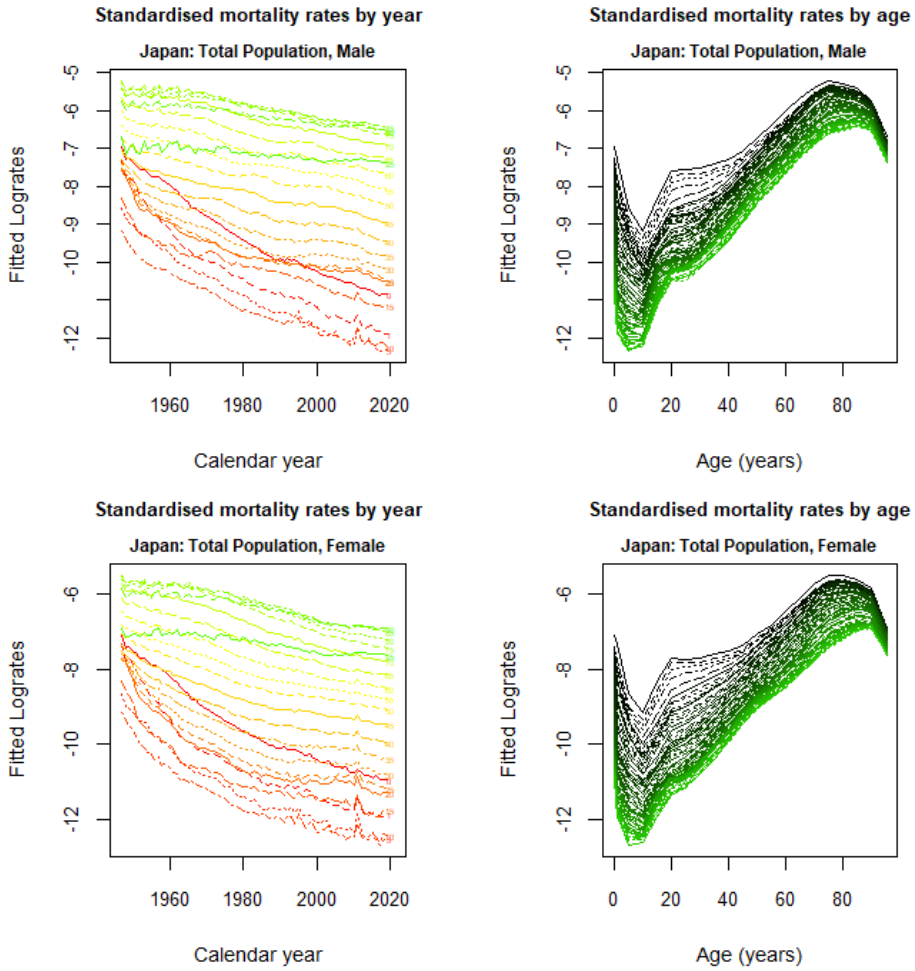

Figure 4.3. Logarithm of Japanese standardised mortality rates (European standard population 2013) for the period 1947-2019, by age (upper panel) and by calendar year (lower panel).

Figure 4.3 is similar to the previous one but designed to portray Japanese rates, which seem somewhat akin to Portuguese. Again, differences are negligible, with similar trends described over the past years.

4.1.2. IHD Mortality

For the analysis of CVD trends, data was narrowed to account only for members aged 30 to 84 (11 five-year age groups) from 1995 to 2016 for both countries.

The case of Portugal

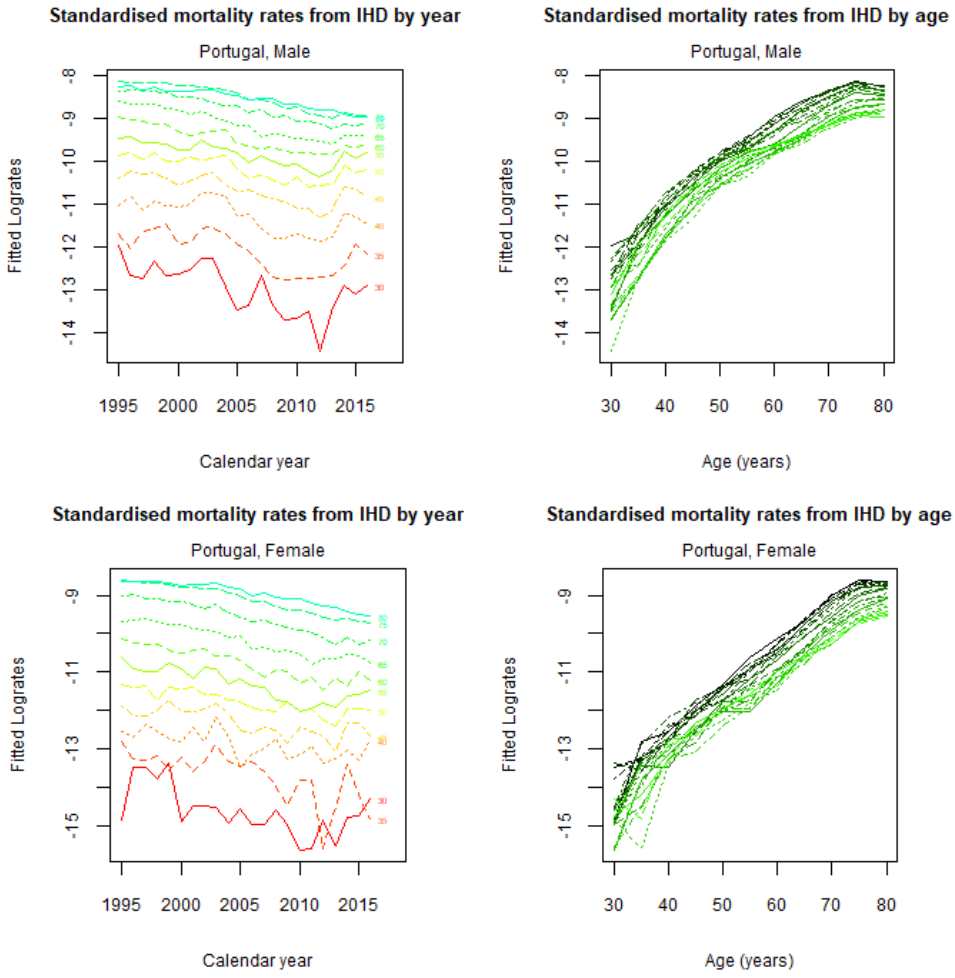

Figure 4.4. Logarithm of Portuguese standardised mortality rates (European standard population 2013) due to IHD for individuals between age 30 and 84, during the period 1995-2016, by age (upper panel) and by calendar year (lower panel).

Regarding IHD, results show that Portuguese men present, on average, higher mortality rates for all years and almost at all ages in comparison with Portuguese women.

For the female gender, rates were higher for the age group of 80-84 for all years, apart from 1995 in which the age group of 75-79 presented a slightly higher rate. On the contrary, the age group of 80-84 composed of Portuguese males accounted for the highest rates only between 2006 and 2013, whereas in the remaining fourteen years of the dataset, these were higher for the age group of 75-79.

Concerning the lowest mortality rates for men, these were always verified in the age group of 30-34. However, this pattern was not the same regarding women, with the age group of 35-40 accounting for the lowest mortality rates in three years of the dataset (1999, 2012 and 2016).

By looking at the graphs presented in Figure 4.4, it can be noticed that mortality rates for this type of disease have been declining, accompanying the general mortality trends across the country. However, these are much more evident for the older ages, with the younger generations verifying much more oscillations, either decreasing or increasing each year, especially in the case of women.

The case of Japan

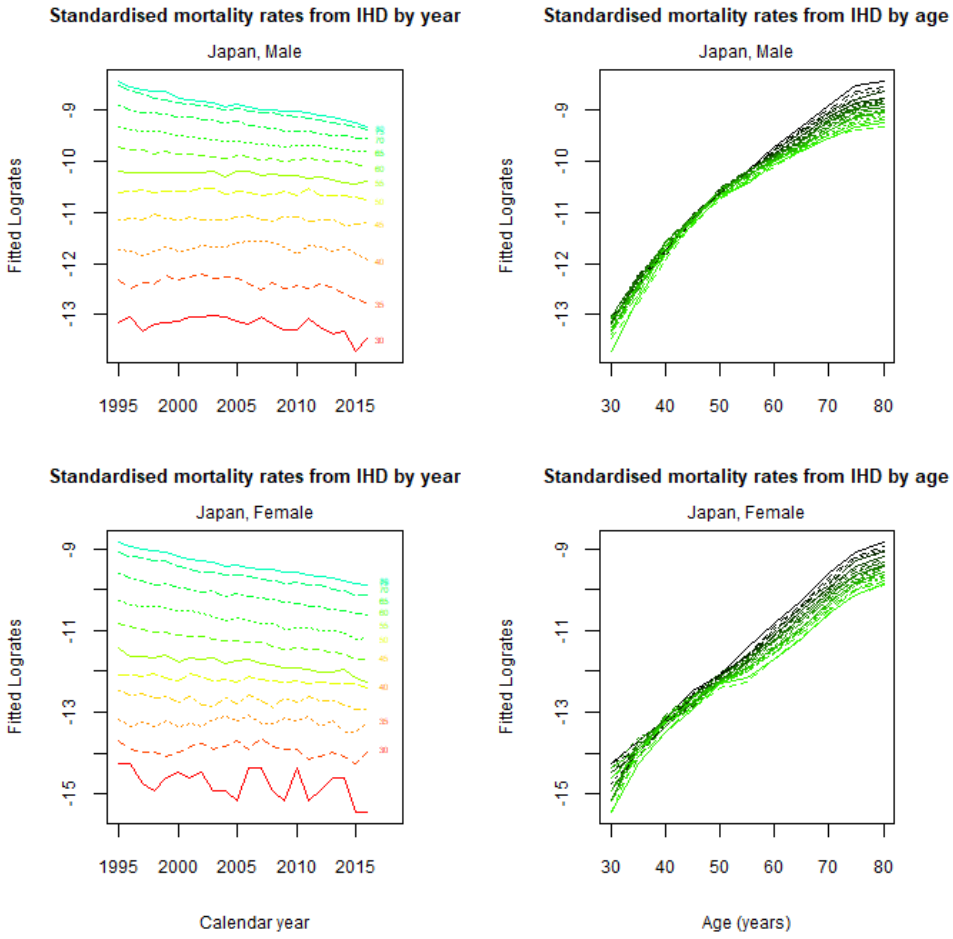

Figure 4.5. Logarithm of Japanese standardised mortality rates (European standard population 2013) due to IHD for individuals between age 30 and 84, during the period 1995-2016, by age (upper panel) and by calendar year (lower panel).

According to Figure 4.5, the highest mortality rates due to IHD in Japan are also attributable to men for all years and at all ages.

The highest and the lowest mortality rates were shown for the age group 80-84 and 30-34, respectively, for all years and both sexes.

A declining trend of mortality from this type of disease is not much evident in Japan, especially in middle ages, in which rates have even increased in some years. Nonetheless, the older ages here also registered a decline in death rates as years passed by.

4.1.3. CBVD Mortality

<u>The case of Portugal</u>

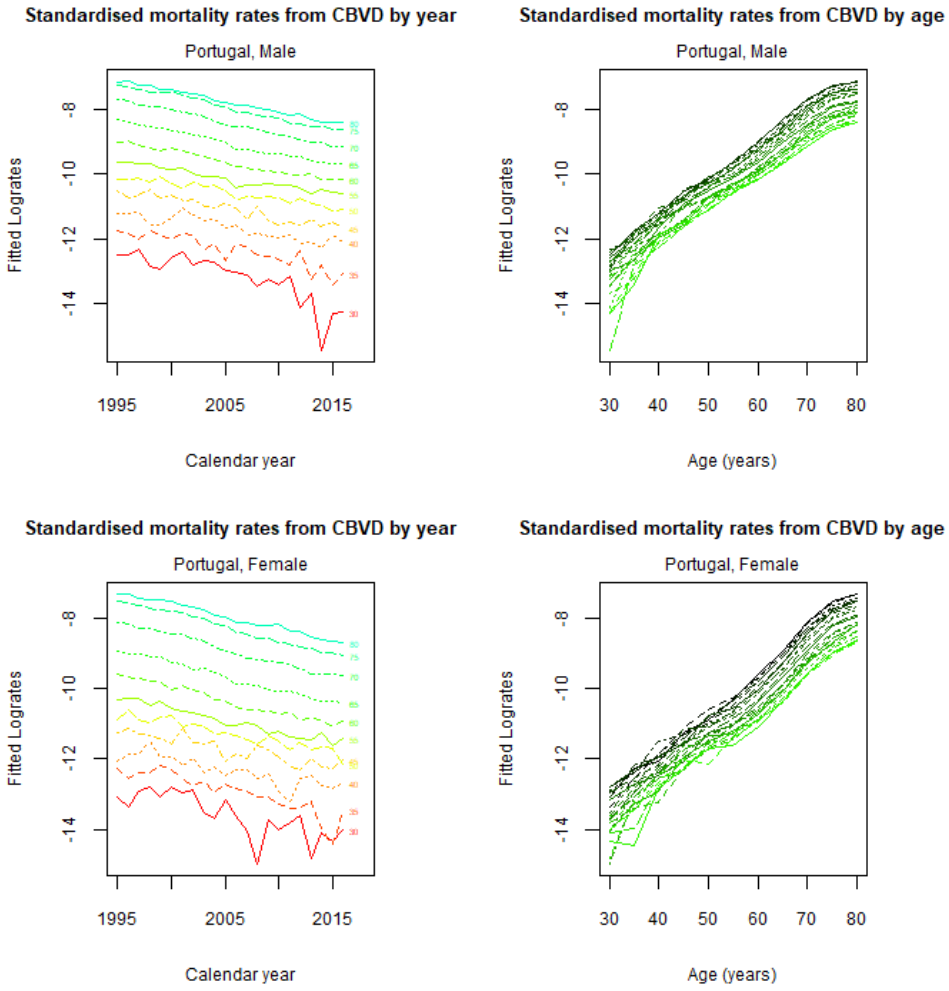

Figure 4.6. Logarithm of Portuguese standardised mortality rates (European standard population 2013) due to CBVD for individuals between age 30 and 84, during the period 1995-2016, by age (upper panel) and by calendar year (lower panel).

Analogously to IHD, mortality rates due to CBVD are also higher for Portuguese men, at all years and almost at all ages. Nevertheless, for both genders, mortality rates were consistently higher for the age group 80-84 and lower for early adulthood (ages 30-34).

The falling of mortality rates from this type of disease is well-evidenced in Figure 4.6, which portrays rates moving in the same direction for both sexes at a similar pace.

The case of Japan

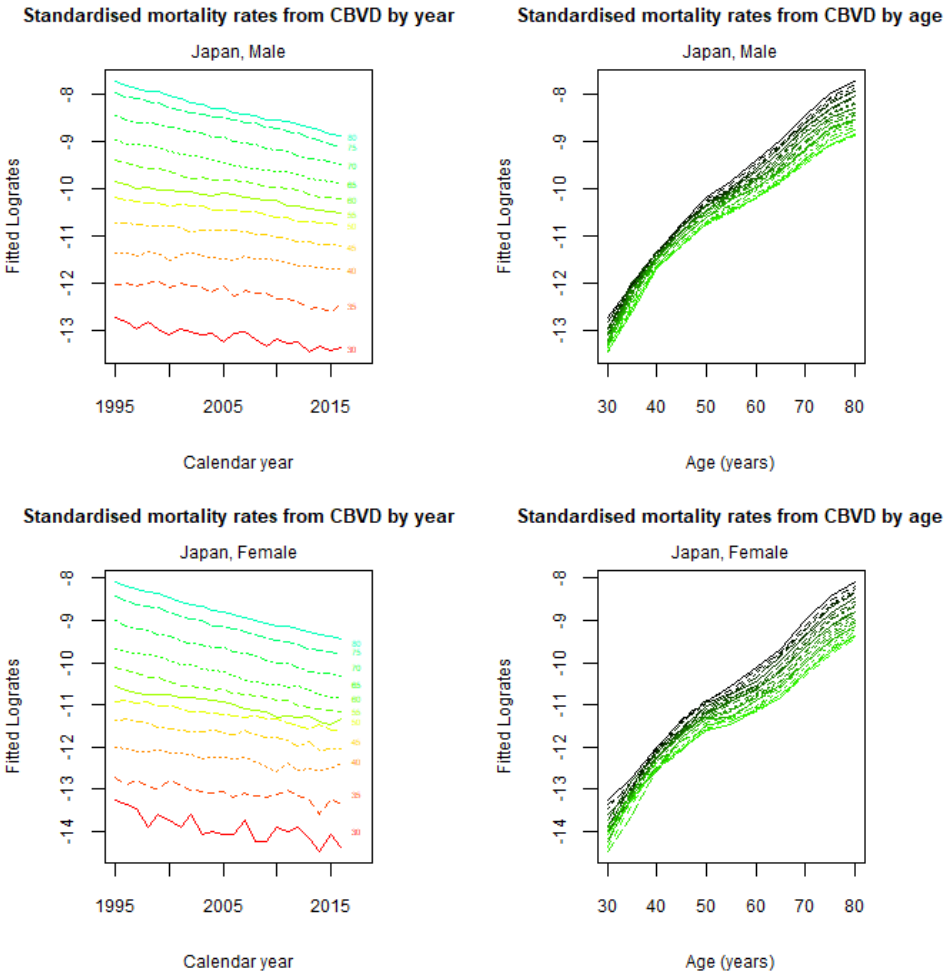

Figure 4.7. Logarithm of Japanese standardised mortality rates (European standard population 2013) due to CBVD for individuals between age 30 and 84, during the period 1995-2016, by age (upper panel) and by calendar year (lower panel).

Once again, males present, on average, higher mortality rates due to CBVD than females at all years and almost at all ages. The decrease in death rates between 1995 and 2016 is much clearer at advanced ages and is less considerable for the younger age groups. Generally, these Japanese mortality rates tended to maintain much closer to a linear trend than the Portuguese ones, with fewer fluctuations over the years, especially regarding the youngest ages.

4.1.4. A comparison between Portugal and Japan

Despite the decrease in mortality that has been verified over the years in both countries, Portugal presented and continues to present the highest rates for both diseases.

Using the age distribution of the European Population as of 2013 as the standard, the standardised rates of Portugal and Japan were calculated by multiplying each of the age-specific rates of each country by the fraction of the European's population in each age group. Summing these up for each type of disease allows obtaining the total standardised rates each year for both countries.

To compare them, SRR were computed during the period 1995 to 2016 by dividing Portugal's standardised mortality rates by the Japanese ones. Results are highlighted below in Table 4.1, suggesting that the risk of dying from these two types of CVD is higher in Portugal when compared to the Asian country. This has remained the truth in all cases for all years, though the variation on the risk has not been constant over time, with the difference in the risk of death between the two countries either increasing in some years or decreasing in others. Nonetheless, SRR are lower for both sexes in 2016 than in 1995, concluding that, in more recent years, Portugal is approaching a more similar situation to the one verified in Japan regarding CVD deaths.

Table 4.1. Standardised mortality rates per 100,000 inhabitants (European standard population 2013) due to IHD and CBVD for Portugal and Japan, by sex, during the period 1995-2016 and the corresponding SRR for each year.

	IHD						CBVD					
	Males			Females			Males			Females		
	Portugal	Japan	SRR	Portugal	Japan	SRR	Portugal	Japan	SRR	Portugal	Japan	SRR
1995	127.7	79.2	1.61	63.6	40.5	1.57	246.0	133.5	1.84	176.9	81.9	2.16
1996	127.1	72.9	1.74	62.4	36.6	1.71	242.2	122.5	1.98	169.9	74.7	2.28
1997	120.4	70.2	1.72	60.6	34.3	1.77	217.6	117.0	1.86	156.6	69.0	2.27
1998	123.0	67.9	1.81	59.0	32.6	1.81	207.2	112.0	1.85	149.1	65.5	2.28
1999	116.5	67.3	1.73	56.8	32.5	1.74	198.2	110.0	1.80	145.7	62.6	2.33
2000	109.4	62.4	1.75	54.0	29.0	1.86	193.5	100.6	1.92	135.2	57.2	2.37
2001	107.9	61.3	1.76	52.8	27.9	1.90	176.6	96.1	1.84	127.4	52.5	2.42
2002	112.0	59.9	1.87	51.7	26.3	1.97	165.9	90.7	1.83	117.0	49.5	2.36
2003	105.2	58.9	1.79	53.2	25.6	2.08	156.3	88.6	1.77	110.4	47.6	2.32
2004	99.7	55.7	1.79	45.8	23.7	1.94	137.7	82.5	1.67	93.1	44.2	2.11
2005	90.3	57.8	1.56	42.9	24.3	1.76	127.6	82.5	1.55	87.5	43.4	2.02
2006	80.8	55.3	1.46	36.3	23.2	1.56	111.6	76.5	1.46	75.7	40.0	1.89
2007	79.2	53.0	1.49	37.2	22.1	1.69	110.9	73.9	1.50	72.4	37.6	1.93
2008	74.9	52.7	1.42	33.8	21.6	1.57	104.0	71.5	1.45	67.8	35.5	1.91
2009	69.6	51.0	1.36	31.9	20.0	1.60	97.6	67.1	1.45	65.8	33.2	1.98
2010	67.7	50.8	1.33	30.3	20.1	1.51	92.5	65.9	1.40	63.8	31.5	2.03
2011	62.3	50.4	1.24	27.8	19.3	1.44	84.0	63.0	1.33	57.4	30.8	1.87
2012	59.4	48.8	1.22	25.7	18.8	1.37	84.2	59.9	1.41	54.3	28.7	1.89
2013	58.3	46.4	1.25	24.5	17.6	1.39	74.7	56.4	1.32	48.5	27.0	1.80
2014	67.1	45.1	1.49	25.2	16.8	1.50	70.6	53.5	1.32	45.5	25.4	1.79
2015	63.8	43.2	1.48	23.6	15.4	1.53	67.4	50.7	1.33	43.6	24.4	1.79
2016	64.4	41.8	1.54	22.8	15.0	1.52	66.6	48.7	1.37	41.6	23.4	1.78

4.2. YEARS OF LIFE LOST

Following the GBD approach, trends in YLL were shown to be quite similar in the two countries for both causes of death and both genders. Yet, since the absolute number of deaths was higher in Japan, the YLL were also higher for this country, as it was expected. A detailed analysis for each country is presented in the two subsections below.

The case of Portugal

As illustrated in Figure 4.8, the YLL from IHD in Portugal were almost always lower than those from CBVD for both genders. Nevertheless, whilst there was a continuous and accentuated decline of the YLL from CBVD, the YLL from IHD remained similar during the years, presenting slight increases or decreases. Yet, after 2013, YLL from IHD among men started to increase again and even surpassed those from CBVD, being higher thereafter.

Regarding the trends between genders, the YLL from IHD were always higher among Portuguese men whilst the YLL from CBVD were higher among Portuguese women until approximately 2007, becoming pretty similar to those among men and then even lower after 2011.

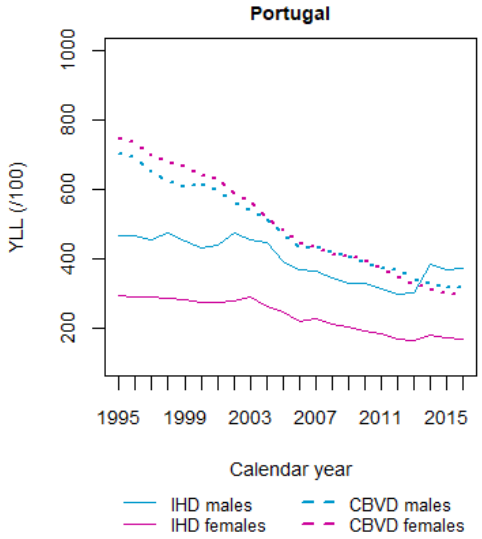

Figure 4.8. Total YLL in Portugal from IHD (solid line) and CBVD (dotted line), for both genders from 1995 to 2016.

The case of Japan

Regarding Japan, the YLL were always higher among men from 1995 to 2016, regardless of the cause of death, as depicted in Figure 4.9.

In terms of IHD, the YLL did not vary much from 1995 to 2016, with only a slight decrease for women and a slight increase for men in most of the period under analysis. On the contrary, the YLL due to CBVD have been decreasing for both genders. Although these continue to be higher than the YLL due to IHD, the values have been getting closer and closer, and in the case of men, these are already quite similar, anticipating an overstepping by IHD.

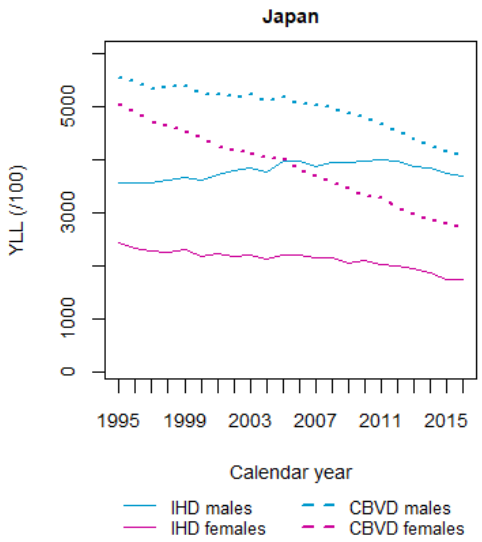

Figure 4.9. Total YLL in Japan from IHD (solid line) and CBVD (dotted line), for both genders from 1995 to 2016.

4.3. FACTORS OF CHANGE IN THE INCIDENCE/MORTALITY FROM CVD

The case of Portugal

Making avail of the *RiskDiff* tool, the change in the observed mortality between 1995 and 2016 in Portugal was evaluated and is presented in Tables 4.2 and 4.3.

Overall, a high decrease in the number of deaths and crude rate is observed for the two types of disease through the selected period. For both sexes, the significant decline attributable to changes in risk completely offsets the slight increase due to changes in population structure and size, therefore leading to a decrease in the net change in the crude rate. Nonetheless, these trends are more significant in terms of the female gender and concerning CBVD.

By way of example, looking at IHD for men, the net change in the crude death rate was 68 deaths per 100,000 person-years (from 166 to 98), which corresponds to a decrement of 40.8%. A decrease of 95.1 deaths per 100,000 person-years (57.5%) can be attributable to changes in risk. In contrast, an increase of 27.5 deaths per 100,000 person-years (16.6%) was due to changes in population structure, namely the ageing of the Portuguese male population. Concerning the absolute number of deaths, the net change was 1,322 deaths (from 4,479 to 3,157), thus declining 29.5%. Once again, this can be partitioned into that due to a growth of the population size (506.83 deaths, 11.3%), that due to the ageing of the population (744.6 deaths, 16.6%) and that due to risk, which fell off about 57.5%.

An analogous analysis can be conducted for CBVD.

Table 4.2. Evolution of mortality from IHD in Portugal from 1995 (baseline year) to 2016 (comparison year), with a partition of the key contributor factors.

	MALE			FEMALE		
	Deaths	**Population**	**Crude rate**	**Deaths**	**Population**	**Crude rate**
Data from 1995	4,479	2,704,770	165.6	2,983	3,091,255	96.5
Data from 2016	3,157	3,222,043	98.0	1,531	3,715,367	41.2

Change in	**Crude rate**	**%**	**Number**	**%**	**Crude rate**	**%**	**Number**	**%**
Risk	-95.1	-57.5	-2,573.4	-57.5	-72.5	-75.1	-2,240.3	-75.1
Structure	27.5	16.6	744.6	16.6	17.2	17.8	531.1	17.8
Size	n/a	n/a	506.8	11.3	n/a	n/a	257.2	8.6
Net change	-67.6	-40.8	-1,322.0	-29.5	-55.3	-57.3	-1,452.0	-48.7

Table 4.3. Evolution of mortality from CBVD in Portugal from 1995 (baseline year) to 2016 (comparison year), with a partition of the key contributor factors.

	MALE			FEMALE		
	Deaths	**Population**	**Crude rate**	**Deaths**	**Population**	**Crude rate**
Data from 1995	8,098	2,704,770	299.4	8,362	3,091,255	270.5
Data from 2016	3,263	3,222,043	101.3	12,885	3,715,367	77.7

Change in	**Crude rate**	**%**	**Number**	**%**	**Crude rate**	**%**	**Number**	**%**
Risk	-270.6	-90.4	-7,319.7	-90.4	-251.3	-92.9	-7,766.8	-92.9
Structure	72.5	24.2	1,960.9	24.2	58.4	21.6	1,805.1	21.6
Size	n/a	n/a	523.8	6.5	n/a	n/a	484.6	5.8
Net change	-198.1	-66.2	-4,835.0	-59.7	-192.9	-71.3	-5,477.0	-65.5

The case of Japan

Results concerning the change in the observed mortality between 1995 and 2016 for Japan are pretty akin to Portugal's. These are depicted below in Tables 4.4 and 4.5.

Regarding the three factors in analysis that contribute to the variation of the mortality, the growth and the ageing of the population can also be noticed in the Japanese population. Nonetheless, the decrement in risk of dying from both types of diseases is much more considerable and completely countervails the other two effects. Hence, the net change in the crude rate decreased in the period considered. Despite this decrease being much more modest with respect to IHD, especially for men, the decrement of risk is also substantial for both sexes.

Table 4.4. Evolution of mortality from IHD in Japan from 1995 (baseline year) to 2016 (comparison year), with a partition of the key contributor factors.

	MALE			FEMALE		
	Deaths	**Population**	**Crude rate**	**Deaths**	**Population**	**Crude rate**
Data from 1995	32,636	26,492,560	89.4	22,680	39,299,486	57.7
Data from 2016	30,609	42,018,697	72.8	14,288	44,34,9,034	32.2

Change in	**Crude rate**	**%**	**Number**	**%**	**Crude rate**	**%**	**Number**	**%**
Risk	-55.7	-62.3	-20,323.2	-62.3	-50.0	-86.6	-19,630.7	-86.6
Structure	39.1	43.7	14,271.1	43.7	24.5	42.4	9,611.5	42.4
Size	n/a	n/a	4,025.6	12.3	n/a	n/a	1,626.8	7.2
Net change	-16.58	-18.5	-2,026.6	-6.2	-25.5	-44.2	-8,392.5	-37.0

Table 4.5. Evolution of mortality from CBVD in Japan from 1995 (baseline year) to 2016 (comparison year), with a partition of the key contributor factors.

	MALE			FEMALE		
	Deaths	**Population**	**Crude rate**	**Deaths**	**Population**	**Crude rate**
Data from 1995	53,291	26,492,560	146.0	46,130	39,299,486	117.4
Data from 2016	36,072	42,018,697	85.8	21,994	44,34,9,034	49.6

Change in	**Crude rate**	**%**	**Number**	**%**	**Crude rate**	**%**	**Number**	**%**
Risk	-130.8	-89.6	-47,741.4	-89.6	-116.6	-99.4	-45,832.3	-99.4
Structure	70.8	48.4	25,777.5	48.4	48.8	41.6	19,191.8	41.6
Size	n/a	n/a	4,744.0	8.9	n/a	n/a	2,504.2	5.4
Net change	-60.2	-41.2	-17,219.9	-32.3	-67.8	-57.8	-24,136.4	-52.3

4.3.1. A comparison between Portugal and Japan

Looking at IHD, though the net change in the crude death rate presents a higher decrement for Portugal than for Japan, the risk of dying from both types of diseases decreased slightly more for Japan, albeit the difference is not considerable. This is primarily because the ageing of the Japanese population is more significant.

The aforesaid is also true in terms of CBVD for women. Notwithstanding, the contrary is verified for males. Both the decrements in the risk of dying from CBVD and the population structure are less pronounced in Japan, leading to a lower decrease in the net change in the crude death rate than in Portugal.

Despite the analysis done above, and as suggested by the authors of the method, looking only at the extremes of the dataset may not give a proper understanding of the mortality evolution. This can be easily overcome by looking at a set of consecutive years, so, in this case, observing the evolution of the percent change in terms of the crude rate for the whole dataset (from 1995 to 2016), keeping the baseline year as 1995. This is illustrated in Figure 4.10, which depicts that, for both countries, the risk of dying either from IHD or CBVD started to dimmish soon in mid 90s, as well as the net change in the crude rate.

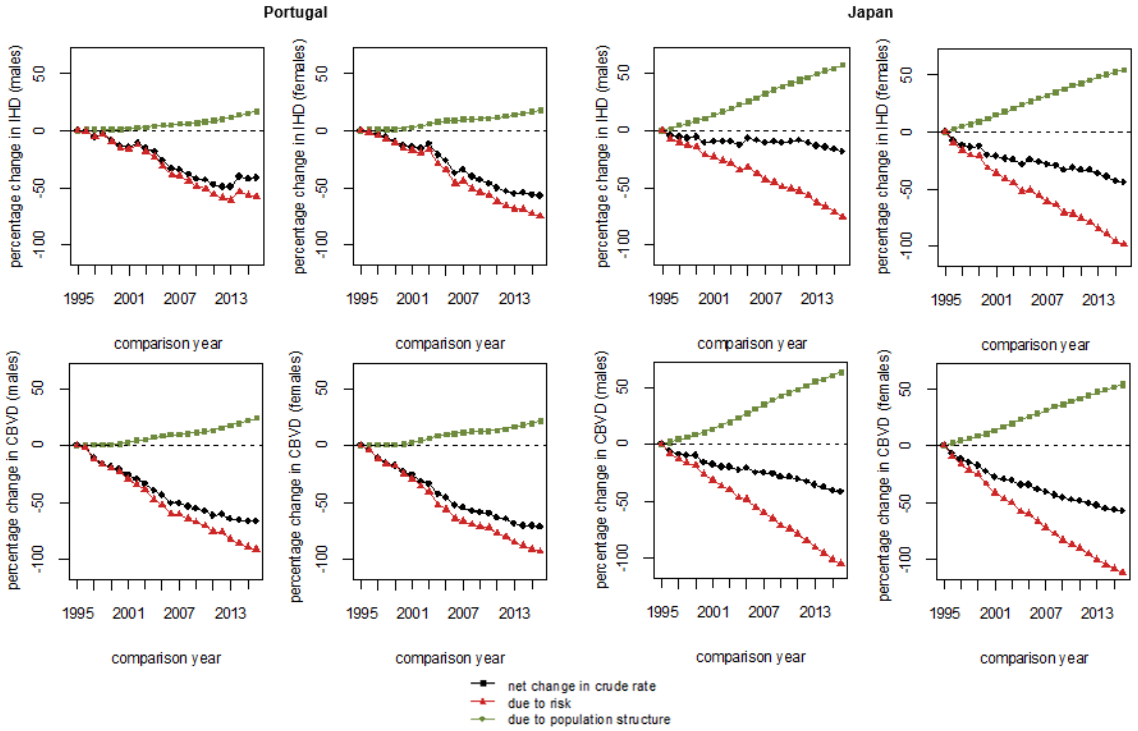

Figure 4.10. Evolution of the variation in deaths from IHD (upper panel) and CBVD (lower panel) in Portugal and Japan from 1995 to 2016, considering 1995 as the baseline year.

4.4. APPLICATION OF STOCHASTIC MORTALITY MODELS

4.4.1. LC model

The case of Portugal

As previously mentioned, to obtain the estimations of the parameters of the model, the function $\sum_{x,t}\left[ln(m_{x,t}) - \alpha_x - \beta_x k_t\right]^2$ had to be minimized. Results are portrayed in Figures 4.11 and 4.12, for IHD and CBVD, respectively.

Accordindly to the available literature, all cohorts with less than three observations were excluded (Haberman & Renshaw, 2011).

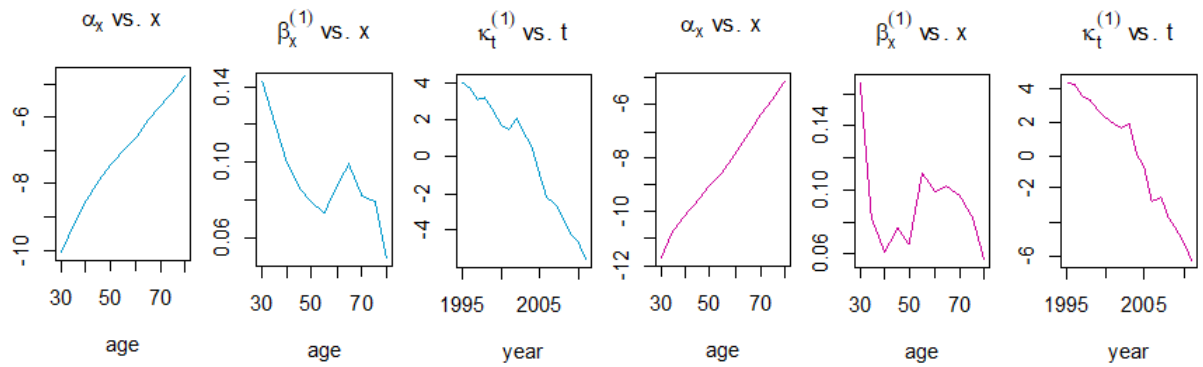

Figure 4.11. Estimated LC parameters for IHD in Portugal, for males (in blue) and females (in pink).

Looking at the figure above, the parameter α_x shows an almost linear growing trend for both sexes, meaning that the average mortality increases with age. However, these estimates are lower for females than males of all ages. This alludes to higher mortality for men which is in line with the literature analysed in section 2.

Regarding $\beta_x^{(1)}$, this is always positive, for both sexes, suggesting that mortality due to IHD is getting better. Notwithstanding, it depicts a downward trend for almost all ages, apart from some small jumps, namely between ages 45-69, visible in the female results, and around the sixties in the case of Portuguese men. The pattern is similar between both sexes, though the decrease is sharper for the female gender. As the parameter is higher for younger ages, mortality improvements for IHD in Portugal are more significant at younger ages.

The estimates for $k_t^{(1)}$, the time trend in mortality, show the changes in mortality over time. Apart from a slight increase in 2003 and 2007 for females and in 2002 for males, the parameter shows an overall declining trend, which proves that the level of mortality due to IHD in Portugal is decreasing and individuals of both sexes live longer and longer.

With regards to CBVD, the parameters α_x and $k_t^{(1)}$ show similar trends to the ones in the case of IHD, as illustrated in Figure 4.12. Conversely, parameter $\beta_x^{(1)}$ reveals almost an opposite trend. There are decreases at some ages for Portuguese men, but there is a pronounced increase between ages 50 and 74. A roughly U-shaped trend is comprehended among Portuguese women, with a significant increasing trend observed for women aged 45 to 74. For this type of disease in Portugal, mortality improvements are quicker at older ages than at younger ones, since the parameter is higher for the age group of 70-74, in the case of women, and of 75-79, in the case of men.

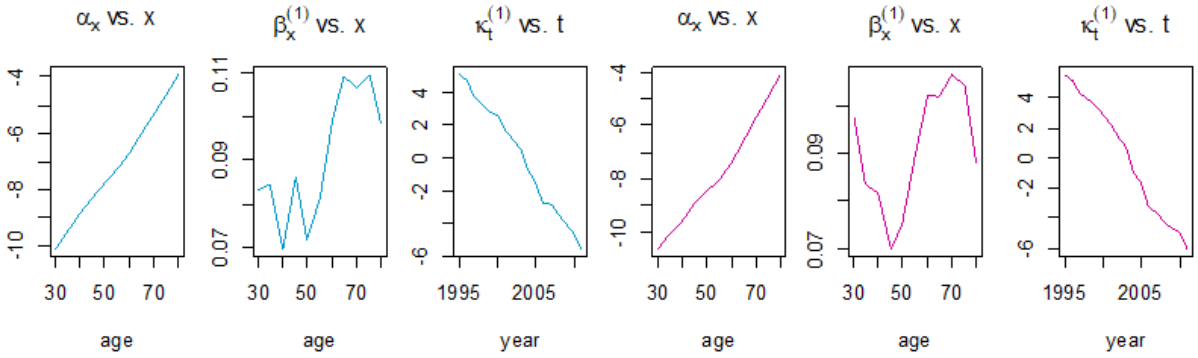

Figure 4.12. Estimated LC parameters for CBVD in Portugal, for males (in blue) and females (in pink).

The case of Japan

Figures 4.13 and 4.14 reveal the estimated parameters of the LC model for Japan concerning IHD and CBVD, respectively. Assuredly, it can be perceived that the trends are quite similar for both types of diseases and both sexes.

Be that as it may, α_x reveals an almost linear growing trend for both sexes, though these are slightly lower for females. Hence, it can be said that the older the age of Japanese individuals, the higher the average mortality, which is notably higher in the case of men.

In terms of the time trend of the mortality, a declining trend is reflected, meaning that mortality due to both types of diseases is improving.

With respect to parameter $\beta_x^{(1)}$ for both types of diseases, despite a downward trend at younger ages, an increased systematic pattern is observed among the subsequent ages. The parameter reaches the highest values at older ages, suggesting a higher sensitivity to the variation of the parameter $k_t^{(1)}$ at these ages, which means that the mortality has a quicker response whenever the general mortality index changes. However, it should be pointed out that the parameter reaches negative values in the case of IHD in the age group of 40-44 for both sexes. This implies that mortality

due to IHD in this age group is getting worse in Japan either for females or males. With such low values around this age group, the mortality rates present modest variations when the general level of mortality changes.

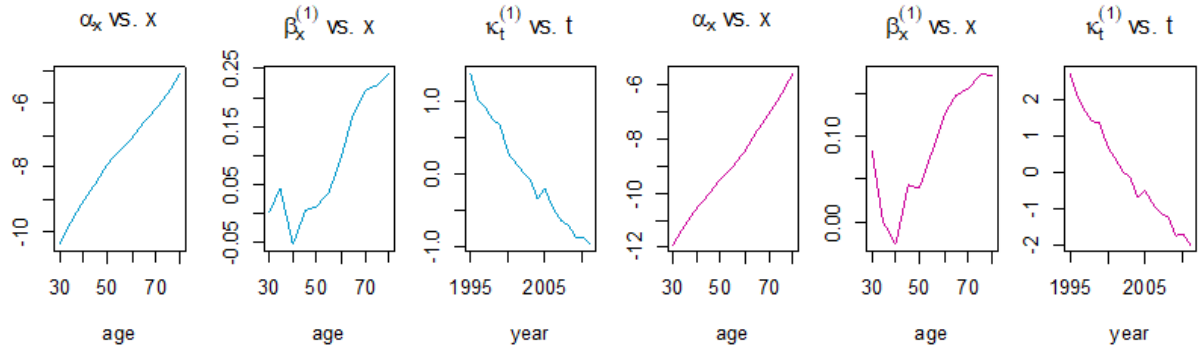

Figure 4.13. Estimated LC parameters for IHD in Japan, for males (in blue) and females (in pink).

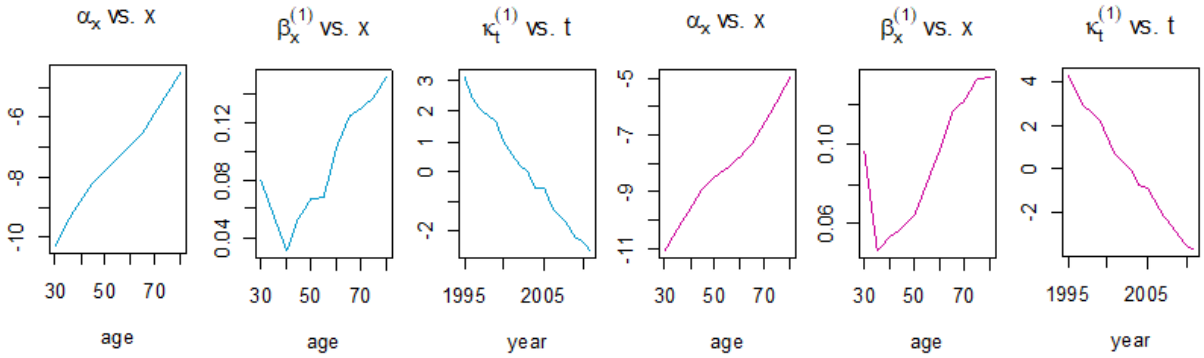

Figure 4.14. Estimated LC parameters for CBVD in Japan, for males (in blue) and females (in pink).

4.4.2. BAPC model

To describe the age, period, and cohort effects so one could discern what trends might exist, the BAPC model was firstly estimated assuming a RW1 because only this turns the parameters identifiable through a stochastic constraint in the prior, as outlined in section 2.

Even though different assumptions are used depending on which type of prior is used (RW1 or RW2), they should give similar results when interpolating. Hence, the RW1 model should give a plausible understanding of the size of the effects.

The case of Portugal

Posterior median estimates within 90% pointwise credible intervals of age, period, and cohort components for Portugal were calculated separately by type of disease and gender and can be found in Figure 4.15.

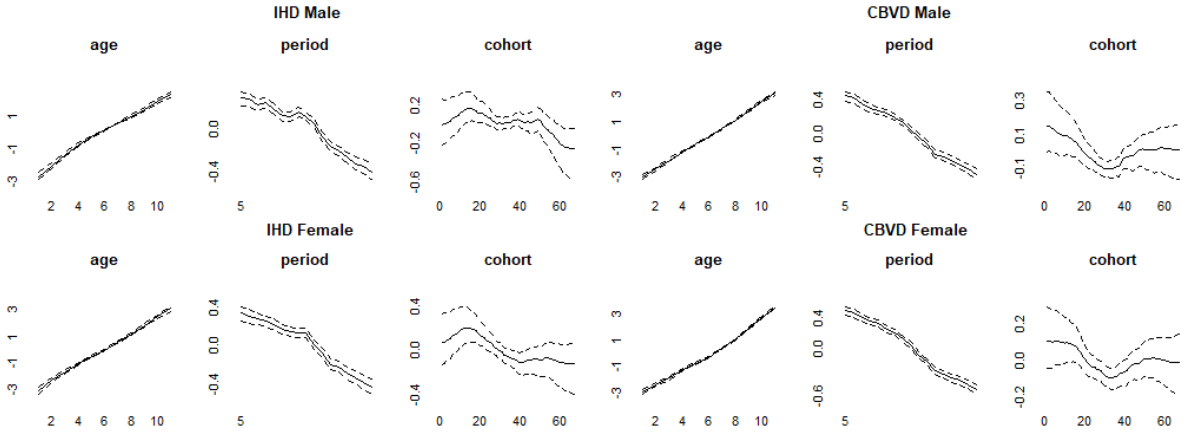

Figure 4.15. Posterior median estimates within 90% pointwise credible regions of age, period and cohort parameters of the RW1 model applied to Portuguese data, separately by gender (males in the upper panel and females in the lower one).

The age effects exhibit a similar increasing slope for males and females and for both types of diseases. Regarding period effects, a decreasing slope can be perceived in almost all periods. Yet, for CBVD, there is a more steadily decreasing trend than for IHD, for which more oscillations are noticed, namely around 2000. Furthermore, after 2004, a sharper decreasing slope is evident for both genders and both types of diseases. The cohort effects have more variability. Concerning IHD, there is a peak for female birth cohorts born around 1930 with a sharply decreasing slope for those born around 1955. For males, there is one significant peak also around 1930, and two more less pronounced peaks, one around 1955 and the other around 1965, followed by a steep decreasing slope. In terms of CBVD, an almost U-shaped curve describes the cohort effects in which a valley is reached for those birth cohorts born around 1945. Important to note that, for all cases, the uncertainty of these estimates increase for the extreme (older and younger) cohorts - born between 1915-1935 and after 1960, respectively.

Regarding the estimates of the hyperparameters k, λ, and v, these are depicted in Table 4.6 for each type of disease and gender, considering the 0.5 quantile.

Table 4.6. Hyperparameter estimates (0.5 quantile) calculated for Portugal.

	IHD		CBVD	
Hyperparameter	**MALE**	**FEMALE**	**MALE**	**FEMALE**
Age (k)	4.128	2.743	2.947	2.560
Period (λ)	239.814	218.652	220.245	179.440
Cohort (v)	1046.038	1354.741	2197.173	2276.627

In light of the fact that larger values allow only slight variations in the baseline effects and smaller ones allow more significant variation, the estimates present in the Table above, show that the most critical factor, that is, the effect that explained most variation for both genders and both types of diseases is age, followed by the period and cohort components, which is in line with the results obtained in the study conducted by Castillo et al. (2014).

The case of Japan

Likewise, posterior median estimates within 90% pointwise credible intervals of age, period, and cohort components for Japan can be found in Figure 4.16.

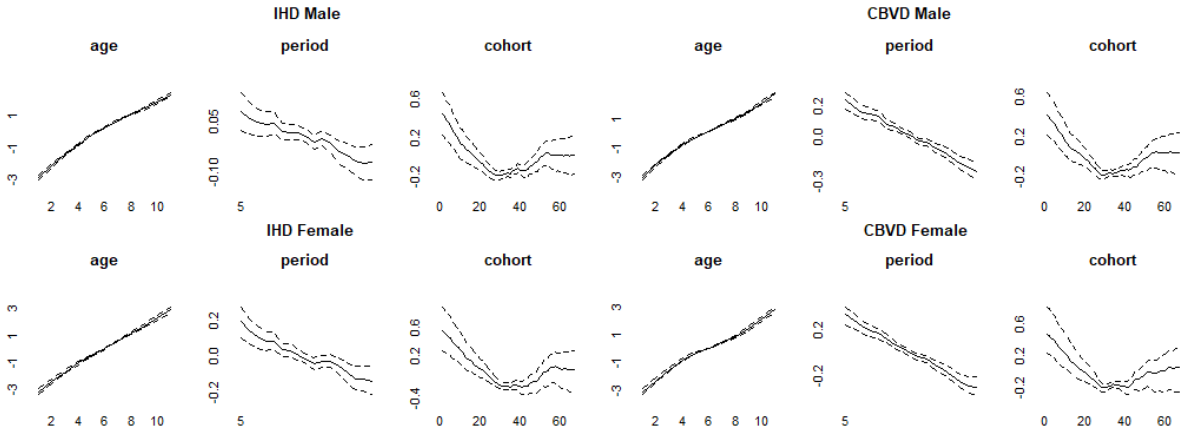

Figure 4.16. Posterior median estimates within 90% pointwise credible regions of age, period and cohort parameters of the RW1 model applied to Japanese data, separately by gender (males in the upper panel and females in the lower one).

Analogous to Portugal, both genders and types of diseases exhibit akin age and period effects – an increasing slope for the first and a decreasing slope for the latter effect. Once more, the period components for CBVD have a more steadily decreasing slope for both genders than IHD, which fluctuates more. Moreover, the uncertainty related to this component is higher for IHD. In Japan, the cohort effects are U-shaped for both diseases, reaching a valley for the birth cohorts born around 1945. The uncertainty of these cohort estimates increases for younger ones born after 1965.

The hyperparameter estimates calculated by RW1 for Japan are represented in Table 4.7, separately by type of disease and gender.

Table 4.7. Hyperparameter estimates (0.5 quantile) calculated for Japan.

	IHD		CBVD	
Hyperparameter	**MALE**	**FEMALE**	**MALE**	**FEMALE**
Age (k)	3.921	3.035	3.245	2.979
Period (λ)	2441.039	857.483	763.874	493.487
Cohort (v)	1136.855	726.071	1350.154	980.639

According to the results obtained, age remains the effect that explains most of the variation for both sexes and types of diseases. Nonetheless, albeit the cohort effect is the one that justifies the variation the least in the case of CBVD, with regards to IHD, the age effect is followed by the cohort effect, and then the period effect.

5. MODEL SELECTION CRITERIA

5.1. BACKTESTING

With the intent of selecting the best model – LC or BAPC -, an evaluation criterion consisting of a posteriori verification procedure – backtesting – was applied. For this, mortality projections were estimated for 2012 to 2016, for which data is available, based on data from 1995 to 2011 and compared with the observed data.

So that both models could be comparable, the predicted mortality probabilities (quantile 0.5) obtained with the BAPC model were firstly transformed into mortality rates.

The case of Portugal

In what concerns IHD, the projection is not satisfactory in the case of Portuguese men because the actual mortality rates suffered significant oscillations during these 5 years, especially for ages between 45 and 59. Be that as it may, the model assumes the declining trend observed from 1995 to 2011 will persist in the future and does not consider these oscillations, ending up underestimating the rates in both models. This is also the case for the female age group of 65-69. The BAPC model tends to overestimate mortality rates in the eldest groups (80-84). These results are shown in Figures 5.1 and 5.2 for males and females, respectively.

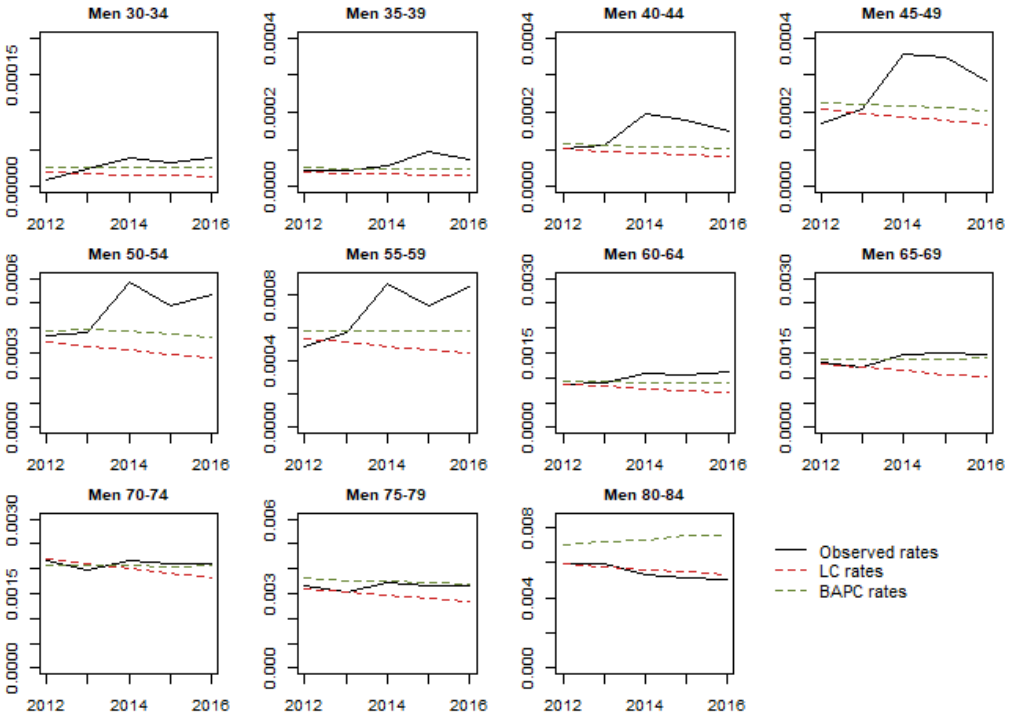

Figure 5.1. Validation of IHD mortality rates for Portuguese men from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

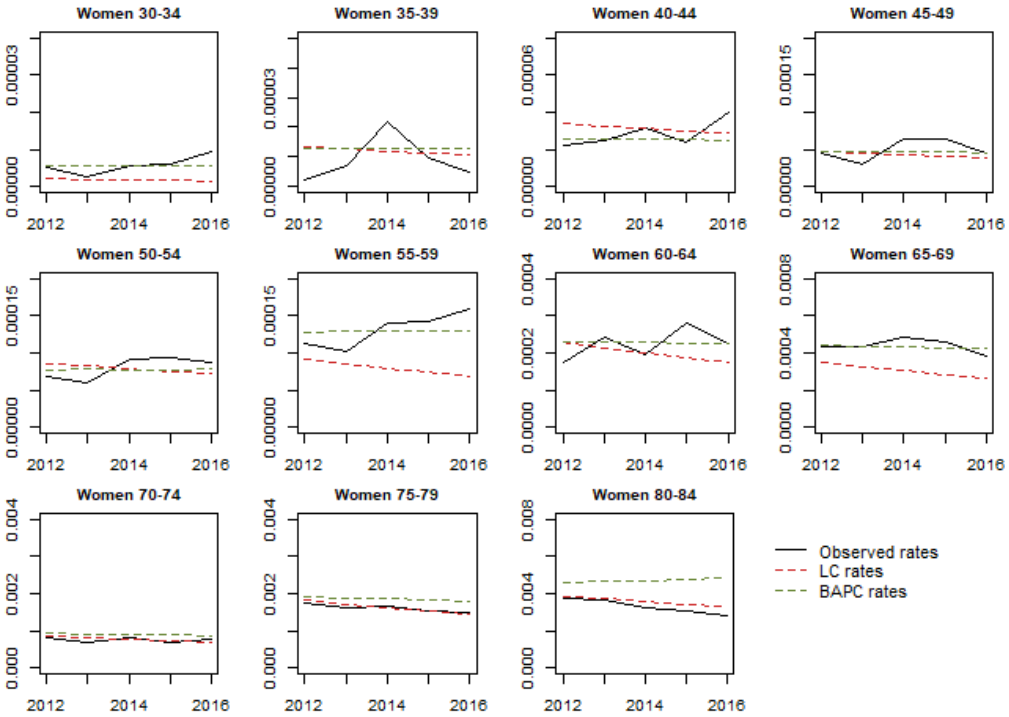

Figure 5.2. Validation of IHD mortality rates for Portuguese women from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

For CBVD, portrayed in Figures 5.3 and 5.4, the projection is much better for both models. Regarding the LC male projections, apart from the male age group of 30-34, in which there is an overestimation of the mortality decline and the age group of 75-79, in which the opposite takes place, the model presents an almost perfect fit. The same is true for LC female projections, with only some underestimation of the rates at younger ages, namely for the age group of 40-44. Although the BAPC model presents a reasonable prediction performance, it tends to overestimate mortality rates for both genders, which is more evident for the younger age group and individuals older than 65.

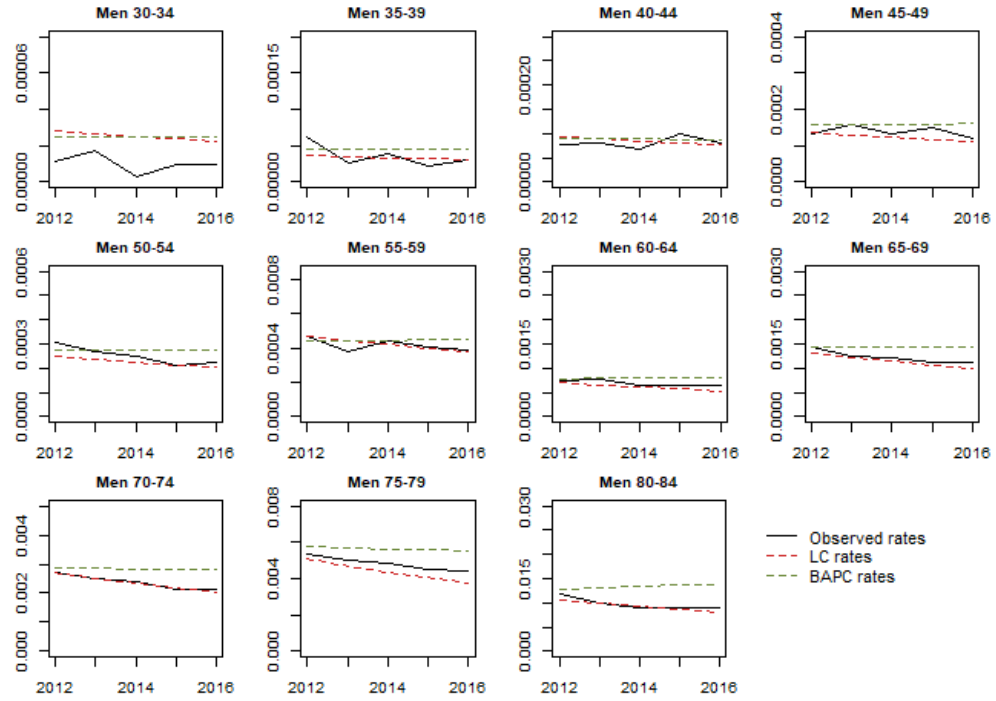

Figure 5.3. Validation of CBVD mortality rates for Portuguese men from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

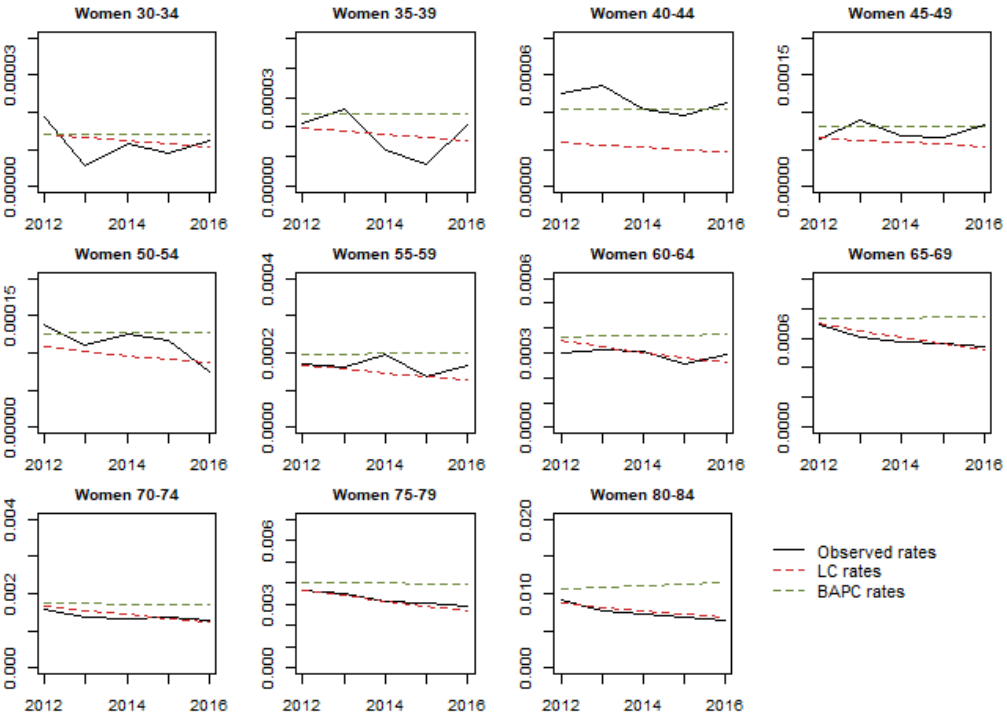

Figure 5.4. Validation of CBVD mortality rates for Portuguese women from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

The case of Japan

For the Asian country, the two models seemed to perform efficiently, as it is depicted in Figures 5.5 and 5.6, for IHD, and 5.7 and 5.8, for CBVD.

The LC model proves to be efficient in predicting mortality rates due to IHD and CBVD for both genders. Regarding IHD, small overestimations are perceived for the male age groups of 30-34 and 60-64 and for the females aged between 40 and 49. The model also slightly underestimated the decline in mortality for females younger than 40. However, these can be considered negligible. There is almost a perfect fit for the eldest groups of both sexes. It is also true for CBVD, both sexes and all age groups.

As for the BAPC model, an overestimation of the mortality rates can be identified for several age groups for both types of diseases.

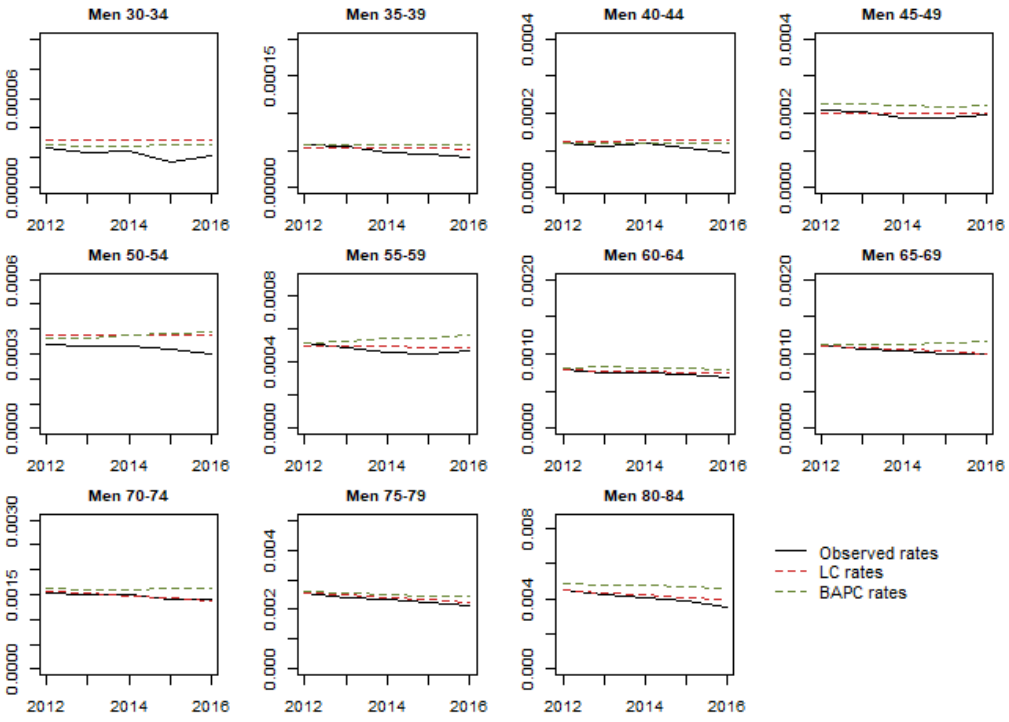

Figure 5.5. Validation of IHD mortality rates for Japanese men from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

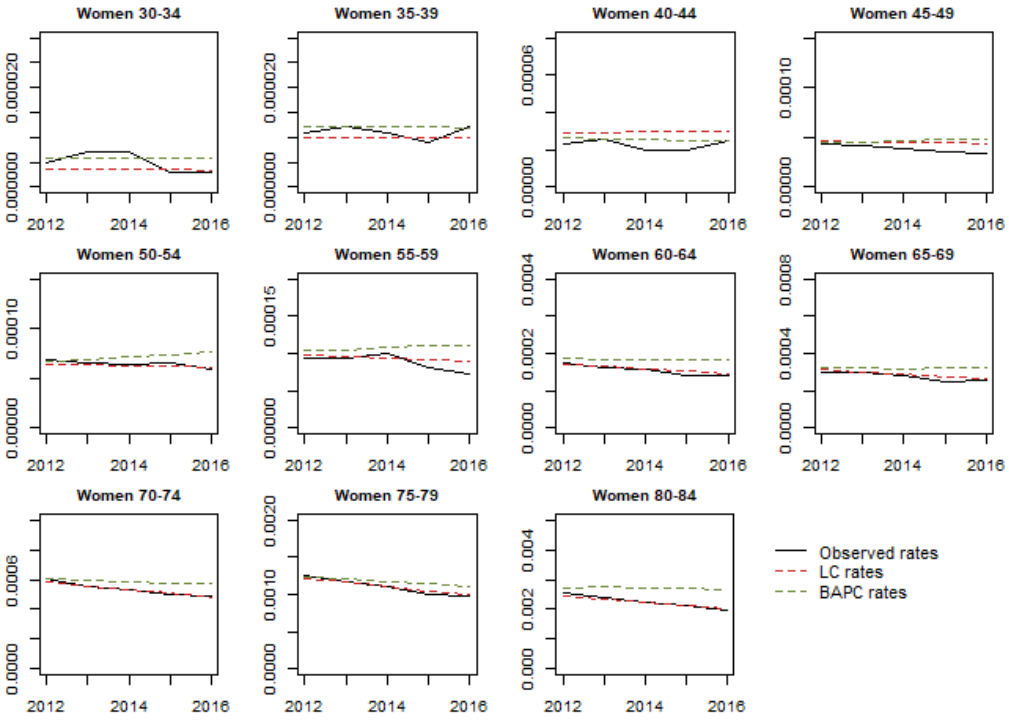

Figure 5.6. Validation of IHD mortality rates for Japanese women from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

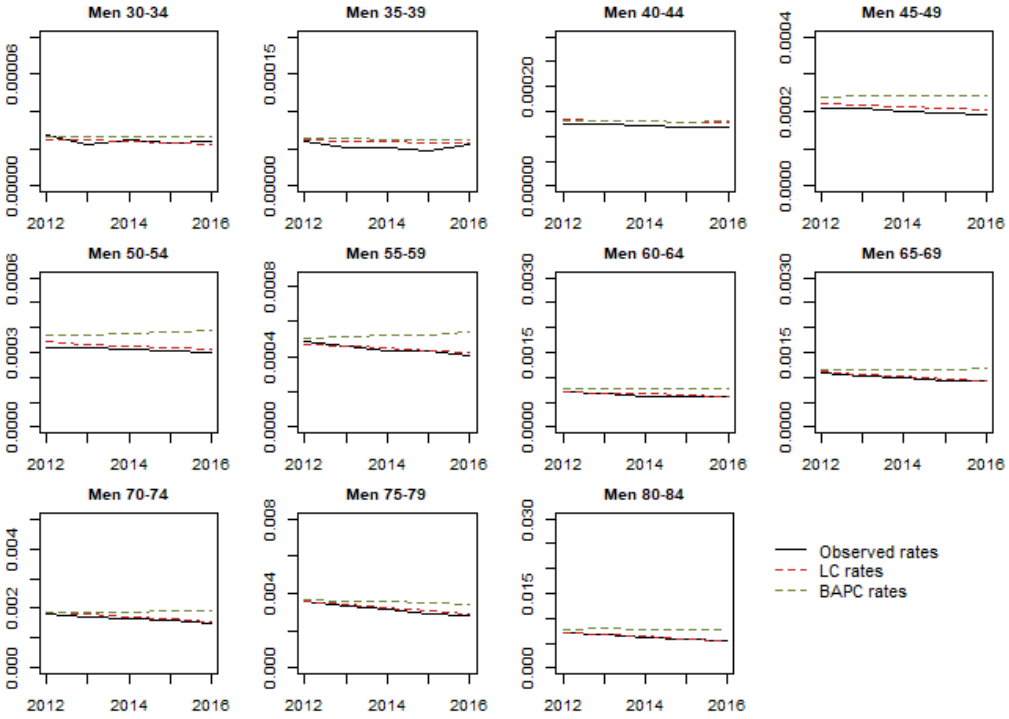

Figure 5.7. Validation of CBVD mortality rates for Japanese men from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

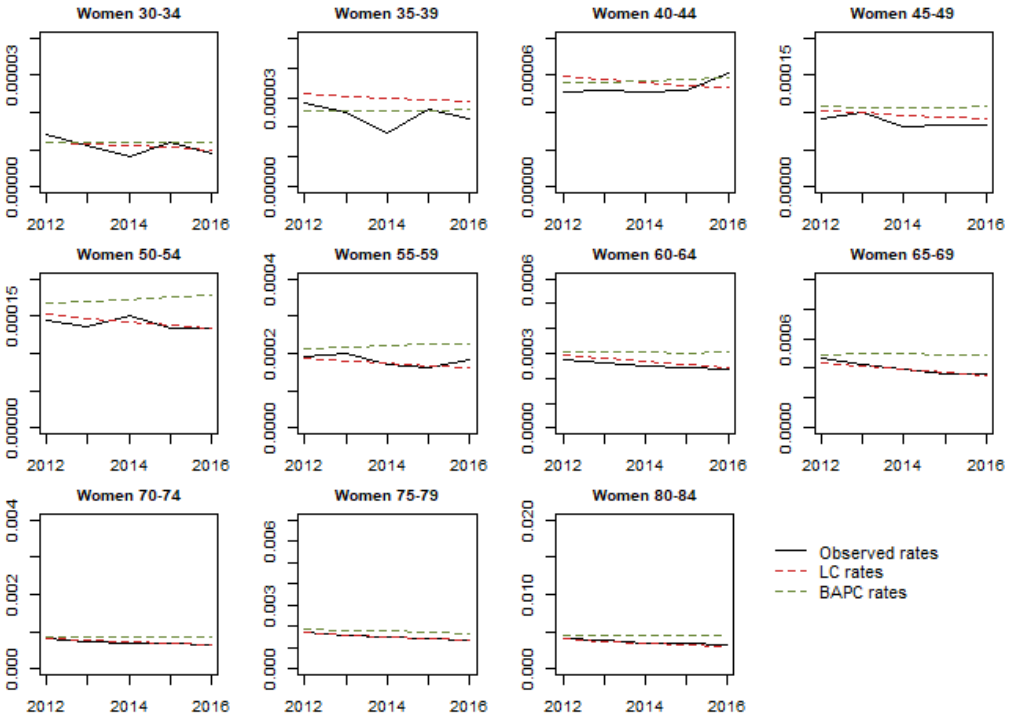

Figure 5.8. Validation of CBVD mortality rates for Japanese women from 2012-2016: Observed rates, LC and BAPC (0.5 quantile) projections.

5.2. PREDICTIVE PERFORMANCE OF THE MODELS

To statistically compare the predictive power of both models, MAPE and MSE were calculated for these 5 years of projection. Tables 5.1 and 5.2 include the obtained values for each model and country (order of the errors in brackets).

Table 5.1. MAPE and MSE for each model applied to Portuguese data and for both genders.

	IHD			
	MALE		FEMALE	
	MAPE	MSE	MAPE	MSE
LC	0.2671484 (2)	0.0000000549 (2)	0.3562181 (2)	0.0000000128 (1)
BAPC	0.1969610 (1)	0.0000000366 (1)	0.2927260 (1)	0.0000000300 (2)
	CBVD			
	MALE		FEMALE	
	MAPE	MSE	MAPE	MSE
LC	0.3141206 (1)	0.0000000628 (1)	0.1959546 (1)	0.0000000168 (1)
BAPC	0.3990603 (2)	0.0000002854 (2)	0.2884576 (2)	0.0000002715 (2)

Table 5.2. MAPE and MSE for each model applied to Japanese data and for both genders.

	IHD			
	MALE		FEMALE	
	MAPE	MSE	MAPE	MSE
LC	0.1024007 (1)	0.0000000058 (1)	0.1076193 (1)	0.0000000003 (1)
BAPC	0.1289555 (2)	0.0000001628 (2)	0.1742158 (2)	0.0000000039 (2)
	CBVD			
	MALE		FEMALE	
	MAPE	MSE	MAPE	MSE
LC	0.04581193 (1)	0.0000000032 (1)	0.08271828 (1)	0.0000000005 (1)
BAPC	0.15536048 (2)	0.0000000826 (2)	0.18398862 (2)	0.0000000219 (2)

Since it was found, through the implementation of the BAPC model, that the cohort effect plays the less important role in explaining either IHD or CBVD mortality in Portugal and Japan, it was expected that both models would give similar results. Indeed, when evaluating the predictive power of the models, results suggest that the BAPC model seems to perform better only in the case of IHD in

Portugal, with the MAPE for this model being lower for both genders and MSE being lower only in what concerns males. In terms of IHD in Japan and CBVD in both countries, the MAPE and MSE were always lower for the LC model. This is in accordance with the graphical comparison between the projections and the observed data outlined in the previous subsection. It was shown that the LC model provided a very good fit whereas the BAPC model tended to overestimate the mortality rates. Thus, the LC model was selected to predict future mortality rates as it showed a better predictive performance.

6. LONG-TERM FORECASTS OF MORTALITY RATES

6.1. UNCERTAINTY OVER ESTIMATES: CONSTRUCTION OF CONFIDENCE INTERVALS

The projection of mortality rates involves an aura of uncertainty partially related to any error arising in the forecast of the period indexes. In order to quantify it, some authors suggest the construction of confidence intervals which provide a reasonable range of values to where the forecast might fall if the dataset is recalculated using new data.

To obtain future projections of mortality, predictions of the period indexes of the LC model were derived for a time horizon of 24 years – from 2012 to 2035 -, assuming that these follow a multivariate random walk with drift. Confidence intervals of 80% and 90% were considered and are represented by the darkest and lightest shades, respectively, in Figures 6.1, for Portugal, and 6.2, for Japan. The blue shades illustrate the male population while the pink ones depict the female population.

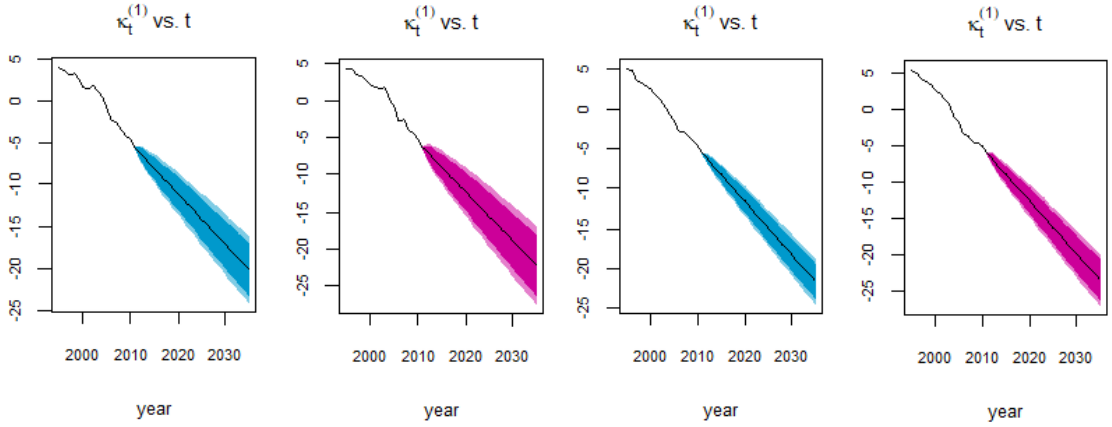

Figure 6.1. Predicted period indexes of the LC model applied to the male (blue panel) and female (pink panel) Portuguese population for the period 2012 to 2035 with regards to IHD (in the left) and to CBVD (in the right).

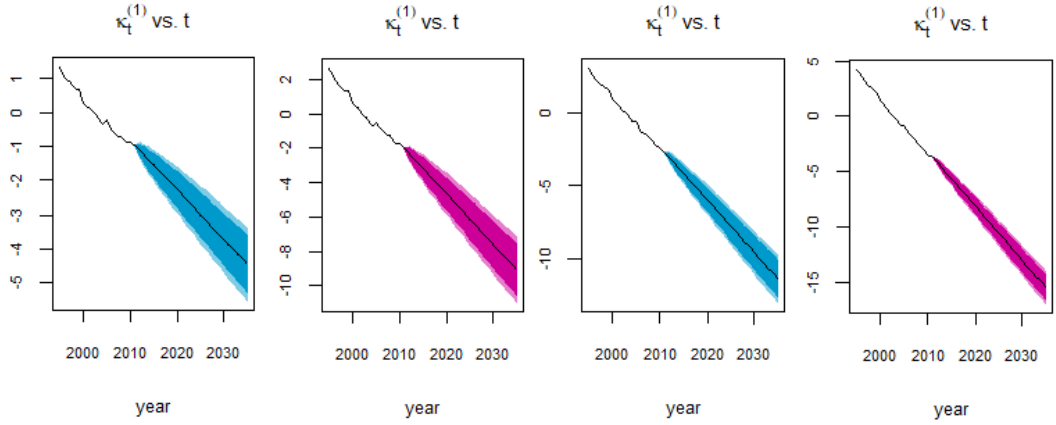

Figure 6.2. Predicted period indexes of the LC model applied to the male (blue panel) and female (pink panel) Japanese population for the period 2012 to 2035 with regards to IHD (in the left) and to CBVD (in the right).

Results show similar trends in the period indexes for the projected 24 years in both countries. However, when looking at this for both types of diseases, it can be noticed that the projections indicate a sharp drop of the mortality level for both males and females, associated with a very tight 90% prediction interval. Hence, this imposes challenges in assessing longevity risk in extreme percentiles. Additionally, as shown in the Figure above, the confidence interval increases in amplitude over the years, which represents an increase in risk, that is, the uncertainty associated with future forecasts.

Afterward, for each of the cases under study, the projected mortality values resulting from the LC model application were obtained. In Figures 6.3 and 6.4, the black dots represent the observed mortality rates between 1995 and 2011 for three age groups, 60-64, 70-74 and 80-84, and the solid black lines indicate the correspondent fitted rates. For the projection period 2012-2035, the black dashed lines represent the projected central values, and the blue/pink dashed lines correspond to the predicted intervals of 90%.

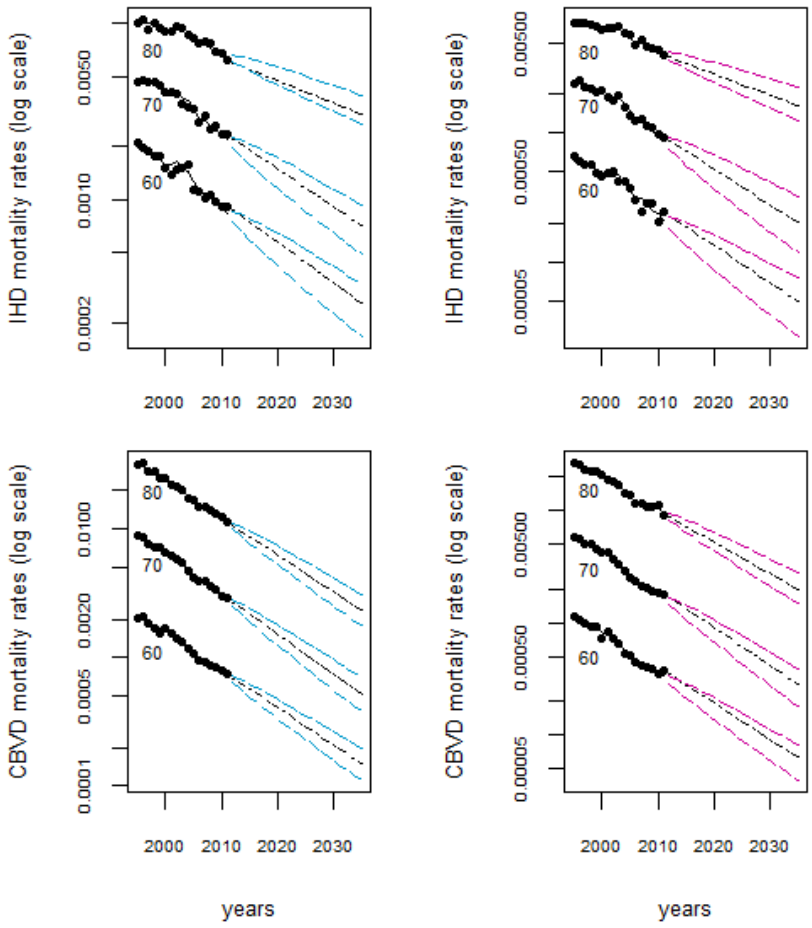

Figure 6.3. Portuguese observed and projected mortality rates (from LC model) due to IHD and CBVD from 1995 to 2035 for the age groups of 60-64, 70-74 and 80-84, separately by sex (blue and pink lines for males and females, respectively), for a 90% confidence interval.

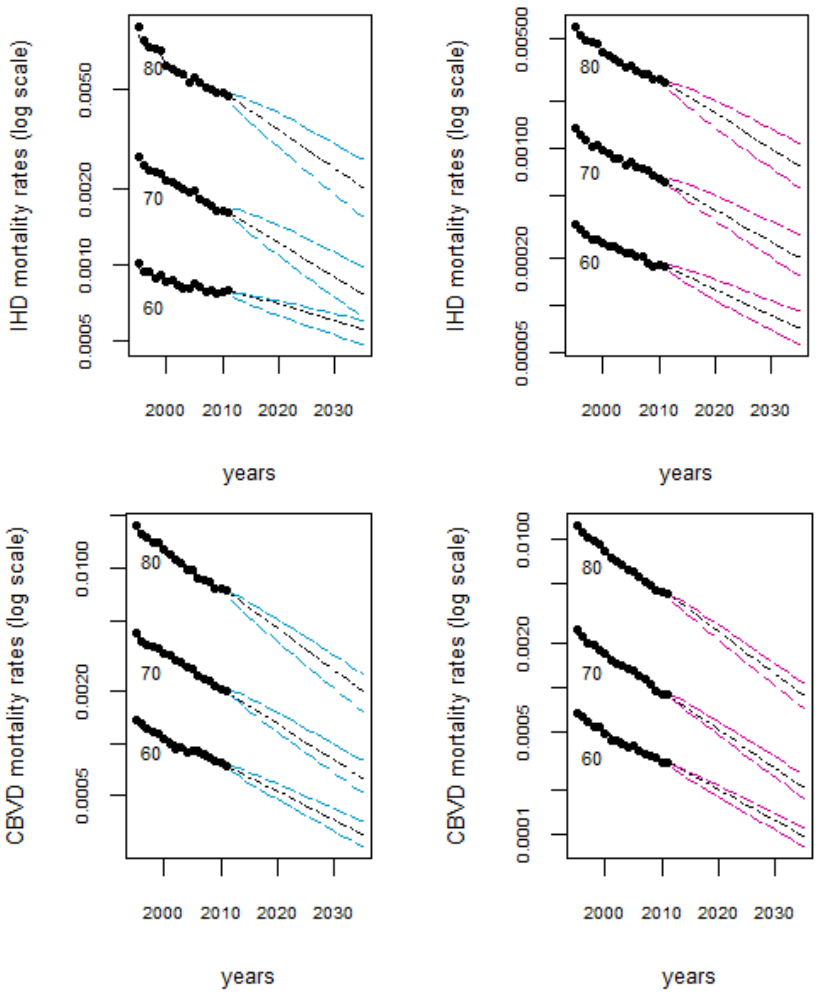

Figure 6.4. Japanese observed and projected mortality rates (from LC model) due to IHD and CBVD from 1995 to 2035 for the age groups of 60-64, 70-74 and 80-84, separately by sex (blue and pink lines for males and females, respectively), for a 90% confidence interval.

6.2. A COMPARISON BETWEEN PORTUGAL AND JAPAN

Aiming to visualise mortality evolution for both populations better, the mortality curves for IHD and CBVD for Portugal (solid lines) and Japan (dashed lines) were designed for each gender and for three future years - 2025, 2030 and 2035. These are illustrated below in Figure 6.5.

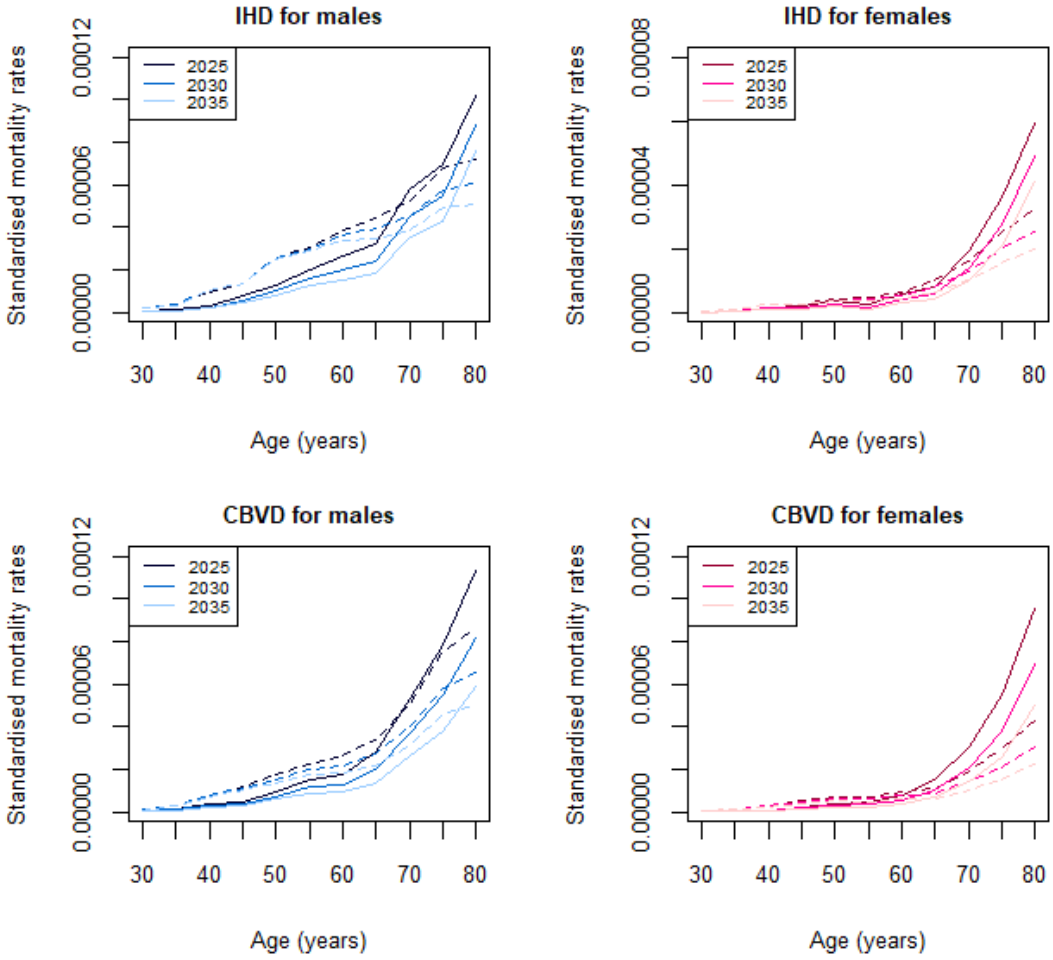

Figure 6.5. Evolution of standardised mortality rates for the Portuguese (solid lines) and Japanese (dashed lines) populations by gender (blue and pink lines for males and females, respectively) and type of disease under study.

For both countries and both types of CVD, the model suggests that mortality rates will decrease in the following years, being evident that these will be much lower in 2035 when compared with 2025, particularly for advanced ages. Moreover, it is noteworthy to mention that women will continue to present lower rates than the opposite gender in all cases, which is congruent with the conclusions taken by Siqueira & Souza (2020) for Brazil. The differences between the two countries are more substantial for males than for females.

In 2025 and according to the model predictions, mortality rates due to IHD and CBVD will already be lower in Portugal for the younger age groups.

In particular, for IHD, predicted mortality rates in Portugal are lower than in Japan until around age 65 for both genders. After that, however, this range increases in the following 5 and 10 years, with predictions for Portugal surpassing the ones for Japan only for male individuals older than 75 years old and females belonging to the age groups of 65-69 and 70-74 in 2030 and 2035, respectively.

As for CBVD, a similar trend is expected, and the age at which predicted mortality rates for Portugal outstrip the ones predicted for Japan increased over the years. Specifically, this goes from 65-69 to 75-79 for men and from 60-64 to 65-69 for women during 2025-2035.

These results conform with the SRRs presented in section 4, where it was demonstrated that Portugal is drawing near Japan in terms of mortality from CVD.

7. CONCLUSIONS

The observed trends in longevity create multiple implications for societies' economic, social, and human development. It is essential to properly design the calculation of the expected present value of future cash flows, both at the level of economic variables and at the demographic level, to minimise the risks of under or overestimate liabilities.

In the matter of recent governmental and actuarial concerns regarding the improved longevity of societies and the need to correctly measure it, research on one of the biggest causes of death in the world - CVD - is of particular interest. The study was restricted to the two most fatal diseases in the group of CVD – IHD (ICD codes: I20-I25) and CBVD (ICD codes: I60-I69). In addition, a comprehensive literature review was undertaken. The vast majority of the studies concluded that the general downtrend in mortality due to these diseases is expected to continue in the following years. Men have a higher probability of being affected in the future than women.

Aiming to contribute meaningfully to the topic, research on the mortality evolution due to CVD in Portugal and Japan was performed, highlighting the YLL, the most significant contributors to its evolution and making future projections. After collecting data and obtaining standardised mortality rates (using the European Standard Population as of 2013 as the standard population) so that both countries could be comparable, it was possible to analyse that mortality trends for these two countries are consistent with the decreasing trends verified in the developed countries since the last decades. The situation is quite similar, including the high infant mortality followed by a sharp decrease in the first years of life and a more pronounced decline for younger ages than for advanced ages. Answering the first research question and comparing with Japan, Portugal revealed higher mortality rates caused by both types of CVD. However, the approximation of the SMRs to 1 implies that Portugal is getting to a situation closer to the one verified in the Asian country.

With a focus on exploring the second research question, an estimation of the years of life that have been lost during the period from 1995 to 2016 was performed, revealing that Portugal (and also Japan) has witnessed a decrease in YLL due to CBVD. Although remaining higher than the YLL due to IHD in almost all cases, the values are getting closer. Furthermore, YLL due to IHD for Portuguese men even overstepped YLL due to CBVD after 2013.

Thereafter, an analysis of the contribution of the variation of demographic factors allowed to draw to the conclusion that the net change in the crude mortality rates is due to the substantial decrease in the risk of dying either from IHD or CBVD which fully compensates the slight increase due to changes in population structure and size. In light of this and as a response to the last research question, the demographic structure of a population does not seem to be that relevant to

understanding and projecting future CVD mortality. Instead, changes in individuals' habits such as diabetes management, smoking consumption and dietary modifications, improved diagnostic capacities and successful treatment might have reduced the risk of dying from these types of CVD. Yet, finding the reasons for this lower risk goes beyond the scope of this study.

After gathering all this information, the modelling and forecasting of mortality due to IHD and CBVD were conducted. Briefly, values of past mortality levels were used to predict the future. The respective mortalities were extrapolated from past trends and a random character, allowing to project future mortality rates. The LC and BAPC models were the two selected to proceed with the study. The two models provided a good fit for both types of diseases in both countries.

Nevertheless, since a good fit to historical data does not necessarily imply good predictive power, the corresponding mortality rates of each of the models were projected for a time horizon of 24 years. The predictive capacity was evaluated by analysing the error measures, MAPE and MSE, in which the LC model stood out in almost all cases for men and women. This was already expected because through the analysis of the BAPC model itself, the cohort effect seemed to be the one with less force in explaining the variations in mortality in Portugal and in Japan. Hence, LC was considered the best model for both countries, given the dataset used in this study.

According to the LC model, mortality rates due to IHD and CBVD are expected to decrease in the following years, with men being more prone to decease due to these diseases than women. A major conclusion is that despite these types of CVD currently having a bigger impact in Portugal compared to Japan, this tendency will not be kept in the future. Indeed, in 2035 the model predicted that mortality rates would already be lower in Portugal for some age groups. It is expected that this will be extended to other age groups some years further.

8. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

Over the years, determining factors in population risk analysis have been evaluated in countless studies to have indicative factors that allow the determination of the number of years the insured person will live, and how many will be with quality.

The most evident limitation of this study is extrapolative methods, which attempt to project future mortality rates based on historical trends. On that account, any surprising upturns due to new cardiovascular treatments and advances in medicine can undermine the results obtained.

Besides, the present study was limited to clinical factors, namely, two types of CVD. Though health problems are known to represent a relevant weight for risk assessment and particularly, CVD account for a significant relevance in terms of mortality worldwide, it is essential to emphasize that it is not just clinical factors that influence the population's life expectancy. Other aspects such as socio-economic and demographic factors, lifestyle and emotional issues of the population and even country-specific factors play a significant role in influencing life expectancy.

Future research could extend this study to other health problems linked to the major causes of death, including respiratory diseases and cancer.

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