M.Sc. in Actuarial Science

Master Final Work

Dissertation

Impaired Life Annuities

Cláudia Sofia Carrilho Barradas

October - 2016

M.Sc. in Actuarial Science

Master Final Work

Dissertation

Impaired Life Annuities

Cláudia Sofia Carrilho Barradas

Supervisor: Onofre Alves Simões

October - 2016

Impaired Life Annuities
Cláudia Sofia Carrilho Barradas
M.Sc. in Actuarial Science
Supervisor: Onofre Alves Simões

Abstract

The problem of the lack of annuitization (F. Modigliani's "annuitization puzzle"), continues to be widely discussed in the literature. A number of studies give a wide range of possible explanations, following two main approaches: the rational and the behavioural economics. Under the first approach, which will be embraced in this work, the adverse selection is one of the most popular explanations. Adverse selection in this context is the lack of actuarially fair supply of life annuities for those with an average or impaired life expectancy.

The ultimate purpose of this thesis is to offer a contribution to partially solve the "annuitization puzzle", giving evidence that it is possible to fairly price life annuities for those lives that disease has diminished.

To accomplish the purpose in question, two steps are required. First it is necessary to assess the impact of some of the most serious and common medical conditions (cancer and some cardiovascular or respiratory diseases) over the survival curve, by using (1) net and (2) crude relative survival estimates, over a reference life table. Second, using the survival curves already adjusted taking in consideration each particular illness, proceed to calculate the life annuity premiums for the lives impaired due to that illness, and compare them with those of the general population.

Although a few problems remain, mostly related with the quality and volume of available data, calling sometimes for precaution with respect to conclusions, some important results could be observed. It was possible to notice that there are no significant differences between the results produced by net and crude relative survival estimates. Further, it was confirmed that the survival of the diseased groups is, in general, substantially lower than that of the reference population, being the effect increasing with the age at diagnosis and the number of years from diagnosis. Finally, as expected, the life annuity premiums for impaired lives are substantially lower than those for standard lives. This effect is more pronounced for earlier ages, decreasing with the age at the beginning of the life annuity. Clearly, should these lives had access to a fair market, business (and profits) would certainly increase.

Keywords: Life annuity, "annuitization puzzle", impaired life, net survival, crude probability of death.

JEL classification: G22.

Rendas vitalícias para pessoas com esperança de vida reduzida
Cláudia Sofia Carrilho Barradas
Mestrado em Ciências Actuariais
Orientador: Onofre Alves Simões

Resumo

A reduzida oferta-procura de produtos de rendas vitalícias continua a ser um tema muito discutido na literatura. Diversos estudos apresentam explicações enquadráveis em duas abordagens distintas: os modelos racionais e a economia comportamental. No âmbito da primeira abordagem, adoptada neste trabalho, a seleção adversa é uma das principais explicações e traduz-se, quando aplicada ao mercado de rendas vitalícias, na inexistência de oferta de produtos actuarialmente justos para aqueles com esperança de vida média ou reduzida.

Com esta dissertação pretende contribuir-se para a resolução parcial do problema da anuitização ("*annuitization puzzle*"), evidenciando a possibilidade de atribuir preços justos aos produtos de rendas vitalícias destinados à população com esperança de vida reduzida por doença.

Para atingir este objetivo, é necessário seguir duas etapas. Em primeiro lugar, mensurar o impacto de cada condição médica na função de sobrevivência, com recurso a estimativas, (1) líquidas e (2) brutas, de sobrevivência relativa entre a população doente e uma população de referência. Em segundo lugar, utilizando as curvas de sobrevivência previamente ajustadas às doenças consideradas, proceder ao cálculo dos prémios de rendas vitalícias referentes à população doente, e compará-los com os da população de referência.

Apesar de se continuarem a verificar alguns problemas, relacionados sobretudo com a qualidade e volume dos dados disponíveis, exigindo portanto alguma precaução ao nível das conclusões, podem ser observados alguns resultados importantes. Os resultados demonstram não existirem diferenças significativas entre as duas abordagens utilizadas. Confirmou-se, adicionalmente, que a sobrevivência da populaçao doente é substancialmente inferior à da população de referência, sendo o efeito crescente com a idade no diagnóstico e o número de anos desde o diagnóstico. Por último, tal como esperado, os prémios de rendas vitalícias referentes à população doente são substancialmente inferiores aos da população de referência. Este efeito é mais pronunciado para idades mais jovens, decrescendo com a idade no início da renda. Claramente, se estas vidas tivessem acesso a um mercado justo, o negócio (e os lucros) aumentariam.

Palavras-Chave: Renda vitalícia, "*annuitization puzzle*", sobrevivência reduzida, sobrevivência líquida, probabilidade bruta de morte.

Classificação JEL: G22.

Acknowledgements

Uma palavra de agradecimento às pessoas que, de forma direta ou indireta, tornaram possível a realização deste trabalho.

Ao Professor Onofre Simões pela orientação, e disponibilidade que sempre demonstrou, especial agradecimento.

Por último, mas certamente não menos importante, um agradecimento à minha família, pela paciência, apoio e dedicação.

Contents

List of Tables

List of Figures

1 Introduction

A whole life annuity is an insurance product that provides a pre-settled periodic amount until the death of the annuitant, see for instance Dickson, Hardy and Waters (2013). The expected present value of a life annuity is calculated by discounting the income stream by the interest rate and the probability that the individual is alive to receive each payment. Since the individual's time of death is uncertain, annuities should be a valuable product (Yaari (1965)). However, empirical evidence from several countries shows that few people purchase annuities (see for e.g. James and Song (2001); Johnson *et al.* (2004)). How could this "annuitization puzzle" be explained?

The concept of "annuitization puzzle" is frequently associated to the Nobel acceptance speech of Franco Modigliani (1986), given in 1985: "*It is a well-known fact that annuity contracts, other than in the form of group insurance through pension systems, are extremely rare. Why this should be so is a subject of considerable current interest. It is still ill-understood.*". The Modigliani's statement remains true more than thirty years later, since the life annuity market is still almost non existent, except for a few countries with some compulsory annuitization of personal pension plans (Lindeman and Yermo (2002)).

On the one hand, life expectancy has substantially improved during the past decades. Data from Global Health Observatory (GHO) suggests that global average life expectancy at birth of 71.4 in 2015 (76.8 for the European region) had increased by 5 years between 2000 and 2015, and that global population aged 60 years in 2015 could expect to live another 20 years on average. On the other hand, reforms in public social security systems and private pension plans, that partially replace defined benefit (DB) plans with funded defined contribution (DC) plans, are performed all over the world (Antolin et *al.* (2009)). While, in the DB system, the pension fund sponsor is responsible for ensuring a fixed monthly payment during the entire life of the beneficiary, in the DC system the longevity risk is taken by the retired person. In this way, the risk of outliving one's retirement wealth is strongly increasing. Both, the increasing trend of life expectancy and the proliferation of DC plans are expected to contribute to solve the "annuitization puzzle", since annuities are a straightforward way to hedge longevity risk. In Portugal, as in other countries where private pension systems are not mandatory, the annuity market tends to be undeveloped. Annual statistics report from Portuguese supervisor authority (Autoridade de Supervisão de Seguros e Fundos de Pensões (2015)) shows that more than a half of annuity individual contracts come from occupational pension funds. Being the investment in a life annuity product required by Portuguese law (Article 8.º, Law n.º 147/2015 from the 9th of September) to occupational pension funds, it becomes clear that only a small proportion of individuals is willing to buy an annuity.

Several studies try to explain the motivation of this annuity market puzzle through different approaches (for a review see Brown (2007)). Under the frameworks of rational models and behavioural economics, researchers found a set of possible explanations. Although these explanations help to understand the problem, apparently none is able

to fully explain it. One of the most popular explanations is that annuity market puzzle occurs because annuity prices tend to be perceived as actuarially unfair for individuals with average life expectancy (see Webb (2006)). This happens, primarily, because insurers have to apply charges over the annuity net premium to cover their costs and allow them to make a profit and, secondly, because of the phenomenon of adverse selection.

Two main variables affect the price of a life risk insurance product, the claim probability and the claim amount. In life annuities the claim occurrence is a certain event, so the product's price entirely depends on the average lifespan of the potential annuitants. If it could be assumed that the whole country population would be willing to buy annuities, the annuity price would be calculated based on the average lifespan of the whole country population. However, if only individuals living longer than average are to buy annuities, the annuity price would be underestimated and the insurance company would incur in a loss. To avoid this situation, insurers usually include in their annuity's price calculations the assumption that potential annuitants are individuals with a life expectancy above the average. This way there is no annuity market for individuals with life expectancies lower than average, thus creating an adverse selection situation for impaired lives.

The main objective of this study is to find ways to minimize the problem of adverse selection in annuity markets. Theoretically, this problem could be solved by calculating the price for each annuitant based on his/her risk level. In practice this is an unrealistic solution since it is almost impossible to effectively assess the risk of each annuitant. So, an intermediate approach is usually chosen, which allows the estimation of different annuity values for diseased individuals, depending on the diagnosed medical condition, the age at diagnosis and time from diagnosis.

In this kind of analysis, the problem of competing risks is usually present. Our relevant event is the observation of an individual's death by the disease under study within a group of diseased people. In a group of individuals diagnosed with the disease of interest one would expect that some would die because of the disease and others would die due to other causes (it is not possible to observe the relevant event) or, regardless of the individual dying due to disease of interest, the death time also depends on other medical conditions (other events change the probability of occurrence of the relevant event).

The existence of competing risks is one of the most important problems in the interpretation of survival analysis results. When one or more outcomes from an experience compete with the relevant outcome, one would say to be in the presence of competing risks. Competing risks can hinder the observation of the relevant event or modify its probability of occurrence.

In survival literature there are two different approaches to deal with competing risks, net and crude probabilities of death. Net or marginal probability of death is a probability of death in a hypothetical world where the disease under study is the only possible cause of death. Crude probability of death is a probability of death in the real world where the diseased person could die of other causes. Both net and crude probabilities can be estimated using relative survival methods. A relative survival intents to compare the

proportion of observed survival in the group of diseased people with the expected survival of a comparable group from the general population.

This work has two main parts. The first investigates the mortality of impaired lives, considering as an impaired live or impaired risk someone who suffers from a pre-existing medical condition responsible for reducing his/her life expectancy. In this study the following groups of medical conditions, which are the leading causes of death, are considered: cancer, cardiovascular diseases - heart attack, hypertension, cholesterol and stroke -, and respiratory diseases - chronic lung disease and asthma. For this purpose, following Dickman, Coviello and Hills (2015) two different methods under the framework of relative survival were used, the net survival and the crude mortality. As seen, net and crude methods differ in the way of dealing with other possible causes of death (competing risks).

The second part presents a comparison of net life annuity premiums between the reference population - *proxied* by GKM95 (male) and GKF95 (female) life tables, widely used by insurance companies - and the population of diseased individuals - using the general mortality corrected by the factors estimated in the first part for each age group and medical condition.

The text is structured as follows. Section 2 presents the literature review. Sections 3 and 4 describe the methodology and data. The main empirical results and the comparison of life annuity values are in Section 5. Section 6 concludes.

2 Literature Review

This section is divided in two different main subsections. The first intends to review the leading explanations of the annuitization puzzle, distinguishing the rational and the behavioural frameworks. The second subsection presents the main approaches used to study the survival of a group of diseased individuals, being the most relevant the cause-specific mortality and the relative survival.

2.1 Annuitization puzzle

The problem of the lack of annuitization has received great attention in literature (see, e.g. Brown (2007) and Benartzi, Previtero and Thaler (2011)). There are two main approaches to explain the annuity puzzle, the rational models framework and the behavioural economics framework.

2.1.1 Rational models framework

Under the rational models approach, the main explanations for the annuitization puzzle found in literature are the problem of adverse selection, pre-existing annuitization, risk sharing in couples, bequest motive and the existence of incomplete annuity markets.

Finkelstein and Poterba (2002) argue that the main difference between the expected present value of all future annuity payments and the premium paid for the annuity reflects what they call, "active" and "passive" selection. "Active" selection refers to adverse selection that comes from private health information about expected longevity. "Passive" selection refers to other factors that are also correlated with mortality such as the higher income and wealth of the annuitants.

Several studies, such as Brown (2001) and Brown *et al.* (2007), reinforce the idea of "active" selection showing that only healthy individuals are willing to pay for an annuity product, which implies that the annuity market for individuals with poor self-reported health is almost non-existent. Blake and Burrows (2001), Blake, Burrows and Orszag (2002), Blake, Cairns and Dowd (2006), Friedberg and Webb (2007) and Brown and Orszag (2006) conclude that the uncertainty about the health conditions of the annuitants makes it impossible for insurance companies to adequately hedge the longevity risk, therefore they must charge a higher price to compensate for the risk taken.

Some researchers, such as Mitchell *et al.* (1999) and more recently Gentry and Rothschild (2006), argue that the risk margin is not the most important explanation of the annuity puzzle since there is no empirical evidence of a strong price elasticity of demand for annuities. Besides, in theory, risk margins are not sufficiently large to offset utility gains of the annuitization.

Standard models define a decreasing expected marginal utility of the annuitization, so the higher the individuals level of pre-existing annuitization, from Social Security or

private defined benefits, the lower the demand for additional annuitization (Dushi and Webb (2004)).

Traditional annuity products have no value at the individual's death, so it is not a good solution for those who want to leave a bequest to their heirs. This is why some studies, such as Yaari (1965), show that the full annuitization, described as the propensity of a certain consumer to annuitize all of their savings, is only possible if there is no bequest motive. Even though this is true, other researchers, such as Brown *et al.* (2008), demonstrate that this is not enough to explain the annuity puzzle. Each individual has to make a choice between savings and consumption. Considering the wealth amount as a limited resource, the saving level decreases, as the consumption level increases. Annuitization is the only possible way to ensure that the size of bequest is fixed and stable, otherwise this amount depends on the individual's time to death. Regardless of the lack of empirical evidence holding the bequest motive, several studies show that there is no correlation between the number of children and the annuitization choice (Brown and Poterba (1999), Johnson *et al.* (2004) and Brown *et al.* (2007)) and other studies show that the propensity to acquire annuities is lower for couples than for single people.

All these works try to provide explanations for the annuity puzzle under the framework of "rational models". Although each one contributes to explain the lower demand of annuities, empirical evidence suggests that they are not strong enough explanations for the whole puzzle.

2.1.2 Behavioural economics framework

Recently, there have been a number of developments in the framework of "behavioural economics", a new approach that attempts to explain the consumer behaviour based on psychology insights. There are several studies (see, e.g. Benartzi *et al.* (2011)) applying behavioural economics to the annuitization decision. The main goal of these studies is to incorporate in the consumer models some predictable consumer psychological biases that are not compatible with the hypothesis of pure rationality.

Potential annuitants tend to consider annuities a very complex product on which there is lack of information (Brown (2007)). Generally they consider that a product providing life contingent payouts is extremely confusing, so they are simply not interested in it. Several studies reinforce this idea concluding on the lack of financial sophistication in population and how people became unable of applying a fully informed decision-making process (Smith and Stewart (2009) and Lusardi and Mitchell (2007)). Brown, Casey and Mitchell (2007) give evidence that agents having some knowledge about compound interest are more likely to choose annuitization.

Individuals tend to perceive annuities as a risky gamble in which, with some probability, they lose if they die soon and they just win if they live well past life expectancy. This theory, associated with the loss aversion concept, makes annuities seem an unattractive product because "losses" are overestimated exceeding the annuity potential "gain" (Tversky

and Kahneman's (1992) and Hu and Scott (2007)). Beyond the fact that individuals are risk averse, they are regret averse too, because they are generally very concerned about the probability of dying soon after they have bought the annuity. Despite of this probability being usually very low, individuals tend to overestimate it in the annuitization decision-making process (Tversky and Kahneman (1974)). Regret aversion individuals tend to avoid extreme outcomes and, in this sense, they are less likely to fully insure but also less likely to not insure at all (Braun and Muermann (2004)). In this perspective, regret aversion should lead individuals to diversify the risk, reserving at least a small amount to annuitization.

Immediate liquidity gives the illusion of control, which means the belief that all outcomes are under control even if they are not (Langer (1975)). In this sense, people feel more confident by holding wealth rather than by receiving income and, for this reason, people are reluctant to pay a lump-sum to an insurer to receive a periodic payment stream.

The development of prospect theory is an important contribution to understanding the framing role in economic decisions (Tversky and Kahneman (1986)): choice is not purely rational, but instead depends on the particular frame used to interpret the situation. Brown *et al.* (2008) showed that annuities are perceived as an attractive product when presented in a consumption frame (how to consume) because it serves as a form of insurance but it is considered a risky asset in an investment frame (how to invest) because the payoff depends on the random variable time to death.

Regarding the previously exposed, it can therefore be concluded that there is no simple solution to the problem of lack of annuitization.

2.2 Survival analysis

2.2.1 Competing risks

To estimate the survival function of a group of patients diagnosed with a particular disease two main different measures can be used, crude and net probabilities. These measures essentially differ in the way they consider competing risks. The concept of competing risk was first introduced by Daniel Bernoulli (1760), when he questioned "*if in a given population smallpox could be eradicated, what would be the effect on the population mortality at different ages?*".

Several studies are focused on the problem of competing risks and their consequences on the accuracy of survival estimates. Berkson and Gage (1952) argue that patients with cancer, before treatment, are subject to the effect of two mortality forces, the force of the cancer and the force of other diseases. After the treatment, a percentage of patients is cured and is subject only to the mortality force of other diseases, and the remaining patients are still influenced by the two forces, being not necessarily equal to the ones before treatment: "*The determination of whether a death is entirely due to cancer or entirely due to other causes is difficult to establish, if indeed it is even possible to define precisely. Actually, in most cases it is impossible to establish unequivocally*". In Berkson

and Gage (1952), p.510

Cornfield (1957) confirms the previous idea showing that, in presence of competing risks, other causes of death compete with the development of the disease of interest in a formal and in an empirical way. In a formal sense, all the individuals that had died from other causes cannot develop the disease of interest leading to the conclusion that, in presence of other causes of death, the chance of developing the disease of interest decreases. In an empirical sense, all the individuals dying from other causes have a different probability to develop the disease of interest.

Prentice *et al.* (1978) identified the main problems that arise in the analysis of failure times in presence of competing risks. First, the estimates of a treatment effects in presence of competing risks may be incorrect. Second, to produce unbiased estimates it is necessary to ensure that failure times are statistically independent, but this is impossible to ascertain once it is just possible to observe the time to failure which occurs first. Third, the problem of estimating a certain failure rate after other failure cause had been removed.

An additional source of bias may come from incomplete follow-up data. Cutler and Ederer (1958) describe a life table method to estimate survival with five years survival data for cancer patients, including for this purpose both patients with five or more and less than five years of observation (partial information). Ederer *et al.* (1961) quoting Heise (1959) argued "*including the data for late entries, one assumes that their survival experience subsequent to the closing date will be similar to that of patients under observation for the entire period. If this assumption is not valid, the procedure is biased*". In Ederer *et al.* (1961), p.103

Chiang (1961) provides a refinement of Cutler's method dealing with the problem of incomplete follow-up data. The author also provides a method to assess mortality from specific-causes when competing risks are present. Wong (1977) developed a non-parametric competing risk model that is intended to deal with what he calls "relative susceptibility", a concept that is equivalent to the empirical effect of Cornfield described previously. The proposed method aims to adjust the number of survivals and deaths in an interval when a competing cause of death was eliminated in the previous interval, thereby eliminating the assumption of independence between all causes of death. Berry (1979) proposes an improvement to Wong's method assuming that death occurs at middle of the interval instead of at the beginning.

2.2.2 Cause-specific survival

The previous methodologies are developed under the framework of cause-specific survival, which is implemented using a standard life table approach where individuals who die of causes other then those specified are considered to be censored. A number of studies focus on describing the limitations of this approach. Erhardt (1958) and Spiegelman *et al.* (1958) showed that the information on cause of death in certificates is inaccurate and incomplete. Percy and Dolman (1978) and Percy and Muir (1989) argue that the cause-

specific survival approach is inappropriate for international comparisons since the coding practices vary substantially among countries. Parkin and Khlat (1996) and Pineda *et al.* (2001) show that when comparing cause-specific survival rates across diverse groups, if different racial or ethnic groups have different rates of follow-up, the estimates produced are biased.

Taking into account the limitations of the cause-specific approach described previously, relative survival methods that are independent from potential miscoding of the underlying cause of death are the measure of choice to reporting survival rates when international comparisons are made (Coleman *et al.* (2008)).

2.2.3 Relative survival

The concept of relative survival was firstly introduced by Berkson (1942), who proposed an estimator for survival in cancer patients, that is an estimator for net survival. It was then developed by Ederer *et al.* (1961), p.103, as "*the ratio of the observed survival rate in a group of patients, during a specified interval, to the expected survival rate*". They defined the expected survival rate as belonging to "*a group similar to the patient group in such characteristics as age, sex, and race, but free of the specific disease under study*". A group of individuals are selected from the general population respecting the following two criteria: they do not have the disease of interest and they match with the disease group at the beginning of the follow-up time with respect to covariates that are supposed to affect the survival. Conversely to Berkson (1942), these authors view both the cause-specific survival and relative survival as possible estimators of net survival.

Relative survival models are largely applied in literature to study the excess of mortality due to cancer disease. Nelson *et al.* (2008) show that the utility of this methodology is not restricted to cancer analyses. They also apply the relative survival method to study coronary heart disease and conclude that the cause-specific method, generally used to assess the survival after myocardial infarction, produces estimates that allow no distinction between mortality associated with the condition of interest and mortality due to all other causes.

The major limitation of the relative survival method is that it only produces unbiased estimates if deaths due to the disease of interest are independent of the mortality in general population. The expected survival rate is usually available from general population life tables. However, life tables are not free of the specific disease under study, in the sense they reflect the force of mortality from all causes of death.

Berkson (1942), Berkson and Cage (1950), Cutler *et al.* (1957), Milmore (1958), Ederer and Heise (1959), argued that the presence of the disease under study in the population life tables only produces a very negligible effect on relative survival estimates. Nelson *et al.* (2008) prevent that this is a risky assumption, exemplifying with heart disease which is the most important cause of death, essentially for oldest age groups.

Howlader *et al.* (2010) show that cause-specific survival is sometimes preferable to the

relative survival approach. Relative survival models establish a comparison between the mortality of the group of interest and the mortality of general population. These estimates require a matching between life tables (general population) and the group of interest population by age, sex, race, socioeconomics status and other risk factors. Relative survival may not be the best measure to apply when one intends to generate survival statistics to minority groups. This methodology is very likely to produce biased estimates since the sub-group associated factors are not accounted for in life tables, although they exist, for example, to minority racial subgroups, different socioeconomic strata and populations with strong risk factors for disease.

3 The models

3.1 Net survival framework

Net survival is a theoretical probability that can be estimated using cause-specific survival or relative survival methods.

Cause-specific survival estimates are calculated in such a way that the individuals who die of causes other then the cause of interest are censored. The main problem of this approach is the difficulty to obtain complete and accurate information about the cause of death, which can lead to biased estimates in the sense that different causes of death could not be independent.

The cause-specific method just provides unbiased estimates of net survival when the independence assumption is satisfied. The independence assumption means that there are no factors that influence simultaneously the mortality of the diseased and non-diseased individuals other than those factors that have been controlled in the estimation. This independence is crucial for the interpretation of survival curves. If the assumption is satisfied the survival curves represent survival in the absence of all competing causes of death. If the independence assumption is not satisfied cause-specific survival curves provide biased estimates of net survival.

To overcome these problems one can use the relative survival method instead of the cause-specific one. Since the relative model does not require the cause of death information it is less likely to produce the bias mentioned before. Relative survival is estimated as the ratio between the proportion of observed survivors in the cohort of individuals diagnosed with the disease under study and the proportion of observed survivors in a comparable group from the general population free of disease of interest. The reference population is usually *proxied* by generally used life tables.

Although net survival methods can produce hypothetical and sometimes biased estimates, it is a very useful measure because of its independence from background mortality and therefore allows to compare estimates across time, countries and age groups.

Due to lack of cause of death information, this study only estimates the net survival under the relative survival framework.

3.1.1 Relative survival estimators

The relative survival method provides the following relative survival rate attained as the ratio between the observed survival probability of the diseased people under study $S(t)$, and the expected survival probability of a comparable group of the background population $S^*(t)$,

$$r(t) = \frac{S(t)}{S^*(t)}. \tag{1}$$

While the numerator just considers the observed individuals diagnosed with the disease of interest, the denominator is estimated from life tables, which means that not only healthy individuals are taken into account but also those diagnosed with any kind of disease, including the disease of interest.

As previously referred, some authors believe that this method does not significantly affect the estimates, since the percentage of diseased individuals considered in the background population is negligible. Nevertheless, the intention being to estimate the excess of mortality due to a certain disease of interest over the general population free of this disease, one has to acknowledge that, in some cases, the presence of the studied disease among the general population may be significant enough to produce biased estimates.

Some of the most commonly used methods to estimate the expected relative survival given by equation (1) are the estimators developed by Ederer, Axtell and Cutler (1961), Ederer and Heise (1959), Hakulinen (1982) and Perme *et al.* (2012).

3.1.1.1 Ederer, Axtell and Cutler (1961)

The estimator developed by Ederer, Axtell and Cutler (1961), hereinafter 'Ederer I', allows to estimate the expected survival assuming that each diseased individual under observation would be a member of the general population from diagnosis to entire follow-up. This means that 'matched' individuals from the background population are considered to be at risk indefinitely and the time at which a diseased individual dies or is censored has no effect on the expected survival. For each diseased individual j the expected survival probability until the end of the i^{th} interval is

$$p_i^{EI}(j) = \prod_{k=1}^{i} p_k(j), \tag{2}$$

where $p_k(j)$ is the expected interval-specific survival proportion from the life table and the i^{th} interval specifies the partition of the follow-up time into bands corresponding to life-table intervals. These intervals do not need to be equidistant. They are typically one year in length, although in specific circumstances could be shorter at the beginning of the follow-up, where mortality is often higher and changing rapidly. In this study it was chosen to use one year intervals.

The cumulative expected survival for all diseased individuals ($j = 1, .., l_1$) from date of diagnosis to the end of the i^{th} interval is

$$p_i^{EI} = \sum_{j=1}^{l_1} \frac{p_i^{EI}(j)}{l_1} \tag{3}$$

where l_1 is the total number of diseased individuals alive at the start of follow-up.

Ederer I method would produce unbiased estimates of the expected survival; however, in presence of informative censoring, it produces biased estimates of the relative survival ratio. This method usually overestimates the relative survival since it does not allow for

the unequal potential follow-up times.

Hakulinen (1982) argue that Ederer I produces biased estimates in presence of heterogeneous patterns of withdrawal from different subgroups like, for example, in populations where the number of old people increase and the number of young people decrease, because the potential follow-up time is longer for young than for old sick people.

3.1.1.2 Ederer and Heise (1959)

The estimator developed by Ederer and Heise (1959), hereinafter 'Ederer II', estimates the expected survival for the diseased individuals at each point of follow-up. This means that the 'matched' individuals from the background population are considered to be at risk until the corresponding diseased individual dies or is censored.

This method allows the existence of different length of follow-up times. To estimate the expected survival in a specific i^{th} interval, it only considers the diseased individuals at risk at the beginning of the interval (l_i)

$$p_i^{EII} = \sum_{j=1}^{l_i} \frac{p_i^{EII}(j)}{l_i}, \tag{4}$$

where $p_i^{EII}(j)$ is the expected survival probability of an individual in the general population, similar to the j^{th} diseased individual alive at the beginning of the i^{th} follow-up interval with respect to age and sex. The cumulative expected survival is of the form

$$p_i^{EII}(j) = \prod_{k=1}^{i} p_k(j). \tag{5}$$

Although the Ederer II method controls for heterogeneous observed follow-up times, it would produce biased estimates of relative survival ratio. This method usually underestimates the relative survival ratio since the expected survival depends on the observed survival.

3.1.1.3 Hakulinen (1982)

Hakulinen method estimates the expected survival for the diseased individuals assuming that the survival function of the censored observations equals the function of the matched individual of the background population. Otherwise, it considers that the matched individual of the background population is at risk until the end of the study when the diseased individual dies. The expected survival proportion from the beginning of follow-up to the end of the i^{th} interval is of the following form:

$$p_i^H = \prod_{k=1}^{i} \left(1 - \frac{d_k}{l_k - \frac{w_k}{2}}\right), \tag{6}$$

where $\frac{d_k}{l_k - \frac{w_k}{2}}$ is the expected mortality rate in the k^{th} interval, considering the individuals

at risk at the beginning of the interval corrected by subtracting half the number of censored individuals, meaning that withdrawals occur uniformly throughout the interval. Note that d_k is the expected total number of individuals dying during the k^{th} interval; δ_k is the expected number of deaths of the H_{jb} individuals; w_k is the number of withdrawals during the k^{th} interval; and l_k is the expected number of diseased individuals under observation alive at the beginning of the k^{th} interval.

Hakulinen method assumes that there are h_k diseased individuals under observation with a possible follow-up time beyond the beginning of the k^{th} interval. From this group, h_{ka} individuals have a possible follow-up time beyond the end of the k^{th} interval and h_{kb} individuals are potential withdrawals during the interval, in such a way that $h_k = h_{ka}+h_{kb}$. This means that at the beginning of the study all diseased individuals under observation are alive ($h_1 = l_1$) and the number of diseased individuals alive at beginning of the $k^{th}+1$ interval corresponds to h_{ka}, i.e., $h_{k+1} = h_{ka}$.

This way, it follows that:

$$d_k = \begin{cases} \left\{\sum_{h\epsilon H_{ka}} p_{k-1}^H(j)[1 - p_k^H(j)]\right\} + \delta_k, \ for\ k \geq 2 \\ \sum_{h\epsilon H_{1a}}[1 - p_1^H(j)] + \delta_1, \ for\ k = 1 \end{cases} \tag{7}$$

$$\delta_k = \begin{cases} \sum_{h\epsilon H_{kb}} p_{k-1}^H(j)[1 - \sqrt{p_k^H(j)}], \ for\ k \geq 2 \\ \sum_{h\epsilon H_{1b}}[1 - \sqrt{p_1^H(j)}], \ for\ k = 1 \end{cases} \tag{8}$$

$$w_k = \begin{cases} \sum_{h\epsilon H_{kb}} p_{k-1}^H(j)\sqrt{p_k^H(j)}, \ for\ k \geq 2 \\ \sum_{h\epsilon H_{1b}} \sqrt{p_1^H(j)}, \ for\ k = 1 \end{cases} \tag{9}$$

$$l_k = \begin{cases} \sum_{h\epsilon H_k} p_{k-1}^{**}(j), \ for\ k \geq 2 \\ l_1, \ for\ k = 1 \end{cases} \tag{10}$$

Hakulinen method produces survival estimates that are independent of the observed mortality adjusted for potentially heterogeneous follow-up times.

3.1.1.4 Pohar Perme (2012)

Pohar Perme (2012) found that standard estimators of relative survival (Ederer I, Ederer II and Hakulinen) are biased. These estimators do not provide information on the mortality caused by the disease of interest that is independent of the national general population mortality, which means that they are not suitable for comparisons between countries.

To overcome this problem Pohar Perme (2012) proposed a new estimator of net survival probability that enables the desired comparability between countries.

The Pohar Perme estimator for continuous time assesses the net survival by weighting by the inverse of the individual-specific expected survival probabilities. The purpose of

the weights is to inflate the observed person-time and number of deaths to account for person-time and deaths not observed as a result of mortality due to competing causes.

Dickman, Coviello and Hills (2015) propose a discrete estimator of net survival following the Pohar Perme approach (NS_i), where weights are based on the cumulative expected survival at the midpoint of the interval.

$$NS_i = \frac{1 - \frac{d_i^w}{n_i^w - c_i^w/2}}{exp\left\{-\frac{\sum_j^{ni} \lambda_j^{*w} - \sum_j^{ci} \lambda_j^{*w}/2 - \sum_j^{di} \lambda_j^{*w}/2}{n_i^w - (d_i^w + c_i^w)/2}\right\}}, \tag{11}$$

where d_i^w is the weighted number of deaths during the interval, n_i^w is the weighted number of individuals alive at the start of the interval, c_i^w is the weighted number of censorings during the interval and λ^{*w} is the weighted expected hazard.

3.2 Crude probability of death framework

As briefly explained before, net survival is a very useful measure that is independent of background population and, for this reason, allows for comparisons across time, different age-groups and different countries. However, the unrealistic assumption that there are not other possible causes of death beyond the disease of interest, causes the overestimation of the probability of dying from the disease under study. Although it is a very useful measure, it is also of interest to estimate crude probabilities.

The crude probability of death measures the mortality patterns actually experienced in a cohort of a patients diagnosed with a certain disease on which many possible causes of death are acting simultaneously. This method estimates the probability of dying from the disease under study and dying from other causes in a cohort of patients diagnosed with the disease of interest, by using the expected survival (obtained from the expected life tables) to estimate the probability of dying from other causes in each interval. These methodology is based on the assumption of independent competing causes of death.

3.2.1 Relative mortality estimator

Similarly to net survivals, also crude probabilities can be estimated under the cause-specific and relative survival frameworks. The cause-specific method alows to estimate the probabilities of death from the disease under study and the probabilities of death from other causes for a cohort of individuals diagnosed with the disease of interest by using cause of death information. These probabilities are usually estimated through multiple decrement tables. In this study, as previously explained, accurate and sufficient cause of death information needed to apply the cause-specific framework is not available. The crude measure under the framework of relative survival was introduced by Cronin and Feuer (2000).

3.2.1.1 Cronin and Feuer (2000)

Cronin and Feuer (2000) developed a measure for cumulative crude cause-specific probability of death, using relative survival instead of cause of death information. This is a method analogous to relative survival, that measures mortality in the presence of other causes without the use of cause of death information.

The authors proposed to estimate the crude cause-specific probabilities of death, separately, due to the disease under study ($\tilde{g}_{xc}$) and due to other causes ($\tilde{g}_{xo}$), in the following way:

$$\tilde{g}_{xc} = \left(\prod_{i=1}^{x-1} \hat{P}_i\right)\left(1 - \frac{\hat{P}_x}{E_x}\right)\left(1 - \frac{1}{2}(1 - E_x)\right) \tag{12}$$

$$\tilde{g}_{xo} = \left(\prod_{i=1}^{x-1} \hat{P}_i\right)(1 - E_x)\left(1 - \frac{1}{2}\left(1 - \frac{\hat{P}_x}{E_x}\right)\right), \tag{13}$$

where:

$\hat{P}_x = \left(1 - \frac{d_x}{n_x^*}\right)$ is the maximum likelihood estimator of the probability of surviving interval x conditioned on surviving until the beginning of the interval, estimated using a life table approach and assumed to be a binomial random variable;

E_x is the expected net survival for other causes in interval x conditioned on being alive at the beginning of interval x (that is, the survival that the cohort would have expected if they did not have the disease under study);

$\frac{\hat{P}_x}{E_x}$ is an estimate of net survival for the disease under study;

$n_x =$ is the number of people alive at the beginning of interval x;

$d_x =$ is the number of people who died in interval x;

$l_x =$ is the number of people lost to follow-up in interval x;

$n_x^* = n_x - \frac{1}{2}l_x$ is the number of people at risk during the interval, adjusted for uniform loss to follow-up.

The cumulative estimates are, respectively, $\tilde{G}_{xc} = \sum_{i=1}^{x} \tilde{g}_{ic}$ and $\tilde{G}_{xo} = \sum_{i=1}^{x} \tilde{g}_{io}$.

The estimates proposed assume independent competing causes of death. For simplicity they use the concept of a latent time of death for each competing cause acting within a population; the latent time for cause k is defined as the time death would occur from cause k in the absence of all other causes of death.

Under this concept the probability of dying in interval x conditioned on surviving until the beginning of the interval can be written as $1 - (1 - h_{xc})(1 - h_{xo}) = h_{xc} + h_{xo} - h_{xc}h_{xo}$ where h_{xc} and h_{xo} are the probabilities that the latent time of death (that is, net probabilities of dying) for the disease under study, and other causes occurs in interval x, respectively.

4 Data

This study is based on the scientific release of the Survey of Health, Ageing and Retirement in Europe (SHARE), available at Borsch-Supan et *et al.* (2016).

SHARE is a cross-national longitudinal panel database providing information on health, socio-economic status and social and family networks about people, aged 50 or older, from nineteen European countries plus Israel. Hitherto the methodological research is based on five waves of data - Wave 1 (2004-2006), Wave 2 (2006-2007), Wave 3 (2008-2010), Wave 4 (2010-2012) and Wave 5 (2013) - collected from questionnaires and survey interviews.

In this study the *easy*SHARE database is used since it stores information on all respondents and of all currently released data collection waves in one single dataset. Since this simplified database that group the main variables of the regular panel waves of SHARE has incomplete and inconsistent information about the participants' health condition, it was necessary to merge the information about the type of disease and the start age of disease for each participant, available in each released data wave. Additionally, to accomplish the main intention of this study it was necessary to include information about death conditions available in Wave 5 - end of life interviews. This way there is information available on decease date, age at the moment of decease, the main cause of death, and the period of time the person had been ill before decease.

The subsample used in this study covers the 2004-2012 period and includes males and females from Austria, Belgium, Czechia, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Slovenia, Spain, Sweden and Switzerland. From the twenty countries included in the *easy*SHARE dataset, Israel and Luxembourg are excluded, because the first does not belong to Europe and the second only joins to the study on the last wave, which does not allow to obtain all necessary information.

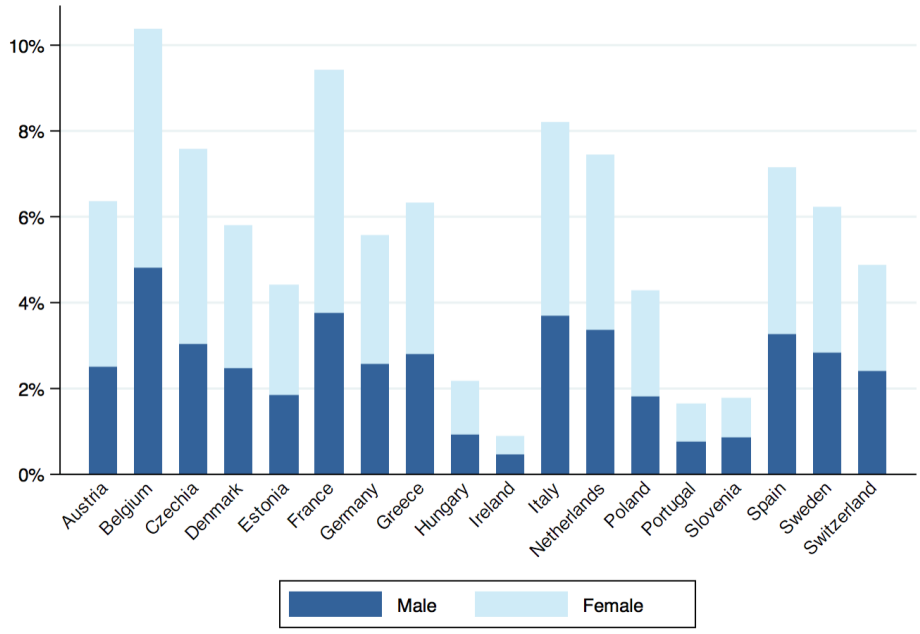
The ultimate aim of this study being to compare the life expectancy of individuals suffering from a determined health condition with healthy individuals, if no restrictions are made over the time period of diagnosis, the results tend to be biased since, for those diagnosed a long time ago, we can just observe the survivors (we can not observe failure time). To overcome this situation the data was restricted to individuals diagnosed with the disease of interest from 1985 onwards.

Another potential source of bias in the database is the high number of censored observations since a considerable number of individuals drop out between waves. Censoring just leads to unbiased results if it is random and non informative, which means if individuals are lost to follow-up due to reasons unrelated to the study. There is strong evidence that the data does not respect this assumption since the mortality observations are clearly underestimated. To deal with this problem the data was changed in order to consider that all observations present in Waves 1, 2 or 3 that were not possible to follow-up in the following waves, have experienced an event of death. In these cases it

was assumed that death occurred at the middle of the average time between interview, which means a year and a half after the date of the last interview. The main disadvantage of this approach is the missing information about cause of death that makes impossible the use of some survival models requiring this information, for instance the cause-specific mortality methods.

4.1 Summary Statistics

The subsample considered gathers individuals from eighteen different European countries. Figure 1 represents the distribution of male and female individuals belonging to each country.



Source: own calculations from *SHARE - Survey of Health, Ageing and Retirement in Europe* database

Figure 1: Percentage of males and females in the sample, by country

The proportion of females is slightly higher than that of males but broadly we can conclude that there is a quite balanced distribution.

The most representative countries in the subsample are Belgium, France and Italy, each one contributing with more than 8% of the total individuals. On the other hand, Ireland, Portugal and Slovenia are the countries with the lowest number of participants, less than 2% of the total population.

Taking into account the low weight of the Portuguese population in the subsample, and being the main interest of this study to obtain results that can be applied to Portuguese reality, a comparison was made of the distribution of deaths by cause between the subsample and observations of deaths occurred in Portugal in 2013 (Figure 2). To assess the adequacy of the data, the same comparison was made between the subsample and observations of deaths occurred in Europe in 2013.

From Figure 2 we can conclude that there are no significant differences in cause of death between the three data sources. Cardiovascular diseases, which include, among others, heart attack and stroke, are the main cause of death, followed by malign tumors. The percentage of death by respiratory disease is considerably lower in the subsample than in the Portuguese population, which is in agreement with data from Eurostat that shows that Portugal is one of the countries with higher mortality rates by respiratory diseases.

(a) Database (b) Portugal (2013) (c) Europe (2013)

Sources:
(a) own calculations from *SHARE - Survey of Health, Ageing and Retirement in Europe* database
(b) and (c) *eurostat*

Figure 2: Percentage of deaths by cause

Table 1: Descriptive Statistics

	Mean		Mean
Age at diagnosis (in years)	65.345	Years of education	9.3211
Male	0.5586	Employed	0.2317
Married	0.6398	Retired	0.4291
Number of children	1.8215	Number of chronic diseases	1.1170
Chronic disease			
Heart attack	0.1248	Osteoporosis	0.0735
High blood pressure or hypertension	0.3147	Cancer	0.0497
High blood cholesterol	0.2065	Stomach or duodenal ulcer, peptic ulcer	0.0638
Stroke	0.0388	Parkinson disease	0.0044
Diabetes or high blood sugar	0.0913	Cataracts	0.0695
Chronic lung disease	0.0485	Hip fracture or femoral fracture	0.0162
Asthma	0.0444	None	0.2723
Arthritis	0.1826	Other condition	0.1770

Note: The subsample obtained from SHARE data covers the 2004-2012 period and includes males and females aged 50 to 104 from 18 european countries.

Table 1 presents means for the variables of interest in the subsample.

This subsample is very representative of the oldest population, being the age at diagnosis of three quarters of total individuals greater than 50 years.

The proportion of females is slightly higher than that of males, the majority of individuals are married, and have, on average, approximately two children. The mean level of education in the subsample is nine years of schooling. About 23% of total individuals are employed, 43% are retired and the remaining 34% are unemployed or permanently sick or disabled.

The group of individuals under study was diagnosed, on average, with only one chronic disease, which is a major advantage to avoid the problems caused by competing risks. The subsample has information about heart attack, high blood pressure or hypertension, high blood cholesterol, stroke, diabetes or high blood sugar, chronic lung disease, asthma, arthritis, osteoporosis, cancer, stomach or duodenal ulcer, peptic ulcer, Parkinson disease, cataracts and hip fracture or femoral fracture. However some of these diseases are unrepresentative and were excluded from the analysis.

5 Impaired lives: mortality and annuity premiums

5.1 Net and crude estimates

This section presents the effect of certain diseases on mortality experience, estimated from both net and crude survival methods, and grouped in four age groups: 0-49, 50-59, 60-69 and +70. [1]

As previously mentioned, there is a lack of death observations on the database that makes it difficult to achieve statistically significant results. Taking into account the nature of the data, it is very likely that deaths have been partially recorded as censored observations. To overcome this problem, the data was corrected assuming that a percentage of the censored observations had experienced an event of death.

To test the results' sensitivity to mortality assumptions, all methods were estimated considering four different mortality scenarios: 0%, 40%, 80% and 100%. From the given scenarios, only the third and fourth produced results in agreement with the literature in the sense that, despite of the considered disease, healthy individuals have a higher life expectancy than diseased ones. Hence it was considered the assumption of 80% mortality over censored observations, in order to take a more real and, simultaneously, more conservative hypothesis. In Appendix A an example can be found for relative survival of heart attack disease for male population.

5.1.1 Net survival estimates

The relative survival was estimated using four different estimators - Ederer I, Ederer II, Hakulinen and Pohar Perme. Comparing the figures we can conclude that the four methods used give very similar results, especially in the first ten years from the diagnosis, which is in agreement with literature.

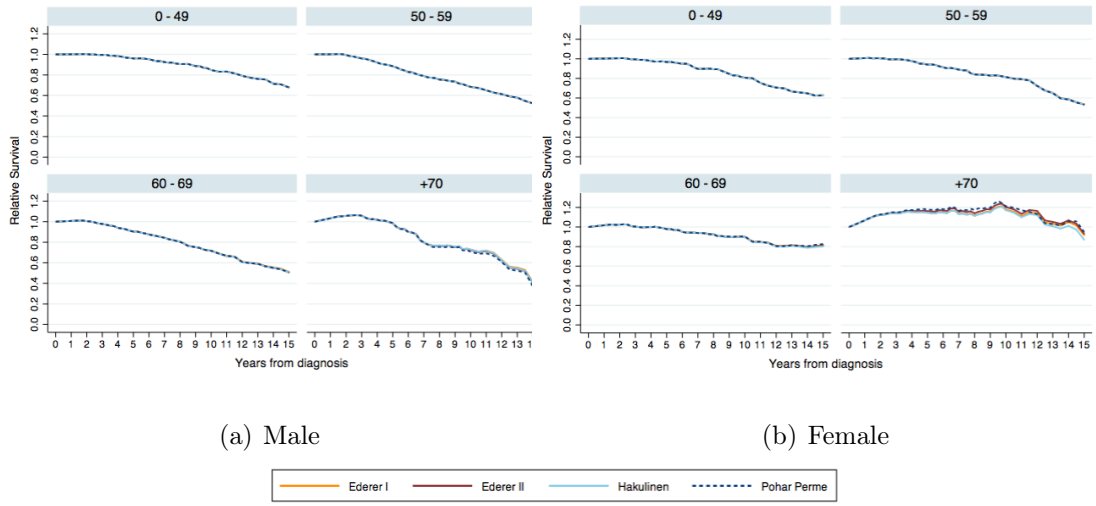
In general, Figures 3 to 9 show the decrease on life expectancy over the reference population, due to medical conditions and diseases of cardiovascular and respiratory system, as well as cancer. The results can be interpreted as the relative proportion of patients alive after i years from diagnosis in the hypothetical situation where the disease under study is the only possible cause of death.

5.1.1.1 Cardiovascular diseases

In this study the relative mortality of two cardiovascular diseases - heart attack (Figure 3) and stroke (Figure 6) -, and two medical conditions that are risk factors for cardiovascular diseases - hypertension (Figure 4) and cholesterol (Figure 5) were included.

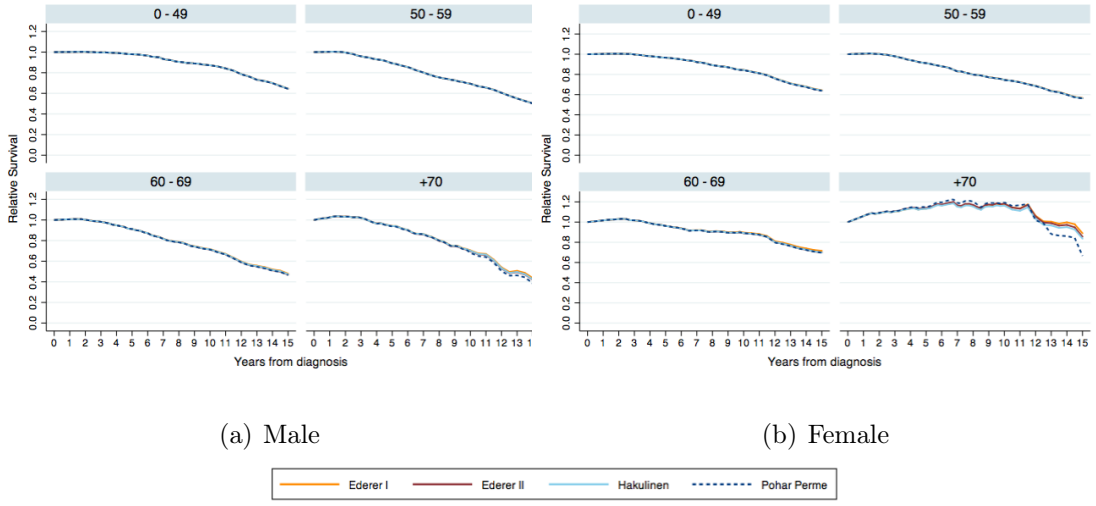
Results show that the main conclusions are not substantially different between these diseases. In general, the life expectancy reduction due to diseases under study is greater

[1] In some cases, the third and fourth age groups were merged together due to the lack of observations. The disaggregated results can be found in Appendix B.



(a) Male (b) Female

Figure 3: Heart attack - net relative survival rates

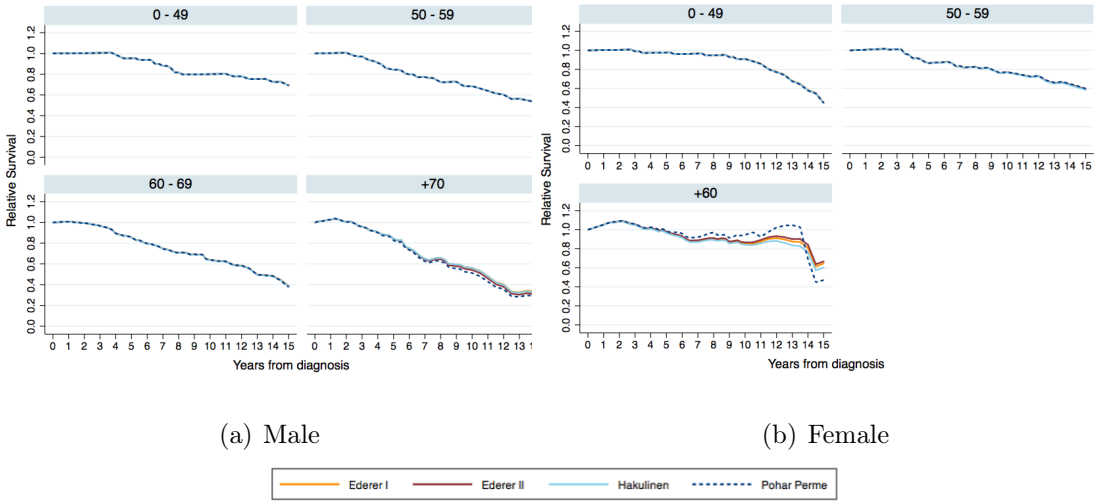


(a) Male (b) Female

Figure 4: Hypertension - net relative survival rates

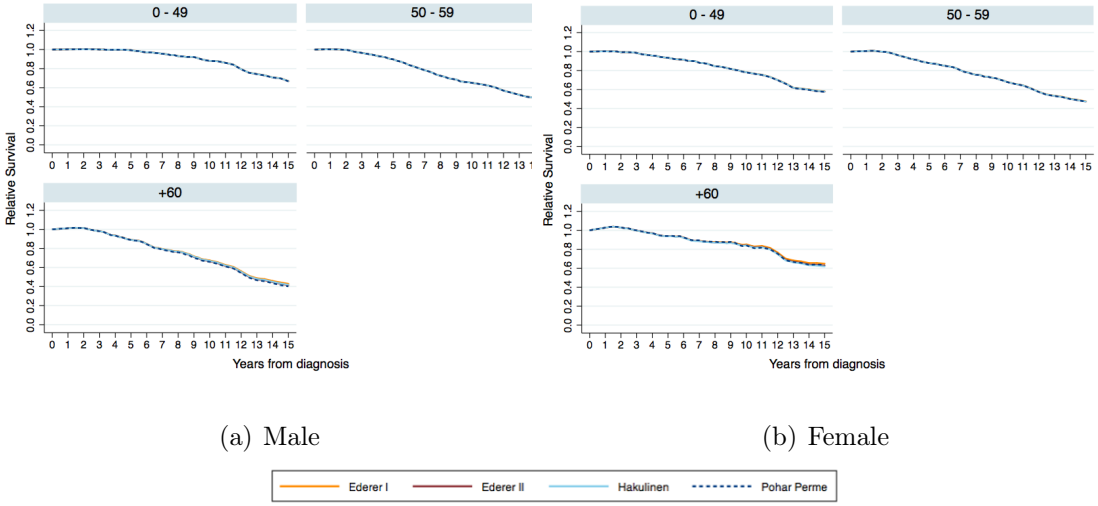
for males than for females. For males, the negative impact of the disease is increasing with age group and years from diagnosis, which means that the recoverability decreases with age. For females, excluding stroke disease, the relative mortality behaviour, from an age at diagnosis until sixty years of age, is very similar to the one observed for males. The relative survival is almost linearly decreasing with time from diagnosis, reaching, after fifteen years from diagnosis, the values of, approximately, 60% for the first age group (0-49) and 40% for the second one (50-59). These values imply that life expectancy for someone diagnosed with heart attack, hypertension or cholesterol disease before the age of 50, corresponds to 60% of the reference population's life expectancy, which, in this study, is approximated by life tables GKM95 and GKF95.

For some cardiovascular conditions, as heart attack, stroke and hypertension, the results obtained for the oldest female group, contrary to what would be expected, demonstrate a life expectancy greater for diseased individuals than for healthy ones. These



(a) Male (b) Female

Figure 5: Stroke - net relative survival rates



(a) Male (b) Female

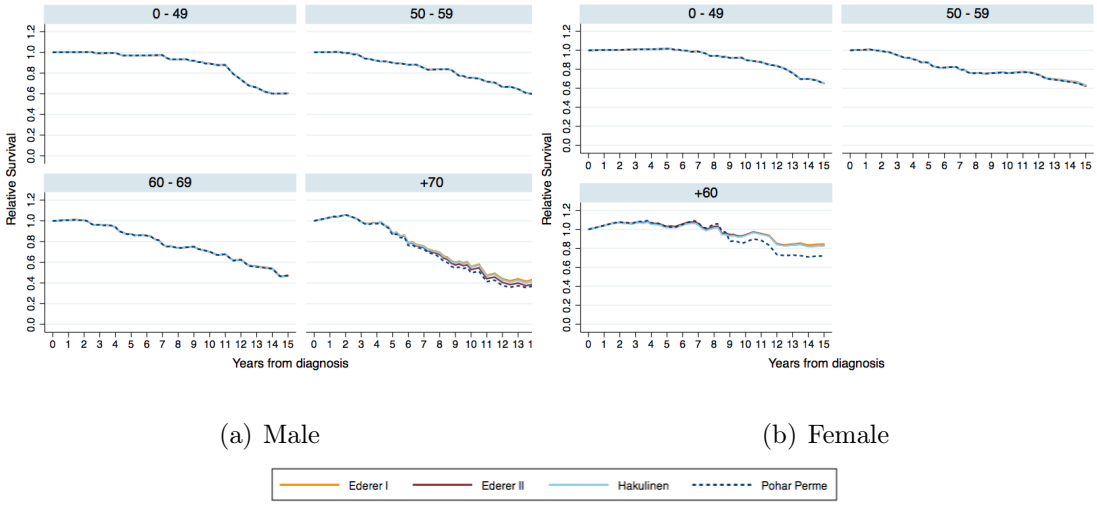
Figure 6: Cholesterol - net relative survival rates

results are in broad disagreement with world statistics showing that cardiovascular disease is the leading cause of death among global population, especially for elder women, which indicates the presence of bias in the estimates. Relative survival models establish a comparison between life expectancy of the individuals diagnosed with the disease of interest and the reference population free of the disease. However, as previously addressed, the survival of the reference population is usually available from general life tables. One possible and very reasonable explanation for the inconsistency of the results was given by Nelson *et al.* (2008), p.946, "*a potentially important issue in the use of relative survival to the assessment of coronary heart disease survival is that in using population life tables to derive the expected mortality rates, deaths due to the condition of interest are included. If the prevalence of that condition in the background population is low enough, then this will have little impact, a reasonable assumption for individual malignancies. However, given the predominant contribution of heart disease to mortality in industrialized society,*

the appropriateness of this assumption in coronary heart disease needs to be assessed, in particular for oldest age groups."

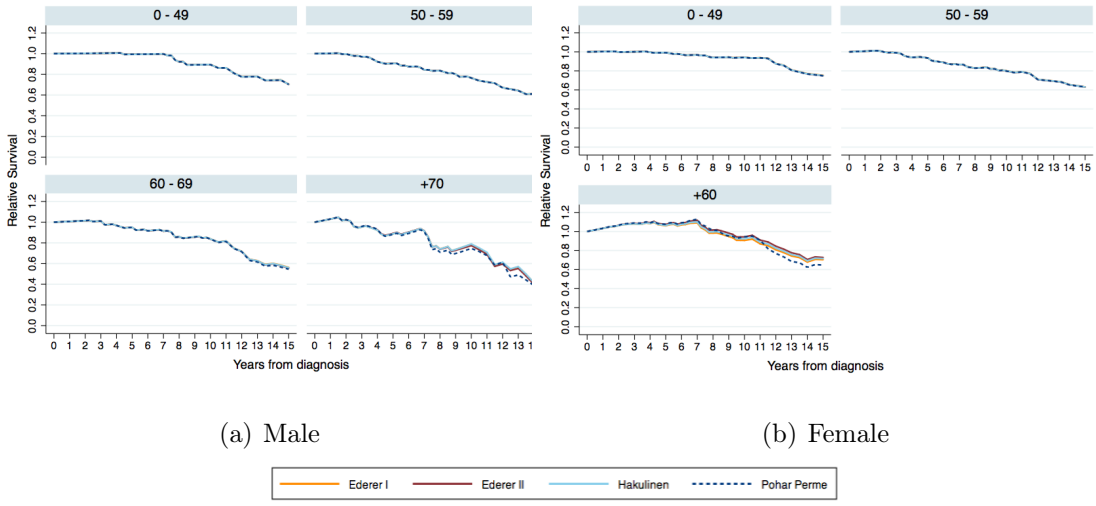
5.1.1.2 Respiratory diseases

In this study, two different respiratory diseases - chronic lung disease (Figure 7) and asthma (Figure 8) - were analysed.



(a) Male (b) Female

Figure 7: Chronic lung disease - net relative survival rates



(a) Male (b) Female

Figure 8: Asthma - net relative survival rates

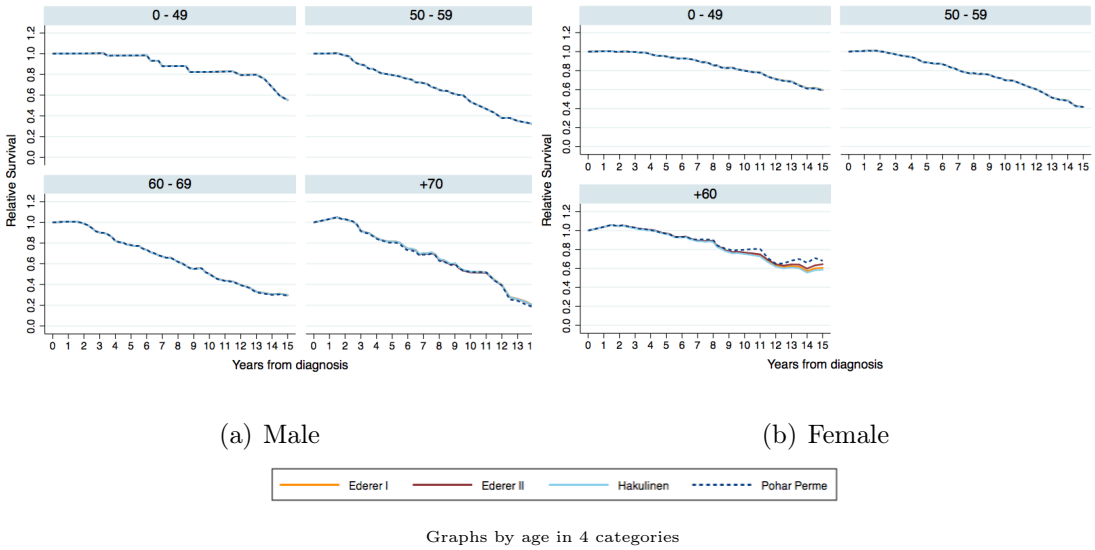
For both conditions one can conclude that the negative effect on life expectancy is substantially greater for male than for female population. The results seem to be in agreement with real evidence since, according to data from World Health Organization, standardised death rates for respiratory diseases were consistently higher for men than for women, which could be explained by different smoking habits and occupational risks between the sexes. For both chronic lung disease and asthma, the negative effect on life

expectancy is increasing with age at diagnosis and years from diagnosis. According to the same source, standardised death rates for diseases of the respiratory system were particularly high at advanced ages, explaining concerns over, for example, Winter influenza epidemics.

5.1.1.3 Cancer

As the previously analysed diseases, cancers figure among the leading causes of death. The World Health Organization predicts a rise of 70% in the number of new diagnosed cases during the following decades. Cancer is a generic term for a large group of diseases that can affect any part of the body and which could be responsible for different mortality patterns depending on the type of cancer, the stage at diagnosis and the treatment followed.

This study does not consider the effect of individual cancer types on mortality, since the dimension of the data does not allow for disaggregation. For all cancers combined, we can observe - Figure 9 - that relative survival rates decrease with the years from cancer diagnosis. This effect is more pronounced for male than for female population, indicating a possible higher recoverability chance for women.



(a) Male (b) Female

Figure 9: Cancer - net relative survival rates

For the male population the negative impact of the disease on survival is, in general, increasing with age at diagnosis. The results show that a five years probability of survival for someone diagnosed with cancer is almost the same as that for healthy individuals until an age of 49, and it is about 80% from an age at diagnosis of 50. For the female population, the achieved results seem to be less reasonable since there is no difference between the five years survival of the healthy and the diseased population, for all age groups considered. Additionally, contrary to the expectations, the negative effect of the disease is less pronounced on older age groups. Again, one possible explanation is that the results are biased due to the fact that reference population is not free of the disease, once cancer - mainly cancers of the lung, breast, colon and stomach - are a leading cause of

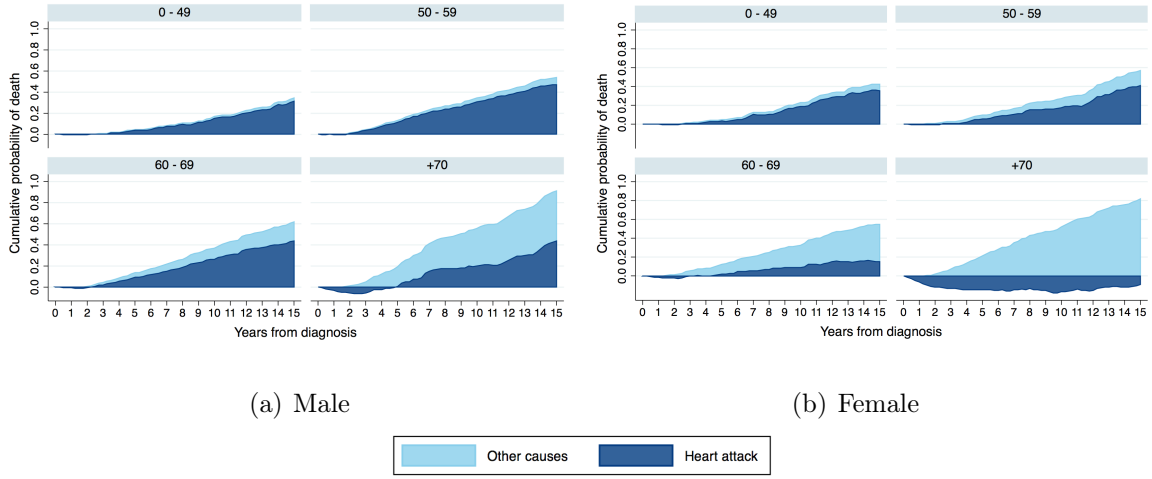
death of the elderly women population, according to information from the World Health Organization.

5.1.2 Crude probability of death estimates

Now the relative probabilities of death follow, distinguishing the proportion of deaths explained by the disease under study from those explained by other diseases (competing risks). The results - from Figure 10 to Figure 16 - computed using the Cronin and Feuer's relative mortality estimator, represent the same reality of the previous subsection, using crude relative death rates instead of net survival ones.

5.1.2.1 Cardiovascular diseases

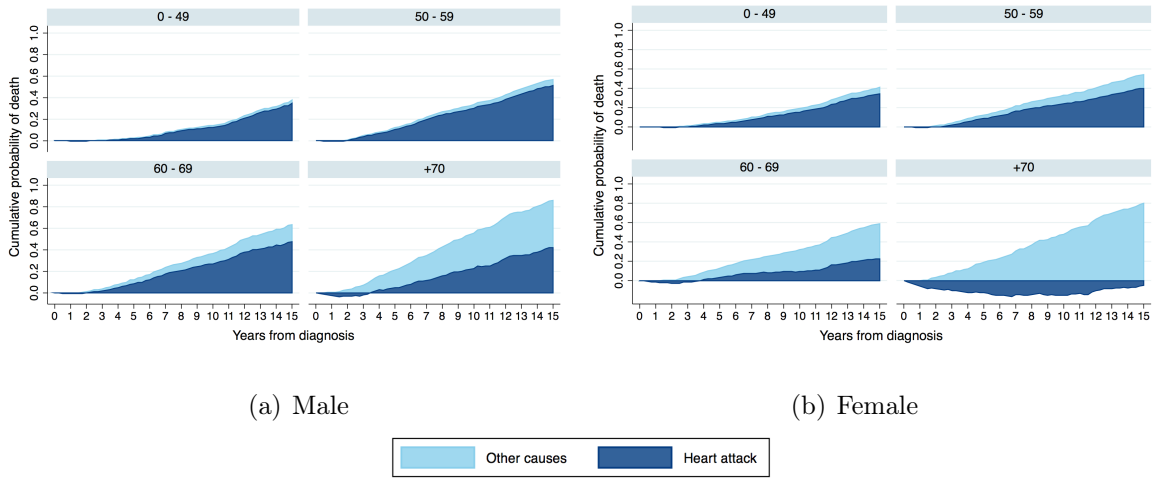
For the group of cardiovascular diseases, the main conclusions are generic to both medical conditions - hypertension (Figure 11) and cholesterol (Figure 12) - and both diseases - heart attack (Figure 10) and stroke (Figure 13) - under study. The impact of other diseases on relative mortality is increasing with the age at diagnosis. At younger ages mortality in the group of individuals diagnosed with cardiovascular diseases is almost entirely explained by the disease of interest. Contrariwise, at the elderly ages the extra mortality of the diseased group over the healthy individuals is also likely to be explained by other diseases. So, the impact of other diseases on relative mortality experience is increasing with both age at diagnosis and years from diagnosis.



(a) Male (b) Female

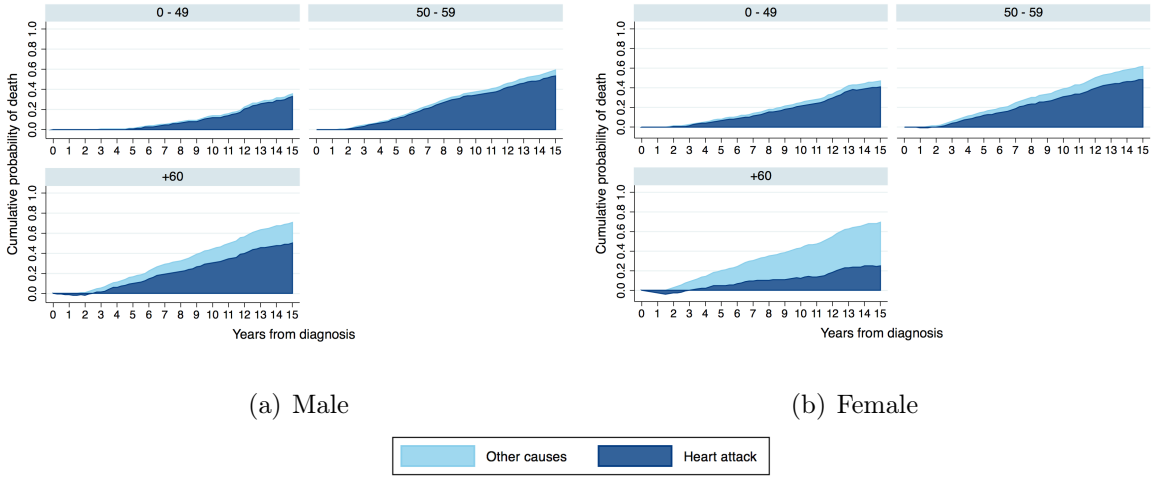
Figure 10: Heart attack - crude relative death rate

For the female population, similar to what was observed in net survival estimates, the aggregate probability of death - death rate by all diseases - tends to decrease in the oldest age group. From crude estimates we can observe that this effect occurs due to a negative relative death rate by the disease of interest. These estimates are possibly biased because the reference population is not free of the disease of interest; the fact is that cardiovascular problems, often associated with men, are the number one killer of elderly women.



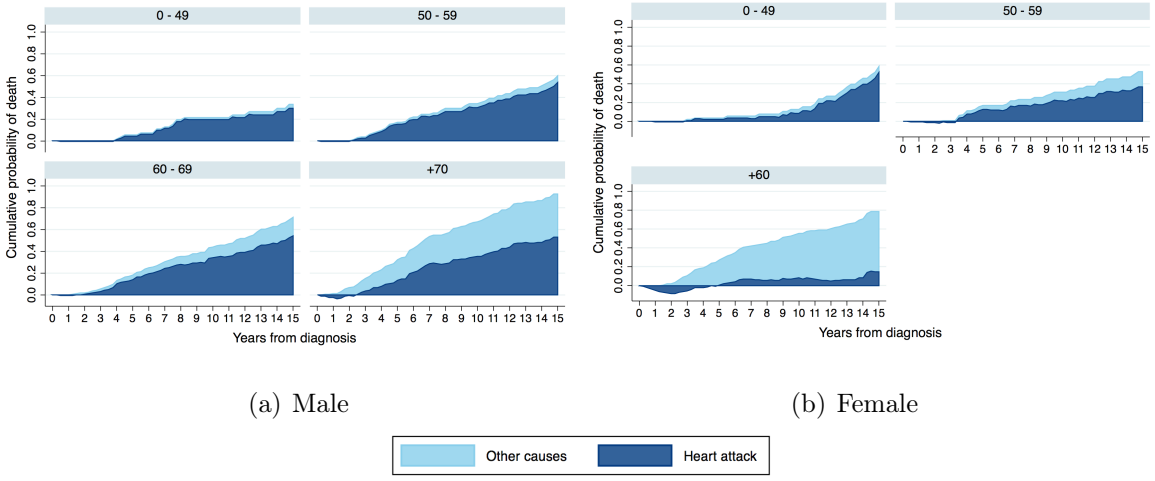
(a) Male (b) Female

Figure 11: Hypertension - crude relative death rate



(a) Male (b) Female

Figure 12: Cholesterol - crude relative death rate

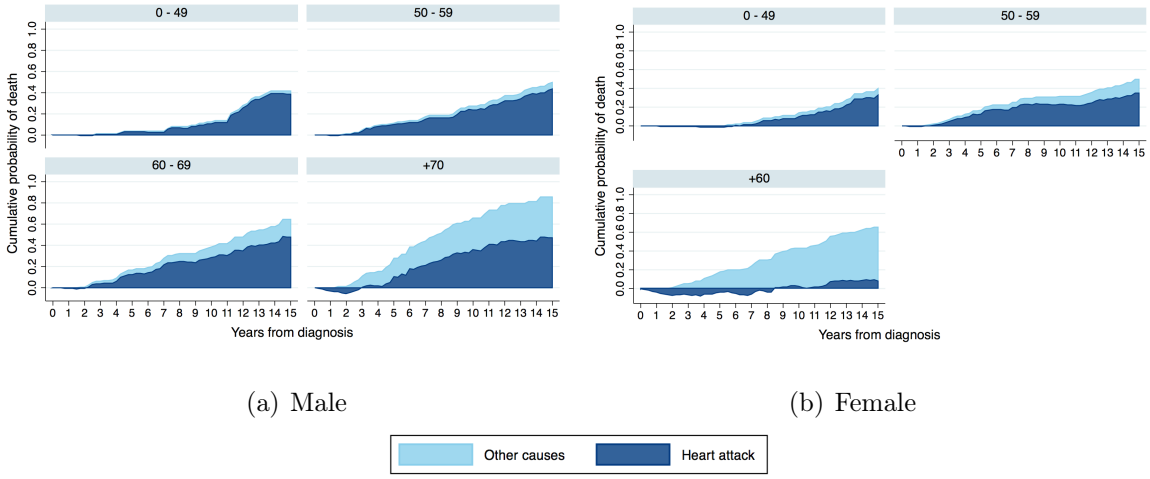


(a) Male (b) Female

Figure 13: Stroke - crude relative death rate

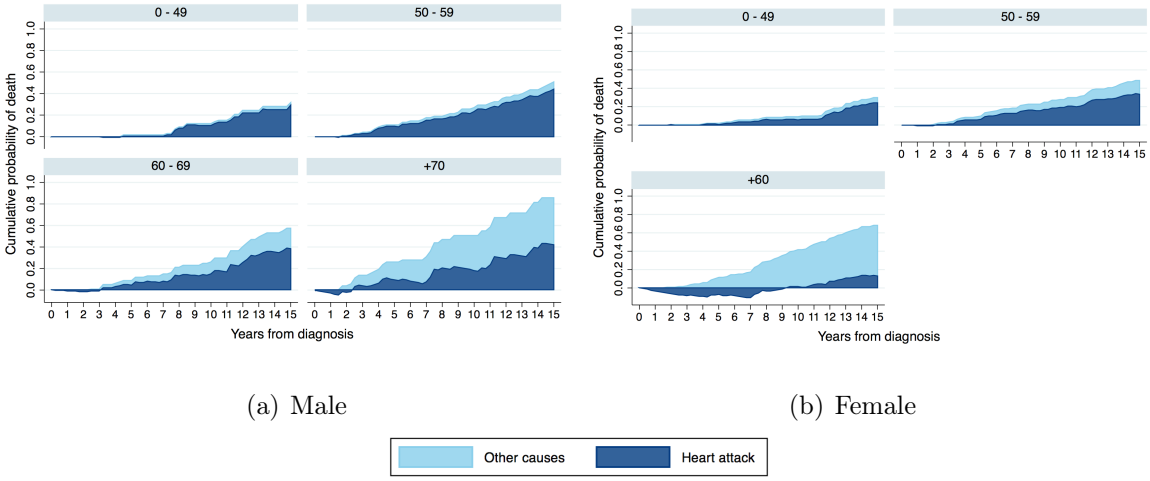
5.1.2.2 Respiratory diseases

For the group of respiratory diseases - chronic lung disease (Figure 14) and asthma (Figure 15) - and for cancer disease (Figure 16), the conclusions are similar to those of the cardiovascular disease group, the relative probability of death due to other causes is increasing with age at diagnosis of the disease of interest and years from diagnosis. In general, the extra mortality is greater for male than for female population.



(a) Male (b) Female

Figure 14: Chronic lung disease - crude relative death rate



(a) Male (b) Female

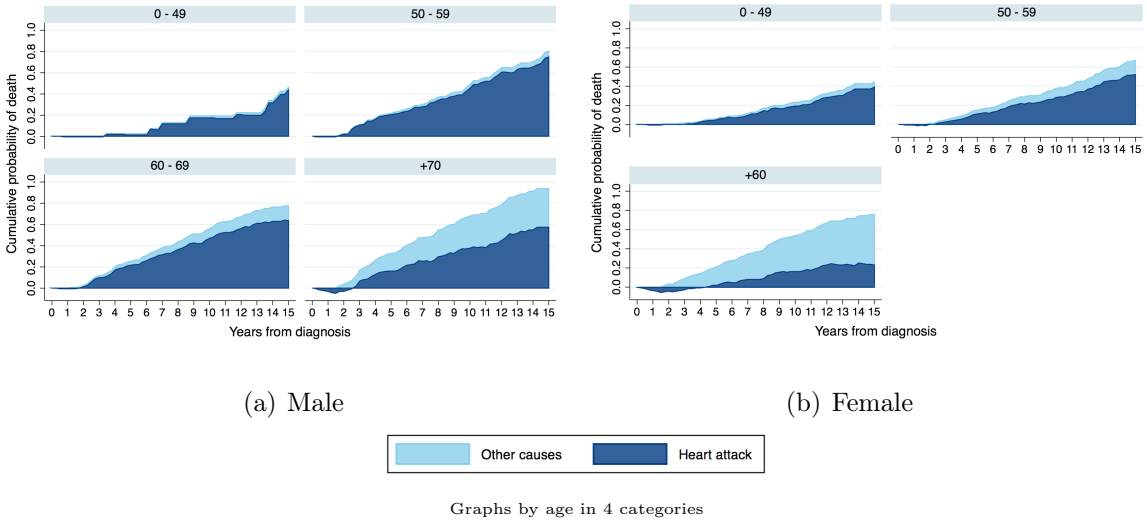
Figure 15: Asthma - crude relative death rate

For the group of elderly women diagnosed with the included respiratory diseases, we can observe that the mortality due to the disease of interest is lower compared with that of the reference population. However, the mortality rate due to other causes is substantially greater for this age group. Once more it could be explained by the bias induced by the relevant presence of the disease in the reference population.

Several studies discuss gender and age discrepancies in asthma prevalence and outcomes that could explain the results' bias induced by the presence of the disease in the

life tables. "*Among the elderly, it is women who suffer most from asthma. (...) The asthma death rate among older women is approximately four times higher than the overall total.*" (Baptist *et al.* (2014), p.1). Additionally, asthma in the elderly population increases the prevalence of concomitant diseases. "*It is known that asthma is associated with a specific pattern of comorbid conditions whose profile depends on age. Within the elderly population, asthmatics have an increased incidence of respiratory diseases, such as chronic bronchitis, chronic obstructive pulmonary disease and chronic sinusitis, but also stomach ulcers, cardiovascular disease, osteoporosis, diabetes, depression and cancer than the rest of the population.*" (Wardzynska *et al.* (2015), p.902).

5.1.2.3 Cancer



(a) Male (b) Female

Figure 16: Cancer - crude relative death rate

Cancer results show a substantially higher extra-mortality over healthy individuals compared with the other diseases under study.

5.2 Impaired life annuities

Now that the survival adjustments to a reference life table for different medical conditions have been estimated. It is possible to find the fair value of an annuity for those who are impaired lives due to different kinds of chronic diseases.

5.2.1 Adjustments in the reference life table with net relative survival rates

Under the net survival framework, the relative survival rates were estimated in subsection 5.1.1, using four different estimators. Since the results are not significantly different, in this section the Pohar Perme's relative survival estimates, that the literature recognises as less likely to be biased, are chosen. The results could be interpreted as the proportion of survivals in the diseased group in relation to the ones of the reference population,

considering that the disease of interest is the only possible cause of death. In this way, the number of diseased individuals alive at age x ($^{net}l_x$) is,

$$
{}^{net}l_x = \begin{cases} l_{x'}, & if \;\; x = x' \\ l_{x'} \times_{(x-x')} p_{x'} \times netRS^{w}_{(x-x')}, & if \;\; x' < x <= x' + 15 \\ l_{x'} \times_{15} p_{x'} \times netRS^{w}_{15} \times_{(x-(x'+15))} p_{(x'+15)}, & if \;\; x > x' + 15 \end{cases} \tag{14}
$$

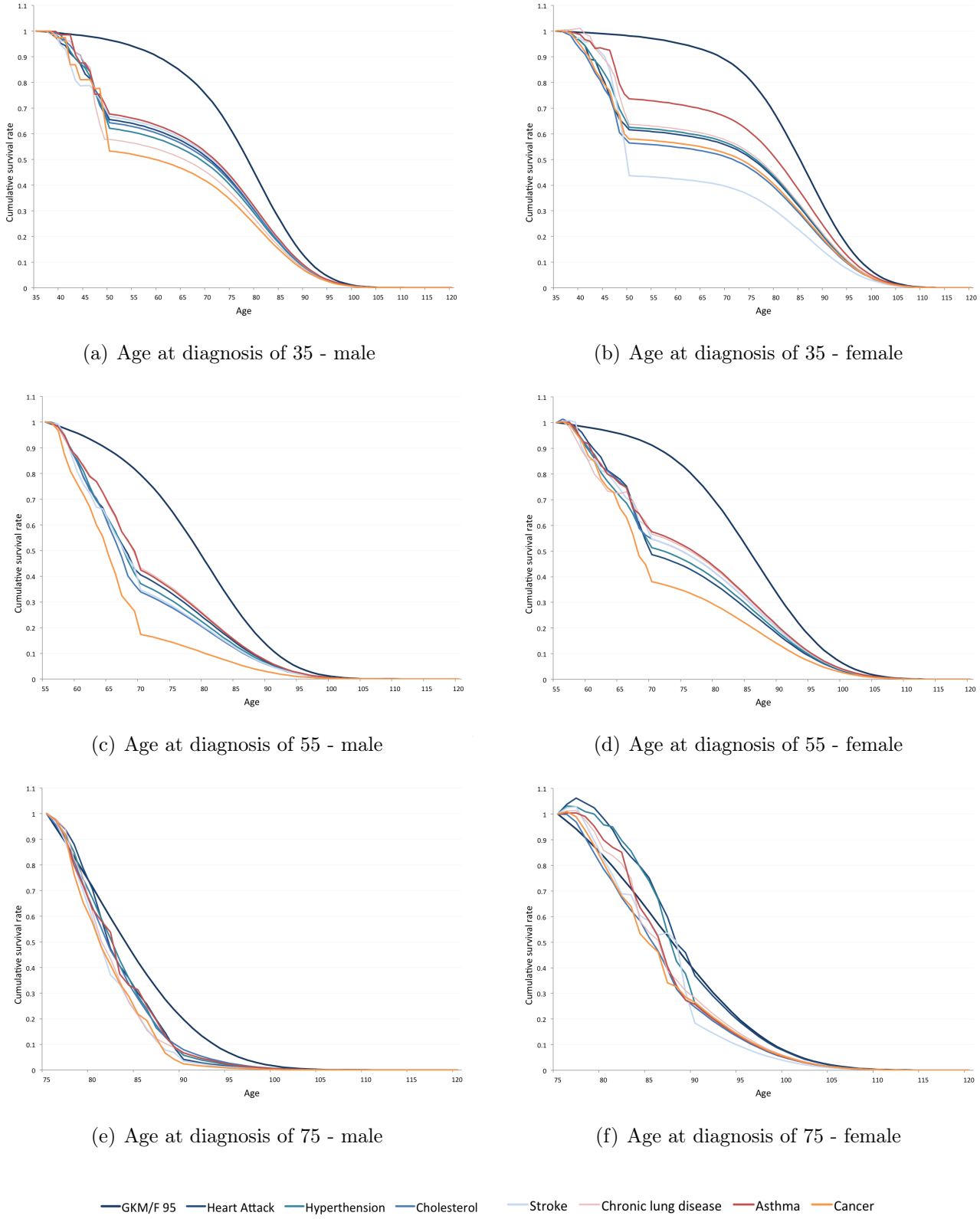
where:

- l_x is the number of individuals alive at age x, evaluated from GKF95 and GKM95 life tables;
- x is the actual age;
- x' is the age at diagnosis;
- w is the age group at diagnosis, computed for four different age groups: $w = 1$ (below 50), $w = 2$ (between 50 and 59), $w = 3$ (between 60 and 69) and $w = 4$ (from 70 onwards);
- p_{x-1} is the probability that someone aged $x-1$ survives until the age x, evaluated from GKF95 and GKM95 life tables;
- $netRS^{w}_{k}$ is the net relative survival of the impaired lives in relation to the general population (*proxied* by GKF95 and GKM95 life tables), evaluated by using the Pohar Perme's estimator.

$netRS^{w}_{k}$ can be interpreted as the relative probability that someone diagnosed with a certain disease at age group w, will survive k years after diagnosis, in relation to a healthy individual with the same age. The net relative survival rates are computed for four age groups at diagnosis (w). For each age group, the relative survival is observed during 15 years from diagnosis, considering the individuals recoverability thereafter.

Figure 17 allows for a comparison of the cumulative survival function for the ages at diagnosis of 35, 55 and 75, between the reference population (survival computed from GKF95 and GKM95 life tables) and the diseased group of individuals, both for male and female. The survival function for those who are impaired lives was computed using the number of individuals alive at age x estimated from equation (14) for each disease.

It can be observed that for an age at diagnosis of 55, for both male and female groups, the survival reduction is more pronounced for cancer, followed by cardiovascular and respiratory diseases. For the youngest age group, the impact of the diseases over the survival function strongly differ between genders. For male population cancer is the disease with the greatest negative impact over survival, followed by chronic lung disease, while for female population the stroke disease is the one with the most considerable impact, a few years after diagnosis. The elderly age group reveal that, for male population, the presence



(a) Age at diagnosis of 35 - male

(b) Age at diagnosis of 35 - female

(c) Age at diagnosis of 55 - male

(d) Age at diagnosis of 55 - female

(e) Age at diagnosis of 75 - male

(f) Age at diagnosis of 75 - female

Figure 17: Net survival rates

of each disease tends to reduce the survival probability almost in the same proportion regardless of the disease in question. For female population, as stated in previous sections, the most representative diseases in the reference population are responsible for the biased output observed.

5.2.2 Adjustments in the reference life table with crude relative probabilities of death

The crude probabilities of death were estimated in subsection 5.1.2.The results can be interpreted as the proportion of deaths in the diseased group in relation to the ones of the reference population, considering all possible causes of death beyond the disease of interest. The number of diseased individuals alive at age x ($^{crude}l_x$) is,

$$
{}^{crude}l_x = \begin{cases} l_{x'}, & if \;\; x = x' \\ l_{x'} \times_{(x-x')} p_{x'} \times \left(1 - crudeRS^{w}_{(x-x')}\right), & if \;\; x' < x <= x' + 15 \\ l_{x'} \times_{15} p_{x'} \times (1 - crudeRS^{w}_{15}) \times_{(x-(x'+15))} p_{(x'+15)}, & if \;\; x > x' + 15 \end{cases} \tag{15}
$$

where,

- $crudeRS^{w}_{k}$ is the relative probability that someone diagnosed with a certain disease at age group w, dies k years after diagnosis, in relation to the matching probability of a healthy individual with the same age. Similarly to the net relative survival rates, the crude relative mortality rates are computed for four age groups at diagnosis (w) and each age group is followed during 15 years from diagnosis, considering the individuals recoverability thereafter.

Figure 18 is analogous to the previous one but, instead of the net survival, shows the crude survival rates calculated using the number of individuals alive at age x estimated from equation (15) for each disease.

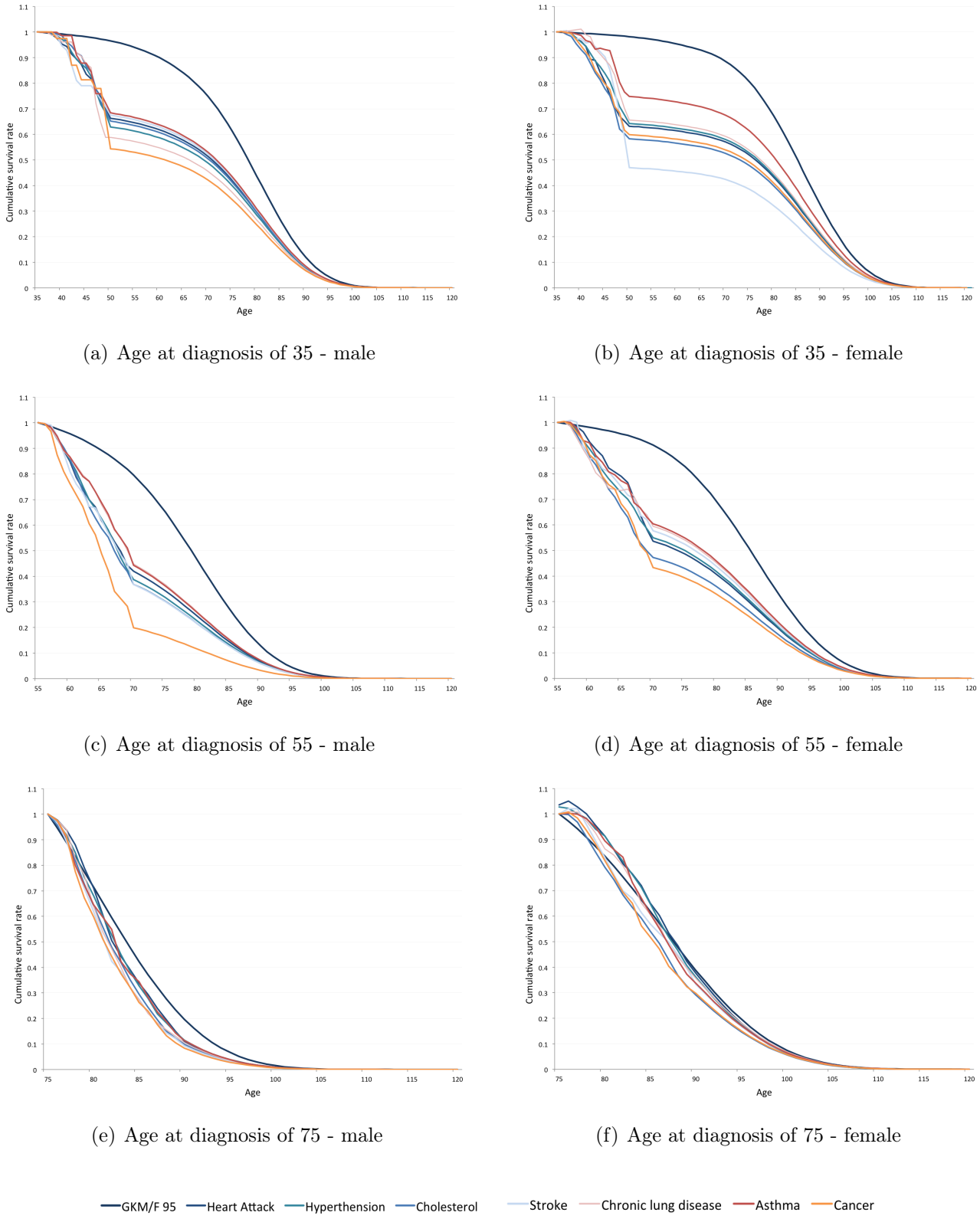
The results are very similar to those in Figure 17. Likewise previous results, at younger ages almost the entire mortality of the group of diseased individuals is explained by the disease of interest, and only for elderly age group the effect of the so-called competing risks prevails. Thus, the survival probabilities computed with the two methods - crude and net survival estimates - are very similar for all ages, because at earlier ages the estimates are matching and at elderly ages the life expectancy is so low that the corrections made to mortality become irrelevant. So, the results of the two methods converge.

5.2.3 Life annuity premiums

The survival curves obtained will now be applied to calculate net premiums of life annuities for impaired lives. In order to compare the results, the annuities for both the reference and the diseased population (net and crude survival estimates) are computed considering the same main assumptions:

- a fixed annuity with twelve monthly payments ($m = 12$) of 1 unit of capital;
- an interest rate of 2% ($i = 0.02$);[2]

[2]For the purpose of this study, the annuity premium values should be considered in relative terms rather than in absolute ones. Hence, the value chosen for the interest rate is merely indicative.



(a) Age at diagnosis of 35 - male

(b) Age at diagnosis of 35 - female

(c) Age at diagnosis of 55 - male

(d) Age at diagnosis of 55 - female

(e) Age at diagnosis of 75 - male

(f) Age at diagnosis of 75 - female

Figure 18: Crude survival rates

– the uniform distribution of deaths (UDD).[3]

[3]It is followed the UDD1 assumption, whereby ${}_sq_x = sq_x$ for an integer x and for $0 < s < 1$.

Hence, net life annuity premiums (P_x) are calculated according to the following equation:

$$P_x = \sum_{k=1}^{(w-x')\times m} \left(\frac{l^{(m)}_{x'+\frac{k}{m}}}{l_{x'}} \times (1+i)^{-\frac{k}{m}} \right), \tag{16}$$

where:

- $x = integer(x^*)$ is the real integer age at the annuity start date;
- w is the terminal age of the life table;
- $x^* = \frac{\text{start date-birth date}}{365.25}$ is the real non integer age at the start date;
- $x' = x + \frac{j}{m} = x + \frac{integer((x^*-x)\times m)}{m}$ is the fractional age;
- $l^{(m)}_{x'+\frac{k}{m}} = l_{x'} - k \times d^{(m)}_{x'+\frac{k}{m}} = l_{x'} - k \times \frac{d_{x'}}{m}$, because it was considered that the number of deaths is uniform throughout the year.
- d_x is the number of deaths in the general population at age x.

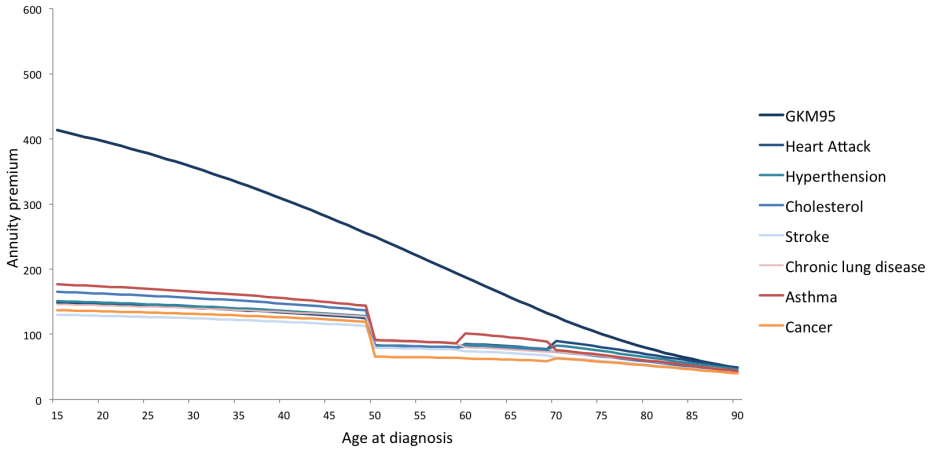
The annuities for impaired lives were computed at time of diagnosis, which means considering that both annuity entry age and age at diagnosis are coincident. Other scenarios could have been included but the constraints of time and work length prevented it.

The recoverability clinical studies usually focus on the disease effect over mortality in a five years period. In this study this effect was estimated until 15 years from diagnosis. For simplicity it was assumed the reference survival thenceforward, which means that someone who survives 15 years from diagnosis, is considered cured from there onwards. Although some of the considered diseases have no cure, it seems to be a proper assumption since it is more conservative and less prone to influence the results.

From Figure 19 it can be observed that, while the annuity values computed with the reference life tables are strictly decreasing with age, reproducing the life tables' age effect, those computed to impaired lives tend to be stable and not strictly decreasing between age groups. This is explained by the fact that, due to lack of data, mortality adjustments have been computed by age groups. When the correction factors are applied to the reference life table, for each age at diagnosis, the reduction in life expectancy in the first 15 years is so significant that almost nullifies the life table's age effect for each age group, in such away that annuity values within the same age group are very similar between different ages at diagnosis.

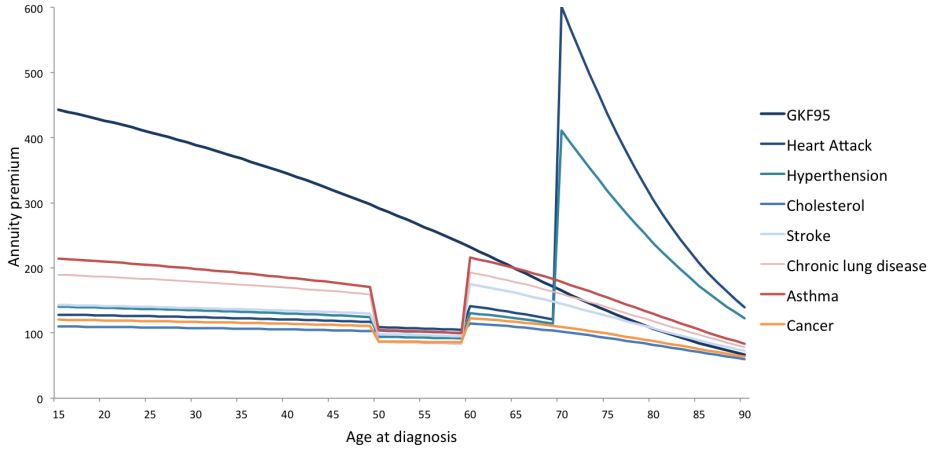
In general, the results show that net and crude survival estimates do not produce significantly different annuity values. For this reason the annuity values computed from crude survival curves are presented in Appendix D.

For the group of cardiovascular diseases - heart attack, hypertension, cholesterol and stroke - the annuity values for the first age group are about less than a half of the reference annuity values. As would be expected, the annuity values for the second age group are lower than those for the first one, however the differences between the reference and



	35	40	45	50	55	60	65	70	75	80	85	90
GKM95	332.7	306.9	279	249.5	218.8	187.8	156.8	126.8	100.5	78.8	61.7	48.4
Heart Attack	137.2	133.3	128.8	81.6	80.2	85.3	81.5	89.8	80.3	69.6	58.8	48.7
Hypertension	140.0	136.2	131.8	83.1	81.6	84.4	80.8	82.9	74.4	64.8	55.0	45.8
Cholesterol	151.7	147.0	141.7	82.4	81.1	81.1	78.0	72.9	66.0	58.3	50.2	42.5
Stroke	122.0	119.2	115.9	79.3	78.0	73.8	71.2	64.0	59.0	53.1	46.7	40.2
Chronic Lung Disease	137.3	134.2	130.6	90.0	87.7	79.9	76.7	72.8	66.6	59.3	51.6	43.9
Asthma	160.8	155.4	149.2	91.1	88.9	101.5	95.5	75.5	68.2	59.9	51.5	43.3
Cancer	128.9	126.0	122.6	65.4	64.7	62.7	61.0	62.8	58.0	52.2	46.0	39.8

(a) Male



	35	40	45	50	55	60	65	70	75	80	85	90
GKF95	367.8	344.6	319.5	292.1	262.7	231.6	198.5	164.9	133.9	107.0	84.7	66.8
Heart Attack	122.7	120.9	118.9	109.0	106.9	141.6	131.0	601.5	436.2	305.1	208.0	140.0
Hypertension	132.6	130.1	127.3	94.5	93.1	130.7	122.6	410.5	318.7	238.4	172.9	122.4
Cholesterol	106.7	105.6	104.4	103.7	101.8	114.8	109.6	102.0	92.5	81.9	70.8	59.9
Stroke	136.6	134.5	132.2	98.4	96.6	175.0	161.4	144.6	126.0	107.1	89.0	72.5
Chronic Lung Disease	174.4	169.6	164.3	86.2	84.8	192.5	178.1	159.9	139.3	118.0	97.3	78.3
Asthma	192.1	185.2	177.5	104.6	102.3	215.7	199.4	178.3	154.4	129.4	105.3	83.5
Cancer	115.7	114.3	112.6	87.3	86.5	122.7	117.2	109.2	99.1	87.6	75.6	63.7

(b) Female

Figure 19: Life annuity premiums (net survival estimates)

diseased populations tend to decrease. For the female population, contrary to what was done for cholesterol and stroke, for heart attack and hypertension the relative estimates of the two elderly age groups were not aggregated, since there was enough data available. This lead to annuity values substantially above the reference for start ages over 70. These values are unpractical and do not match the reality, since cardiovascular disease is one of the leading causes of death of the elderly female population.

For respiratory diseases - chronic lung disease and asthma - the results tend to be very similar to the previous ones, particularly to male population. For female population differences in annuity values between crude and net estimates from age 60 onwards must be highlighted. In fact, for this group of diseases and for this particular age group, the survival is very close and, in some cases, above the reference survival and the mortality is greatly ascribed to competing causes of death, which results in annuity values tendentiously above the reference and greater when the mortality by other causes is excluded (crude estimates).

From cancer results we can conclude that annuity values are lower than the reference for both sexes and all age groups. The values tend to be stable within and across age groups, and are always below the reference, converging to it as age is closer to the end of the life table. For both sexes, until the age 60 the annuity values are less than a half of the reference. Contrary to what would be the normal behaviour, for some ages, the annuity values are lower to female than male population, which occurs for the first age group.

6 Conclusions

The purpose of this study is to analyse the adverse selection explanation to the problem of "annuitization puzzle". According to the adverse selection concept, life annuity premiums are perceived as actuarially unfair for individuals with average life expectancy. To avoid losses, the insurance companies rise premiums assuming that only individuals living longer than average purchase life annuity products. Thus, individuals with average and lower than average lifespan are out of the market. Still, it is possible that some of these individuals were willing to annuitize if fair prices were charged.

A first step to accomplish the stated purpose is obviously to estimate the survival curves for individuals diagnosed with different medical conditions - individuals with a life expectancy above the average - and then (second step) to compare the annuity values computed with these curves with those produced from GKF95 and GKM95 reference life tables. To produce the survival curves of the impaired lives two different approaches were followed: net and crude frameworks. While the first gives estimates in a hypothetical world where all possible causes of death, different from that of interest, are excluded, the second accommodates those, producing more realistic estimates.

The main findings suggest that, excluding some particular age and sex groups where the disease under study is strongly present in the reference population, the relative survival of the diseased individuals tends to be below the reference, the gap increasing with age at diagnosis and years from diagnosis. The crude estimates achieved for the first age groups are very similar to net estimates. The differences between the two methods are only significant to the elderly individuals, inducing that the mortality of the younger individuals is almost entirely explained by the diagnosed disease while for the older ones different health problems tend to act simultaneously.

The achieved annuity values are, as expected, significantly lower for impaired lives. This effect is particularly pronounced at younger ages and tends to disappear as age at the beginning gets closer to the end of the life table. It can be observed that, even assuming the cure of the diseased individuals 15 years after the diagnosis - which means, assuming the reference mortality probability after that -, the survival and, subsequently, the annuity premiums are substantially above the reference.

With this contribution, an attempt was made to introduce a simplified form to estimate life annuity premiums for some groups of individuals with different life expectancies. However, we are aware that there is statistically significant information prone to influence the survival of these groups that is excluded. For a future research we would like to extend the scope of this study to consider relevant information as the stage and the number of occurrences (relapses) of the disease, as well as personal information beyond the gender. Nowadays, and for term life insurance products, this information is beginning to be used by insurance companies to exclude possible contracts or to apply discounts and extra premiums. The use of this information in life annuity products would considerably widen the target scope and improve the fairness of this market.

References

[1] Antolin, P., G. F. Scheuenstuhl, S. Blome, D. Karim, S. Payet and J. Yermo, (2009). Investment regulations and defined contribution pensions. *OECD Working paper on insurance and private pensions*, No. 37.

[2] Autoridade de Supervisão de Seguros e Fundos de Pensões. Estatísticas de Fundos de Pensões, 2015. Available at http://www.asf.com.pt.

[3] Baptist, Alan P., A. Hamad, and M. R. Patel, (2014). Older women with asthma: special challenges in treatment and self-management. *Annals of allergy, asthma and immunology: official publication of the American College of Allergy, Asthma, and Immunology*, 113(2), 125.

[4] Benartzi, Shlomo, A. Previtero, and R. H. Thaler, (2011). Annuitization puzzles. *The Journal of Economic Perspectives*, 25(4), 143-164.

[5] Berkson, J. (1942). In Carcinoma and Other Malignant Lesions of the Stomach, bY W. *Walters et al. Saunders, Philadelphia.*

[6] Berkson, J., and R. P. Gage, (1950). Calculation of survival rates for cancer. *Proceedings of the staff meetings. Mayo Clinic.* Vol. 25. No. 11.

[7] Berkson, J. and R. P. Gage, (1952). Survival curve for cancer patients following treatment. *Journal of the American Statistical Association*, 47(259), 501-515.

[8] Berry, G., (1979). A note on Wong's competing risk model. *International journal of epidemiology*, 8(1), 79-80.

[9] Bernoulli, D., (1760). Essai d'une nouvelle analyse de la mortalité causée par la petite vérole et des avantages de l'inoculation pour la prévenir. Histoire de l'Acad. Roy. Sci.(Paris) avec Mém. des Math. et Phys. and Mém, 1-45.

[10] Blake, D and W. Burrows, (2001). Survivor Bonds: Helping to Hedge Mortality Risk. *Journal of Risk and Insurance*, 339-348.

[11] Blake, D., W. Burrows and J. M. Orszag, (2002). Survivor Bonds and Compulsory Annuitization: Reducing the Costs of Pension Provision. *Innovations in Retirement Financing. Philadelphia, PA: Pension Research Council*, 222-233.

[12] Blake, D., A. J. G. Cairns, and K. Dowd, (2006). Living with mortality: Longevity bonds and other mortality-linked securities. *British Actuarial Journal.*

[13] Borsch-Supan, A., C. Hunkler, S. Gruber, A. Orban, S. Stuck, M. Brandt (2016). easySHARE. Release version: 5.0.0. SHARE-ERIC. Data set DOI: 10.6103/SHARE.easy.500

[14] Braun, M. and A. Muermann, (2004). The Impact of Regret on the Demand for Insurance. *Journal of Risk and Insurance*, 71(4), 737-767.

[15] Brown, J. R. and J. M. Poterba., (1999). Joint life annuities and annuity demand for annuities by married couples (No. w7199). *National bureau of economic research.*

[16] Brown, J. R., (2001). Private pensions, mortality risk, and the decision to annuitize. *Journal of Public Economics*, 82(1): 29-62.

[17] Brown, J. R. and P. Orszag., (2006). The Political Economy of Government-Issued Longevity Bonds. *Journal of Risk and Insurance*, 73(4), 611-631.

[18] Brown, J. R., (2007). Rational and behavioral perspectives on the role of annuities in retirement planning (No. w13537). *National Bureau of Economic Research.*

[19] Brown, J. R., M. Casey and O. S. Mitchell., (2007). Who Values the Social Security Annuity? New evidence on the annuity puzzle (No. orrc07-02). *National Bureau of Economic Research.*

[20] Brown, J. R., J. R. Kling, S. Mullainathan and M. V. Wrobel, (2008). Why don't people insure late life consumption: A framing explanation of the under-annuitization puzzle (No. w13748).*National Bureau of Economic Research.*

[21] Chiang, C. L., (1961). A stochastic study of the life table and its applications. III. The follow-up study with the consideration of competing risks. *Biometrics*, 17(1), 57-78.

[22] Coleman M. P., M. Quaresma, F. Berrino, J. M., Lutz, R. De Angelis, R. Capocaccia and A. Micheli, (2008). Cancer survival in five continents: a worldwide population-based study (CONCORD). *The lancet oncology*, 9(8), 730-756.

[23] Cornfield, J., (1957). Estimation of the probability of developing a disease in the presence of competing risks. *American Journal of Public Health and the Nations Health*, 47(5), 601-607.

[24] Cutler, S. J., M. H. Criswold and H. Eisenberg, (1957). An interpretation of survival rates: Cancer of the breast. *Journal of the National Cancer Institute*, 19(6), 1107-1117.

[25] Cutler, S. J. and F. Ederer, (1958). Maximum utilization of the life table method in analyzing survival. *Journal of chronic diseases*, 8(6), 699-712.

[26] Cronin, K. A. and E. J. Feuer, (2000). Cumulative cause-specific mortality for cancer patients in the presence of other causes: a crude analogue of relative survival. *Statistics in Medicine*, 19(13), 1729-1740.

[27] Dickman, Paul W., E. Coviello and M. Hills, (2015). Estimating and modeling relative survival. *Stata J*, 15(1), 186-215.

[28] Dickson, D., M. Hardy and H. Waters, (2013). Actuarial mathematics for life contingent risks. *Cambridge University Press*.

[29] Dushi, I. and A. Webb, (2004). Household annuitization decisions: simulations and empirical analysis. *Journal of Pension Economics and Finance*, 3(02), 109-143.

[30] Decreto Lei no 147/2015 de 9 de setembro. Diário da República: I série, No 176/XII/4 (2015). Available at www.dre.pt.

[31] Ederer, F. and H. Heise, (1959). The effect of eliminating deaths from cancer on general population survival rates. *Methodological Note No*, 11(23), 169.

[32] Ederer, F., L. M. Axtell and S. J. Cutler, (1961). The relative survival rate: A statistical methodology. *National Cancer Institute Monograph*, 6, 101-121.

[33] Erhardt, C. L., (1958). What is the cause of death?. *Journal of the American Medical Association*, 168(2), 161-168.

[34] Finkelstein, A. and J. Poterba, (2002). Selection effects in the United Kingdom individual annuities market. *The Economic Journal*, 112(476), 28-50.

[35] Friedberg, L. and A. Webb., (2007). Life is cheap: using mortality bonds to hedge aggregate mortality risk. *The BE Journal of Economic Analysis and Policy*, 7(1).

[36] Gentry, W. and C. Rothschild, (2006). Lifetime Annuities for US: Evaluating the Efficacy of Policy Interventions in Life Annuity Markets. *American Council for Capital Formation (available at www. accf. org)*.

[37] Global Health Observatory (GHO) data (webpage on the Internet). Geneva: World Health Organization, 2016. Available at http://www.who.int/gho/en/.

[38] Hakulinen, T., (1982). Cancer survival corrected for heterogeneity in patient withdrawal. *Biometrics*, 933-942.

[39] Heise, H. (1959). The effect of a temporary change in survival on the life table method for computing survival rates. *National Cancer Institute, End Results Evaluation Section*, Methodological Note No. S.

[40] Howlader, N., L. A. Ries, A. B. Mariotto, M. E. Reichman, J. Ruhl and K. A. Cronin, (2010). Improved estimates of cancer-specific survival rates from population-based data. *Journal of the National Cancer Institute*, 102(20), 1584-1598.

[41] Hu, Wei-Yin and Jason S. Scott, (2007). Behavioral obstacles in the annuity market. *Financial Analysts Journal*, 63(6), 71-82.

[42] James, E. and X. Song, (2001). Annuities markets around the world: Money's worth and risk intermediation. *Available at SSRN 287375*.

[43] Johnson, R. W., L. E. Burman and D. Kobes, (2004). Annuitized wealth at older ages: Evidence from the Health and Retirement Study. *Urban Institute*.

[44] Langer, E. J., (1975). The illusion of control. *Journal of personality and social psychology*, 32(2), 311.

[45] Lindeman, D. and J. Yermo, (2002), Private annuity markets, *Financial Market Trends*, OECD, No. 83.

[46] Lusardi, A. and O. S. Mitchell, (2007). Baby boomer retirement security: The roles of planning, financial literacy, and housing wealth. *Journal of monetary Economics*, 54(1), 205-224.

[47] Milmore, B. K., (1958). Influence of changes in general mortality rates, and of age, upon survival of patients with a chronic disease. *Cancer*, 11(6), 1255-1263.

[48] Mitchell, O. S., James M. Poterba, and Mark J. Warshawsky, (1999). New Evidence on the Money's Worth of Individual Annuities. *American Economic Review*, 89(5), 1299-1318.

[49] Modigliani, F., (1986). Life cycle, individual thrift, and the wealth of nations. *The American Economic Review*, 76(3), 297-313.

[50] Nelson, C. P., P. C. Lambert, I. B. Squire and D. R. Jones, (2008). Relative survival: What can cardiovascular disease learn from cancer?. *European heart journal*.

[51] Parkin, D. M. and M. Khlat, (1996). Studies of cancer in migrants: rationale and methodology. *European Journal of Cancer*, 32(5), 761-771.

[52] Percy, C. and A. Dolman, (1978). Comparison of the coding of death certificates related to cancer in seven countries. *Public Health Reports*, 93(4), 335.

[53] Percy, C. and C. Muir, (1989). The international comparability of cancer mortality data results of an international death certificate study. *American Journal of Epidemiology*, 129(5), 934-946.

[54] Pineda, M. D., E. White, A. R. Kristal and V. Taylor, (2001). Asian breast cancer survival in the U.S.: a comparison between Asian immigrants, U.S.-born Asian Americans and Caucasians. *International journal of epidemiology*, 30(5), 976-982.

[55] Perme, M. P., J. Stare and J. Estève., (2012). On estimation in relative survival. *Biometrics*, 68(1), 113-120.

[56] Prentice, R. L., J. D. Kalbfleisch, A. V. Peterson, N. Flournoy, V.T. Farewell and N. E. Breslow, (1978). The analysis of failure times in the presence of competing risks. *Biometrics*, 541-554.

[57] Smith, B. and F. Stewart, (2009). Learning from the Experience of Organisation for Economic Co-operation and Development Countries: Lessons for Policy, Programs, and Evaluations. *Overcoming the saving slump: How to increase the effectiveness of financial education and saving programs*, 345.

[58] Spiegelman, M., M. T. Bellows, C. L. Erhardt, R. J. Keehn, I. M. Moriyama, E. Parkhurst and A. H. Sellers, (1958). Problems in the Medical Certification of Causes of Death: Committee on Medical Certification of Causes of Death-Statistics Section. *American Journal of Public Health and the Nations Health*, 48(1), 71-80.

[59] Tversky, A. and D. Kahneman, (1974). Judgment under uncertainty: Heuristics and biases. *Science (New York, NY)*, 185(4157), 1124-1131.

[60] Tversky, A. and D. Kahneman, (1986). Rational choice and the framing of decisions. *Journal of business*, S251-S278.

[61] Tversky, A. and D. Kahneman., (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty*, 5(4), 297-323.

[62] Wardzyńska, A., B. Kubsik, and M. L. Kowalski, (2015). Comorbidities in elderly patients with asthma: association with control of the disease and concomitant treatment. *Geriatrics and gerontology international*, 15(7), 902-909.

[63] Webb, A., (2006). Is adverse selection in the annuity market a big problem. *Center for Retirement Research at Boston College, Issue in Brief, January,* (40).

[64] Wong, O., (1977). A competing-risk model based on the life table procedure in epidemiological studies. *International Journal of Epidemiology*, 6(2), 153-159.

[65] Yaari, M. E., (1965). Uncertain lifetime, life insurance, and the theory of the consumer. *The Review of Economic Studies*, 32(2), 137-150.

Appendix A

Table A.1: Relative survival of heart attack disease for male population

(a) Age at diagnosis: 0-49

start	end	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme
		0% mortality							40% mortality						
0	1	213	0	0	1.0014	1.0014	1.0014	1.0014	213	0	0	1.0014	1.0014	1.0014	1.0014
1	2	213	0	0	1.0029	1.0029	1.0029	1.0029	213	0	0	1.0029	1.0029	1.0029	1.0029
2	3	213	0	2	1.0045	1.0045	1.0045	1.0045	213	0	2	1.0045	1.0045	1.0045	1.0045
3	4	211	0	3	1.0062	1.0062	1.0062	1.0062	211	1	2	1.0014	1.0014	1.0014	1.0014
4	5	208	0	9	1.0080	1.0080	1.0080	1.0080	208	1	8	0.9983	0.9983	0.9983	0.9983
5	6	199	0	6	1.0101	1.0100	1.0100	1.0100	199	2	4	0.9902	0.9901	0.9901	0.9901
6	7	193	0	12	1.0123	1.0122	1.0122	1.0122	193	4	8	0.9714	0.9713	0.9713	0.9712
7	8	181	0	10	1.0147	1.0146	1.0145	1.0146	181	2	8	0.9627	0.9626	0.9626	0.9624
8	9	171	0	12	1.0174	1.0172	1.0171	1.0171	171	3	9	0.9479	0.9476	0.9476	0.9474
9	10	159	0	15	1.0204	1.0200	1.0199	1.0199	159	4	11	0.9258	0.9255	0.9255	0.9252
10	11	144	0	7	1.0236	1.0230	1.0229	1.0229	144	1	6	0.9222	0.9216	0.9217	0.9214
11	12	137	0	13	1.0271	1.0262	1.0261	1.0262	137	6	7	0.8837	0.8830	0.8832	0.8826
12	13	124	0	10	1.0309	1.0297	1.0296	1.0296	124	2	8	0.8722	0.8712	0.8715	0.8707
13	14	114	0	18	1.0350	1.0334	1.0332	1.0333	114	2	16	0.8592	0.8579	0.8582	0.8573
14	15	96	1	8	1.0282	1.0261	1.0259	1.0258	96	2	7	0.8442	0.8425	0.8430	0.8419
		80% mortality							100% mortality						
0	1	213	0	0	1.0014	1.0014	1.0014	1.0014	213	0	0	1.0014	1.0014	1.0014	1.0014
1	2	213	0	0	1.0029	1.0029	1.0029	1.0029	213	0	0	1.0029	1.0029	1.0029	1.0029
2	3	213	2	0	0.9950	0.9950	0.9950	0.9950	213	2	0	0.9950	0.9950	0.9950	0.9950
3	4	211	3	0	0.9826	0.9825	0.9826	0.9825	211	3	0	0.9826	0.9825	0.9826	0.9825
4	5	208	5	4	0.9605	0.9605	0.9605	0.9604	208	5	4	0.9605	0.9605	0.9605	0.9604
5	6	199	2	4	0.9526	0.9526	0.9526	0.9525	199	4	2	0.9430	0.9429	0.9430	0.9428
6	7	193	6	6	0.9246	0.9245	0.9246	0.9244	193	9	3	0.9006	0.9006	0.9006	0.9004
7	8	181	4	6	0.9060	0.9059	0.9060	0.9057	181	5	5	0.8775	0.8774	0.8775	0.8772
8	9	171	4	8	0.8866	0.8864	0.8866	0.8862	171	5	7	0.8536	0.8534	0.8535	0.8531
9	10	159	7	8	0.8491	0.8487	0.8489	0.8485	159	10	5	0.8014	0.8010	0.8013	0.8007
10	11	144	3	4	0.8337	0.8332	0.8335	0.8330	144	4	3	0.7813	0.7809	0.7812	0.7805
11	12	137	7	6	0.7929	0.7922	0.7925	0.7917	137	9	4	0.7317	0.7311	0.7315	0.7305
12	13	124	5	5	0.7631	0.7622	0.7626	0.7616	124	5	5	0.7042	0.7034	0.7039	0.7027
13	14	114	7	11	0.7167	0.7156	0.7160	0.7149	114	10	8	0.6428	0.6418	0.6423	0.6410
14	15	96	5	4	0.6815	0.6801	0.6807	0.6794	96	6	3	0.6045	0.6033	0.6040	0.6025

(b) Age at diagnosis: 50-59

start	end	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme
		0% mortality							40% mortality						
0	1	580	0	1	1.0030	1.0030	1.0030	1.0030	580	0	1	1.0030	1.0030	1.0030	1.0030
1	2	579	0	10	1.0064	1.0064	1.0063	1.0063	579	4	6	0.9994	0.9994	0.9994	0.9994
2	3	569	0	37	1.0100	1.0100	1.0100	1.0100	569	10	27	0.9849	0.9849	0.9849	0.9849
3	4	532	0	47	1.0139	1.0139	1.0139	1.0139	532	10	37	0.9695	0.9695	0.9695	0.9695
4	5	485	0	34	1.0181	1.0181	1.0181	1.0181	485	7	27	0.9591	0.9591	0.9591	0.9590
5	6	451	0	43	1.0227	1.0227	1.0227	1.0227	451	21	22	0.9174	0.9174	0.9174	0.9174
6	7	408	0	39	1.0277	1.0277	1.0277	1.0277	408	8	31	0.9031	0.9031	0.9031	0.9030
7	8	369	0	47	1.0332	1.0332	1.0331	1.0332	369	11	36	0.8795	0.8794	0.8795	0.8795
8	9	322	0	25	1.0394	1.0393	1.0393	1.0393	322	4	21	0.8734	0.8733	0.8733	0.8734
9	10	297	1	35	1.0425	1.0425	1.0424	1.0425	297	13	23	0.8391	0.8391	0.8391	0.8392
10	11	261	0	29	1.0503	1.0503	1.0503	1.0504	261	4	25	0.8318	0.8318	0.8317	0.8319
11	12	232	1	25	1.0544	1.0545	1.0544	1.0547	232	9	17	0.8050	0.8051	0.8049	0.8053
12	13	206	1	21	1.0591	1.0593	1.0592	1.0594	206	4	18	0.7963	0.7965	0.7962	0.7966
13	14	184	0	28	1.0709	1.0711	1.0711	1.0714	184	8	20	0.7681	0.7683	0.7680	0.7686
14	15	156	0	22	1.0845	1.0852	1.0850	1.0856	156	4	18	0.7568	0.7572	0.7567	0.7573
		80% mortality							100% mortality						
0	1	580	1	0	1.0013	1.0013	1.0013	1.0013	580	1	0	1.0013	1.0013	1.0013	1.0013
1	2	579	6	4	0.9942	0.9942	0.9942	0.9942	579	6	4	0.9942	0.9942	0.9942	0.9942
2	3	569	21	16	0.9604	0.9604	0.9604	0.9604	569	27	10	0.9500	0.9500	0.9500	0.9500
3	4	532	23	24	0.9215	0.9215	0.9215	0.9215	532	31	16	0.8972	0.8972	0.8972	0.8972
4	5	485	21	13	0.8847	0.8847	0.8847	0.8847	485	24	10	0.8559	0.8559	0.8559	0.8559
5	6	451	30	13	0.8287	0.8287	0.8287	0.8287	451	34	9	0.7943	0.7943	0.7943	0.7943
6	7	408	20	19	0.7910	0.7910	0.7909	0.7910	408	28	11	0.7427	0.7427	0.7427	0.7426
7	8	369	18	29	0.7549	0.7548	0.7548	0.7549	369	25	22	0.6945	0.6945	0.6945	0.6945
8	9	322	10	15	0.7352	0.7351	0.7351	0.7353	322	15	10	0.6656	0.6655	0.6656	0.6656
9	10	297	22	14	0.6839	0.6839	0.6838	0.6842	297	27	9	0.6082	0.6081	0.6081	0.6084
10	11	261	14	15	0.6510	0.6510	0.6508	0.6511	261	17	12	0.5718	0.5719	0.5718	0.5721
11	12	232	15	11	0.6130	0.6131	0.6128	0.6132	232	20	6	0.5263	0.5264	0.5262	0.5265
12	13	206	13	9	0.5790	0.5791	0.5788	0.5792	206	16	6	0.4895	0.4896	0.4894	0.4897
13	14	184	19	9	0.5235	0.5236	0.5233	0.5240	184	20	8	0.4400	0.4401	0.4398	0.4404
14	15	156	6	16	0.5087	0.5089	0.5085	0.5093	156	7	15	0.4246	0.4248	0.4244	0.4252

Table A.1: Relative survival of heart attack disease for male population (cont.)

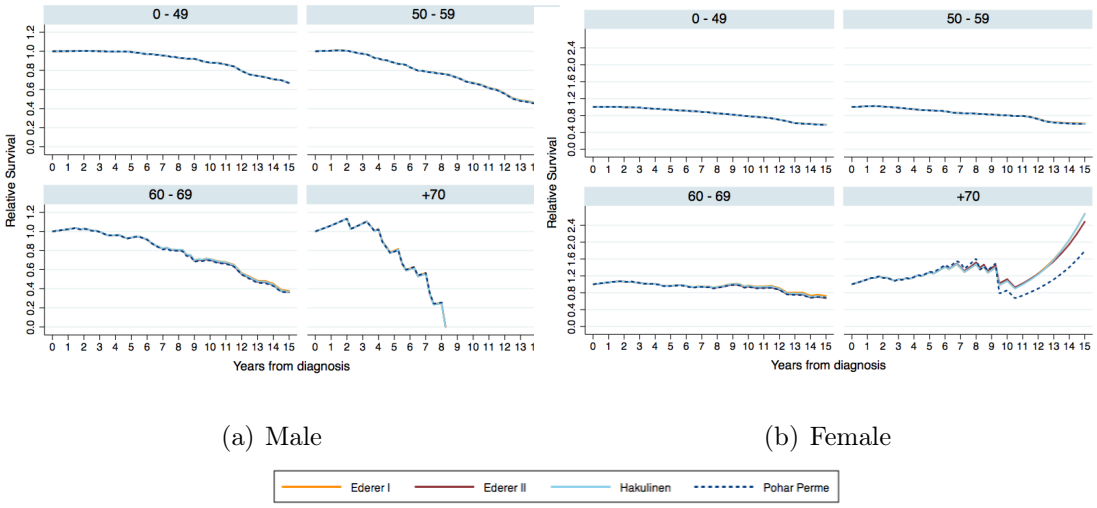
(c) Age at diagnosis: 60-69

start	end	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme
		0% mortality							40% mortality						
0	1	594	0	0	1.0070	1.0070	1.0070	1.0070	594	0	0	1.0070	1.0070	1.0070	1.0070
1	2	594	0	12	1.0150	1.0150	1.0150	1.0150	594	2	10	1.0115	1.0116	1.0115	1.0116
2	3	582	0	37	1.0241	1.0242	1.0241	1.0242	582	7	30	1.0081	1.0081	1.0080	1.0082
3	4	545	0	50	1.0347	1.0347	1.0346	1.0348	545	15	35	0.9895	0.9895	0.9893	0.9895
4	5	495	0	50	1.0469	1.0468	1.0465	1.0468	495	9	41	0.9822	0.9821	0.9818	0.9819
5	6	445	1	39	1.0586	1.0581	1.0577	1.0581	445	13	27	0.9655	0.9651	0.9647	0.9648
6	7	405	0	43	1.0751	1.0740	1.0734	1.0741	405	14	29	0.9454	0.9445	0.9441	0.9440
7	8	362	2	44	1.0878	1.0860	1.0851	1.0865	362	15	31	0.9206	0.9190	0.9187	0.9190
8	9	316	1	37	1.1062	1.1034	1.1023	1.1044	316	14	24	0.8960	0.8938	0.8935	0.8942
9	10	278	1	34	1.1274	1.1238	1.1221	1.1248	278	11	24	0.8788	0.8760	0.8756	0.8767
10	11	243	4	35	1.1363	1.1316	1.1295	1.1337	243	15	24	0.8432	0.8397	0.8392	0.8417
11	12	204	2	39	1.1571	1.1513	1.1483	1.1531	204	8	33	0.8310	0.8268	0.8260	0.8278
12	13	163	0	24	1.1953	1.1878	1.1836	1.1904	163	4	20	0.8360	0.8307	0.8294	0.8318
13	14	139	3	19	1.2107	1.2007	1.1953	1.2013	139	8	14	0.8143	0.8076	0.8060	0.8044
14	15	117	0	20	1.2605	1.2469	1.2399	1.2485	117	4	16	0.8167	0.8078	0.8060	0.8023
		80% mortality							100% mortality						
0	1	594	0	0	1.0070	1.0070	1.0070	1.0070	594	0	0	1.0070	1.0070	1.0070	1.0070
1	2	594	6	6	1.0047	1.0047	1.0047	1.0047	594	9	3	0.9996	0.9996	0.9996	0.9996
2	3	582	20	17	0.9784	0.9784	0.9784	0.9784	582	23	14	0.9682	0.9683	0.9682	0.9683
3	4	545	26	24	0.9402	0.9403	0.9402	0.9400	545	30	20	0.9233	0.9234	0.9233	0.9232
4	5	495	24	26	0.9040	0.9039	0.9039	0.9034	495	25	25	0.8858	0.8858	0.8857	0.8854
5	6	445	19	21	0.8762	0.8758	0.8759	0.8752	445	24	16	0.8486	0.8482	0.8482	0.8476
6	7	405	20	23	0.8446	0.8438	0.8441	0.8430	405	26	17	0.8053	0.8045	0.8047	0.8037
7	8	362	22	24	0.8056	0.8043	0.8049	0.8037	362	29	17	0.7524	0.7511	0.7517	0.7503
8	9	316	26	12	0.7530	0.7512	0.7520	0.7516	316	33	5	0.6869	0.6852	0.6860	0.6849
9	10	278	18	17	0.7190	0.7167	0.7176	0.7173	278	22	13	0.6458	0.6437	0.6447	0.6438
10	11	243	22	17	0.6685	0.6658	0.6667	0.6672	243	28	11	0.5845	0.5821	0.5831	0.5834
11	12	204	22	19	0.6104	0.6073	0.6080	0.6081	204	29	12	0.5136	0.5110	0.5118	0.5121
12	13	163	9	15	0.5940	0.5903	0.5908	0.5909	163	14	10	0.4835	0.4805	0.4811	0.4815
13	14	139	13	9	0.5564	0.5518	0.5521	0.5504	139	15	7	0.4459	0.4422	0.4426	0.4421
14	15	117	13	7	0.5129	0.5074	0.5075	0.5049	117	15	5	0.4034	0.3990	0.3992	0.3973

(d) Age at diagnosis: +70

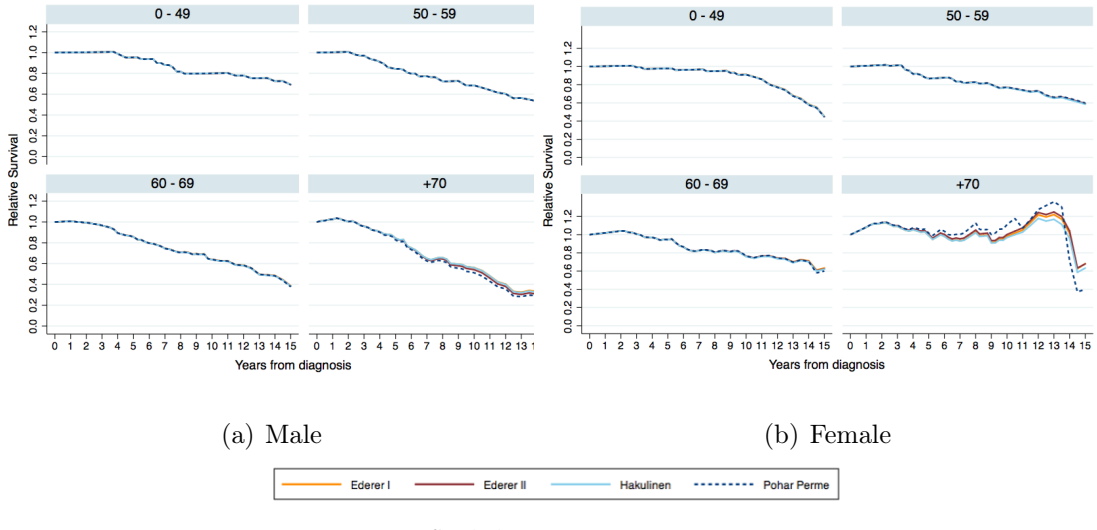
start	end	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme	n	d	w	Ederer I	Ederer II	Hakulinen	Pohar Perme
		0% mortality							40% mortality						
0	1	373	0	0	1.0327	1.0327	1.0327	1.0331	373	0	0	1.0327	1.0327	1.0327	1.0331
1	2	373	0	11	1.0700	1.0704	1.0697	1.0715	373	4	7	1.0584	1.0588	1.0583	1.0594
2	3	362	0	32	1.1126	1.1135	1.1115	1.1159	362	6	26	1.0816	1.0825	1.0812	1.0839
3	4	330	1	45	1.1575	1.1587	1.1551	1.1638	330	14	32	1.0786	1.0797	1.0777	1.0838
4	5	284	2	39	1.2040	1.2062	1.1998	1.2144	284	14	27	1.0720	1.0740	1.0705	1.0782
5	6	243	3	41	1.2504	1.2534	1.2427	1.2676	243	14	30	1.0592	1.0618	1.0568	1.0657
6	7	199	4	40	1.2926	1.2950	1.2794	1.3177	199	20	24	1.0002	1.0021	0.9968	1.0063
7	8	155	2	22	1.3543	1.3547	1.3331	1.3851	155	7	17	1.0119	1.0122	1.0071	1.0047
8	9	131	3	18	1.4106	1.4071	1.3801	1.4465	131	9	12	1.0027	1.0003	0.9966	0.9927
9	10	110	5	10	1.4424	1.4355	1.4016	1.4633	110	9	6	0.9861	0.9813	0.9784	0.9583
10	11	95	0	9	1.5571	1.5437	1.5004	1.5826	95	2	7	1.0412	1.0323	1.0299	1.0115
11	12	86	3	19	1.6250	1.6032	1.5499	1.6329	86	10	12	0.9896	0.9764	0.9742	0.9456
12	13	64	4	13	1.6526	1.6231	1.5599	1.6214	64	7	10	0.9534	0.9364	0.9336	0.8868
13	14	47	5	12	1.5964	1.5622	1.4906	1.5011	47	8	9	0.8514	0.8332	0.8275	0.7674
14	15	30	5	11	1.4077	1.3677	1.2994	1.3357	30	11	5	0.5660	0.5499	0.5448	0.5255
		80% mortality							100% mortality						
0	1	373	0	0	1.0327	1.0327	1.0327	1.0331	373	0	0	1.0327	1.0327	1.0327	1.0331
1	2	373	5	6	1.0555	1.0559	1.0555	1.0563	373	6	5	1.0526	1.0531	1.0526	1.0535
2	3	362	13	19	1.0571	1.0579	1.0570	1.0585	362	19	13	1.0360	1.0369	1.0361	1.0368
3	4	330	25	21	1.0170	1.0181	1.0169	1.0187	330	30	16	0.9807	0.9817	0.9808	0.9823
4	5	284	21	20	0.9843	0.9860	0.9844	0.9873	284	28	13	0.9241	0.9258	0.9246	0.9263
5	6	243	31	13	0.9003	0.9025	0.9006	0.8992	243	39	5	0.8151	0.8171	0.8159	0.8123
6	7	199	31	13	0.7987	0.8001	0.7991	0.7972	199	34	10	0.7108	0.7121	0.7119	0.7088
7	8	155	14	10	0.7693	0.7696	0.7699	0.7555	155	15	9	0.6799	0.6802	0.6812	0.6676
8	9	131	10	11	0.7561	0.7542	0.7564	0.7477	131	19	2	0.6199	0.6184	0.6211	0.6084
9	10	110	11	4	0.7291	0.7256	0.7287	0.7080	110	13	2	0.5862	0.5834	0.5868	0.5660
10	11	95	8	1	0.7205	0.7143	0.7186	0.6930	95	8	1	0.5793	0.5743	0.5788	0.5539
11	12	86	16	6	0.6317	0.6233	0.6276	0.6121	86	20	2	0.4812	0.4747	0.4790	0.4596
12	13	64	12	5	0.5558	0.5458	0.5488	0.5262	64	16	1	0.3934	0.3864	0.3893	0.3710
13	14	47	15	2	0.4120	0.4032	0.4036	0.3723	47	15	2	0.2917	0.2854	0.2862	0.2625
14	15	30	14	2	0.2361	0.2294	0.2289	0.2095	30	14	2	0.1671	0.1624	0.1624	0.1477

Appendix B



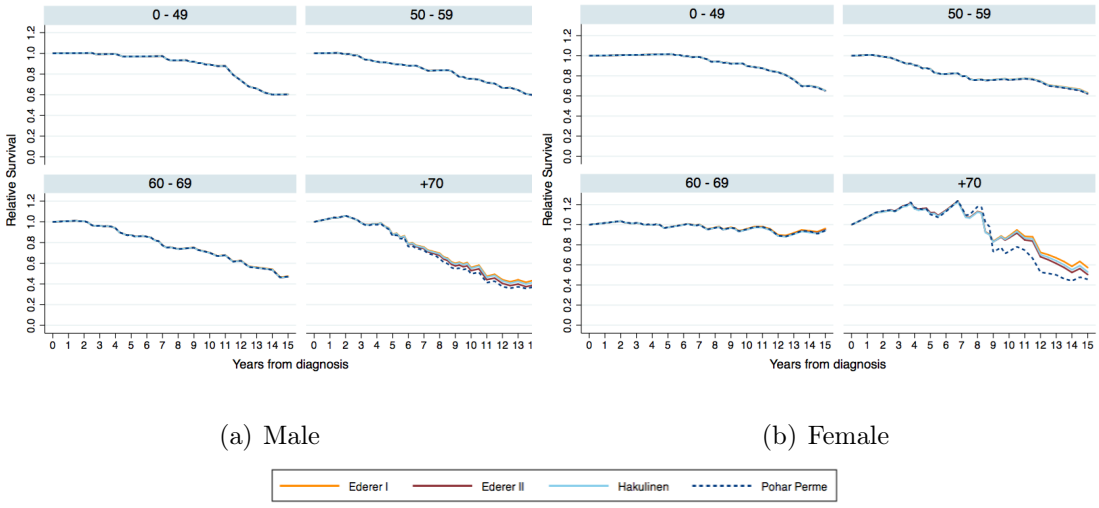
(a) Male (b) Female

Figure B.1: Cholesterol - net relative survival rates



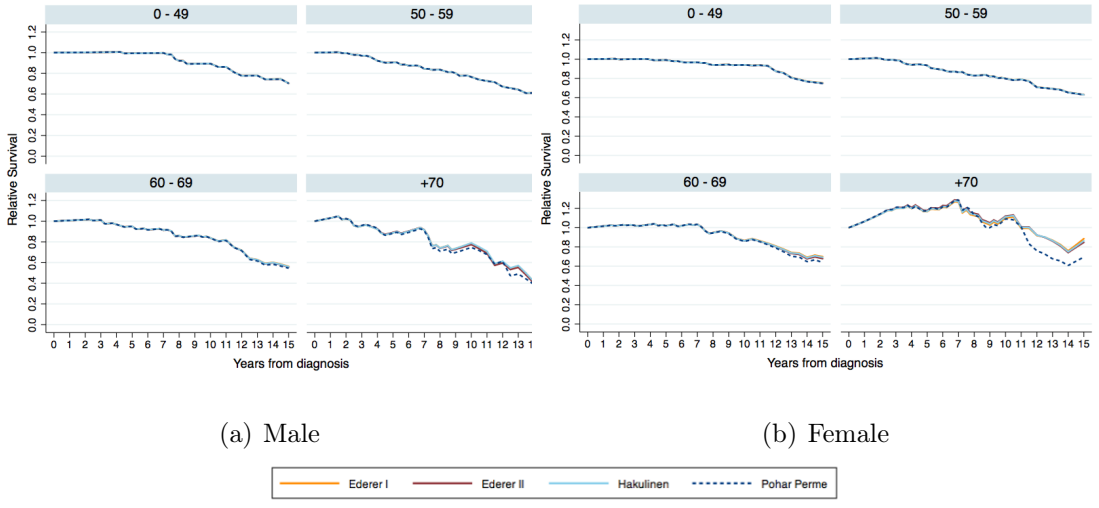
(a) Male (b) Female

Figure B.2: Stroke - net relative survival rates



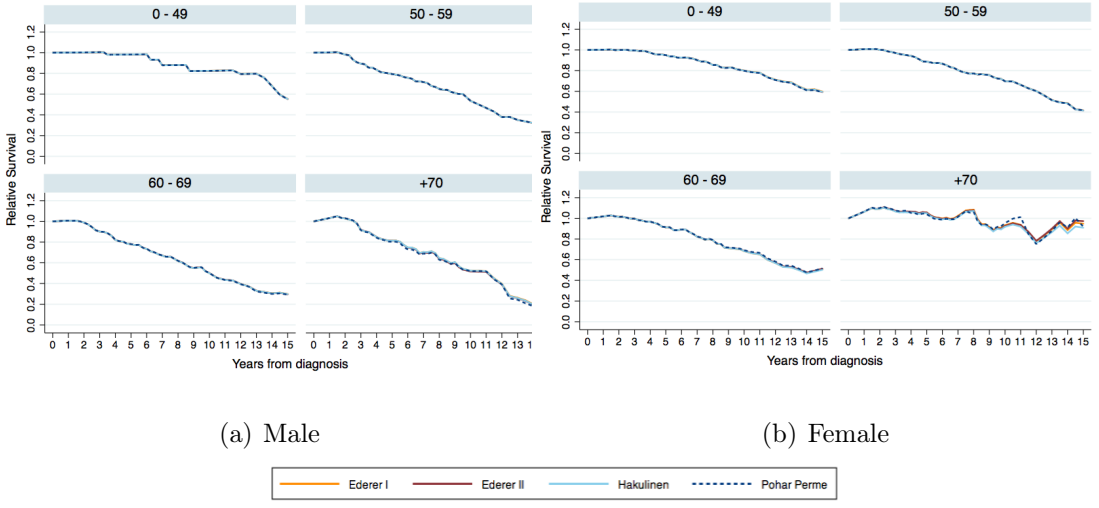
(a) Male (b) Female

Figure B.3: Chronic Lung Disease - net relative survival rates



(a) Male (b) Female

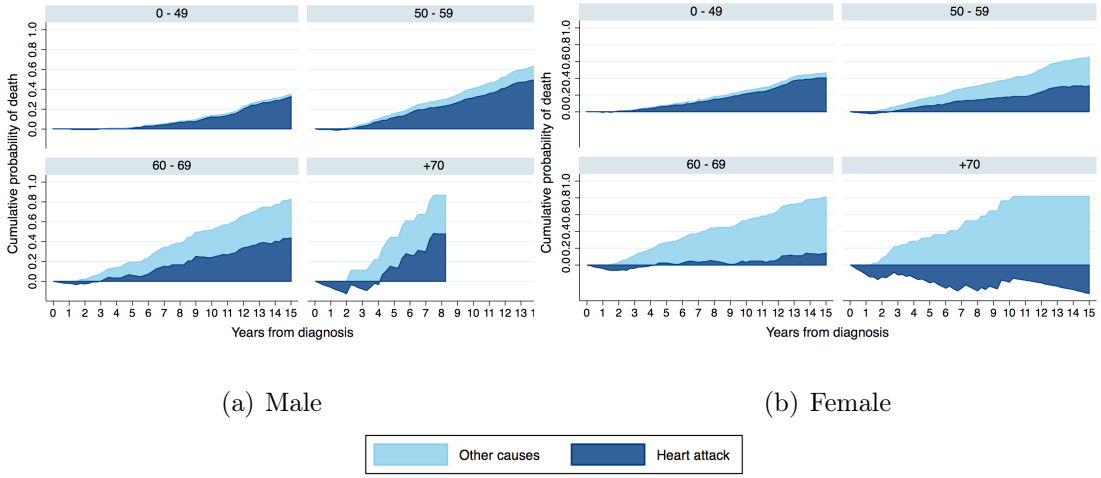
Figure B.4: Asthma - net relative survival rates



(a) Male (b) Female

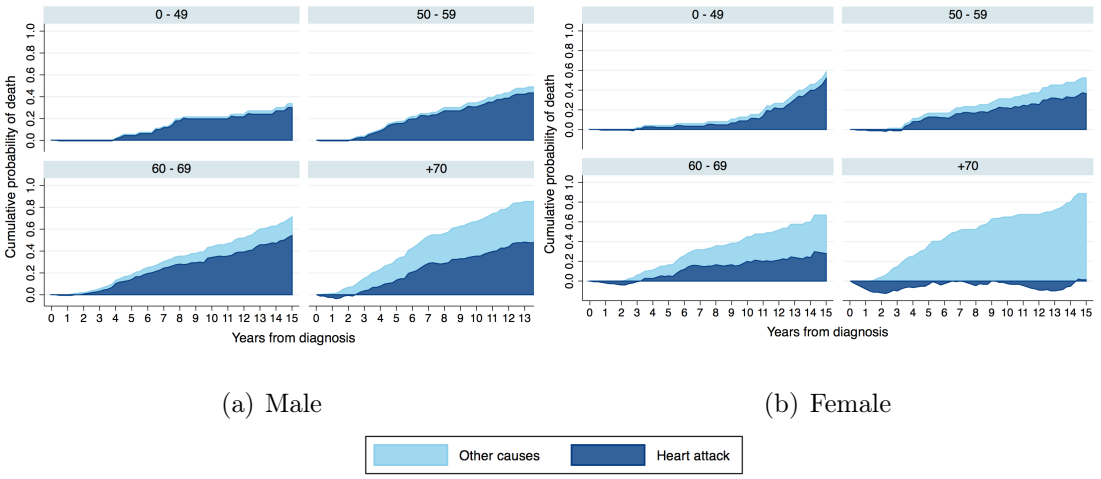
Figure B.5: Cancer - net relative survival rates

Appendix C



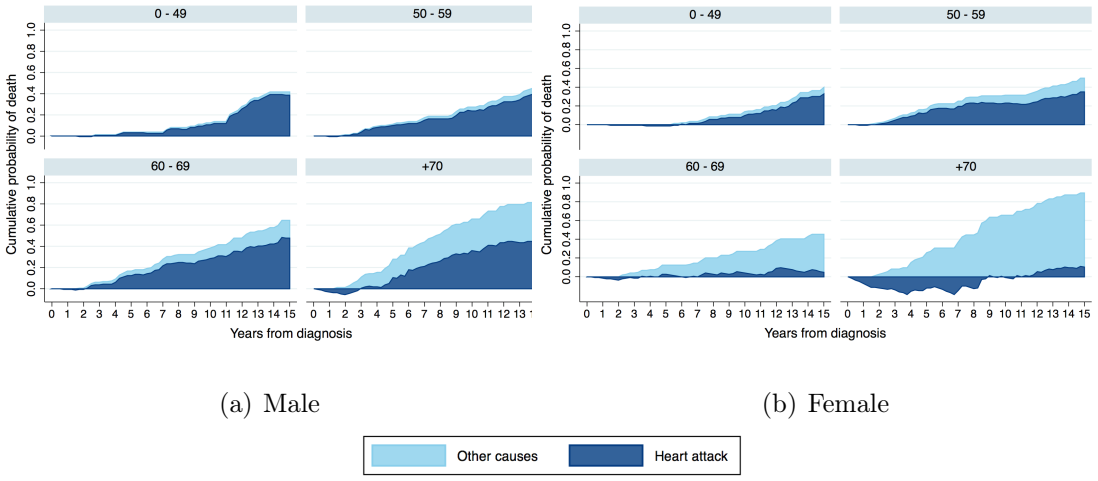
(a) Male (b) Female

Figure C.1: Cholesterol - crude relative survival rates



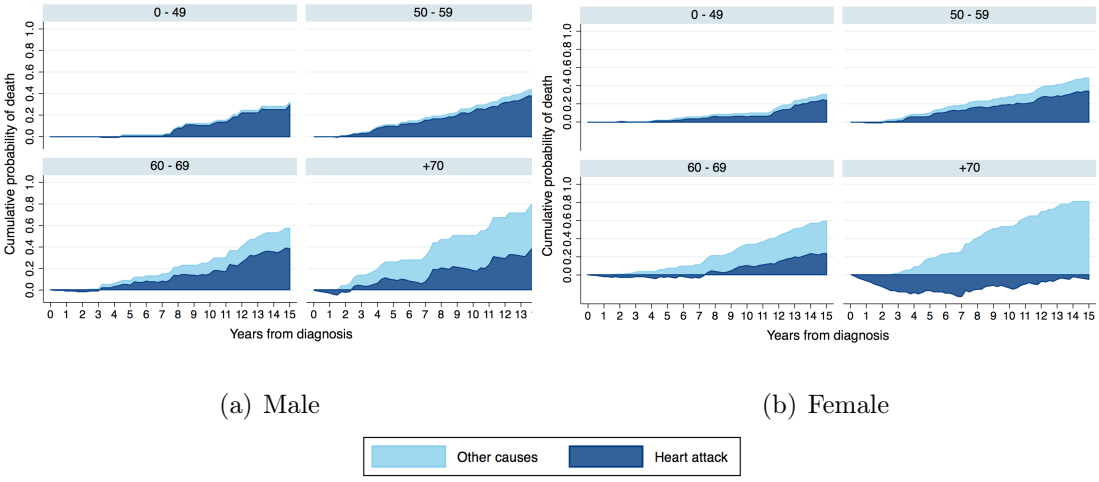
(a) Male (b) Female

Figure C.2: Stroke - crude relative survival rates



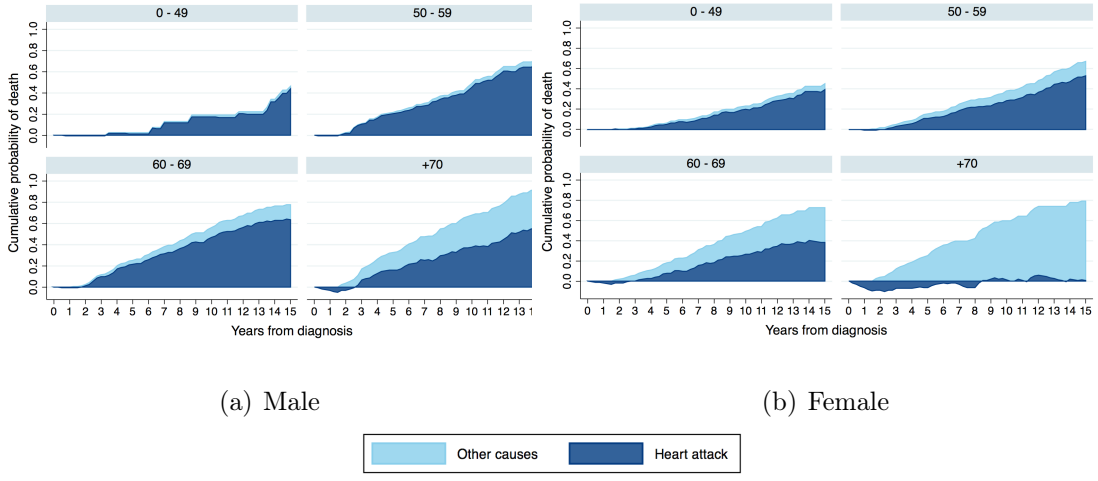
(a) Male (b) Female

Figure C.3: Chronic Lung Disease - crude relative survival rates



(a) Male (b) Female

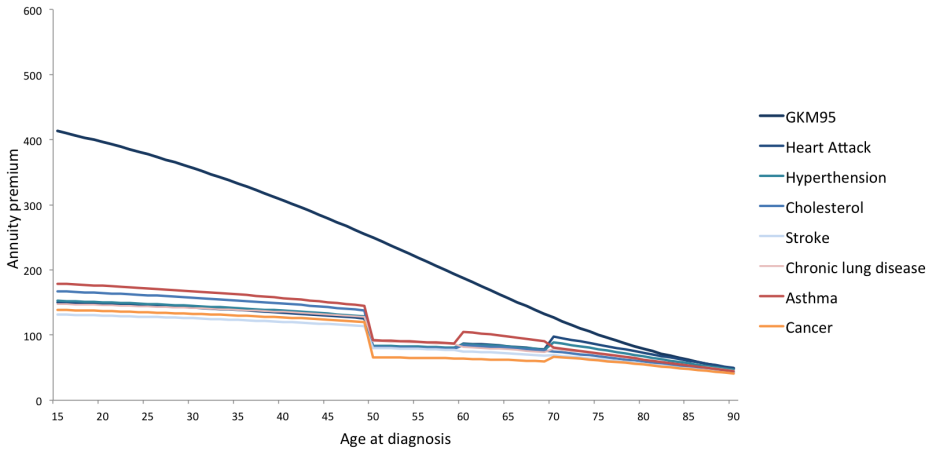
Figure C.4: Asthma - crude relative survival rates



(a) Male (b) Female

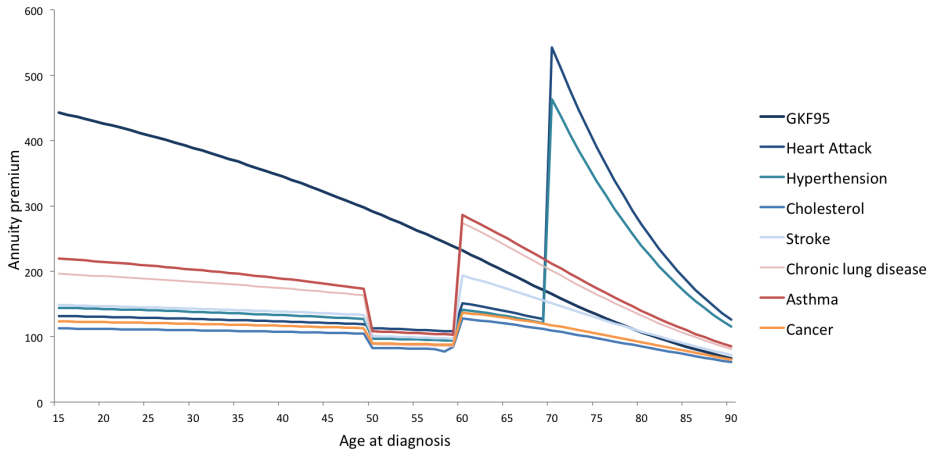
Figure C.5: Cancer - crude relative survival rates

Appendix D



	35	40	45	50	55	60	65	70	75	80	85	90
GKM95	332.7	306.9	279.0	249.5	218.8	187.8	156.8	126.8	100.5	78.8	61.7	48.4
Heart Attack	138.5	134.5	129.9	82.4	80.8	87.2	83.0	97.4	85.4	72.8	60.6	49.6
Hypertension	141.4	137.5	132.9	83.8	82.3	86.2	82.2	88.6	78.3	67.2	56.5	46.6
Cholesterol	153.2	148.4	142.9	81.8	80.4	84.0	80.4	74.7	67.4	59.2	50.8	42.8
Stroke	123.2	120.3	116.9	80.0	78.6	75.0	72.2	69.0	62.9	55.9	48.6	41.5
Chronic Lung Disease	138.8	135.6	131.7	90.9	88.6	81.4	77.9	78.8	71.2	62.5	53.7	45.1
Asthma	162.5	156.8	150.5	92.2	89.8	104.8	97.9	81.2	72.1	62.5	53.0	44.2
Cancer	130.2	127.1	123.6	65.8	65.1	63.5	61.7	66.8	61.2	54.6	47.7	40.9

(a) Male



	35	40	45	50	55	60	65	70	75	80	85	90
GKF95	367.8	344.6	319.5	292.1	262.7	231.6	198.5	164.9	133.9	107.0	84.7	66.8
Heart Attack	125.4	123.4	121.2	113.2	110.6	151.4	138.5	542.6	390.5	272.0	185.7	126.2
Hypertension	135.7	133.0	129.9	97.3	95.6	141.7	131.2	463.3	338.1	239.5	166.6	115.3
Cholesterol	108.8	107.5	106.1	82.6	81.9	127.7	119.7	109.4	97.6	85.1	72.7	60.9
Stroke	140.8	138.4	135.7	101.0	98.9	193.6	173.5	151.3	129.0	107.9	88.8	72.0
Chronic Lung Disease	179.4	174.2	168.4	88.7	87.0	274.1	238.5	200.9	164.7	132.2	104.2	81.2
Asthma	196.1	188.7	180.7	108.1	105.5	286.1	250.4	211.9	174.3	139.8	109.8	84.9
Cancer	118.2	116.5	114.7	89.7	88.7	136.9	128.5	117.6	105.0	91.5	77.9	65.0

(b) Female

Figure D.1: Life annuity premiums (crude survival estimates)