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Breaking Life Expectancy into Small Pieces

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Abstract

Understanding mortality patterns and how they evolve in time has always been a challenging subject and many researchers have worked on it. We wish to enhance existing knowledge on the topic, by decomposing the effects on mortality of more than 400 combinations of "age class/Mortality Chapter", in three countries with different characteristics and for a period of 44 years. Using classic decomposition methods, it is possible to observe a steady increase in Life Expectancy at birth and a decrease in the Gender Gap, identifying the main contributors to the phenomena in terms of "age class/Mortality Chapter". Another finding is the existence of important similarities among countries.

Keywords: Life Expectancy, Mortality Chapters, Human Mortality and Cause of Death Databases, France, Czech Republic, USA.

1. Introduction

Understanding and explaining the sources of change in demographic indicators such as life expectancy at different ages has been in the interest of the scientific community for a long time. However, the topic has gained relevance now more than ever, due to the financial difficulties that have affected, or are expected to affect, pension fund schemes and social security systems in general. Because of this, attention has increasingly turned to better understanding mortality, the patterns shown in the past, and how they have been evolving in time, as a way of enhancing the scientific knowledge that will enable the community to better predict the future.

Contributions of age and causes of death to life expectancy at birth (LE) can be calculated with decomposition methods (Andreev, Shkolnikov and Begun, 2002; Arriaga,1984, 1989; Das Gupta, 1978). This approach has been widely used for various purposes, in particular, to research the effects on mortality of inequalities in socioeconomic conditions and access to health care, in different countries and regions (Agyepong et al., 2017; Bergeron-Boucher, Ebeling & Canudas-Romo, 2015; Khang, Yang, Cho, Choi-Jung & Yun, 2010; Liu et al., 2016; Martikainen, Valkonen & Martelin, 2001; Martikainen, Makela, Peltonen & Myrskyla, 2014; Mondal & Shitan, 2014; Murwirapachena & Mlambo, 2015; Preston & Stokes, 2012; Shkolnikov, Andreev, McKee & Leon,

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2013; Tarkiainen, Martikainen, Laaksonen & Valkonen, 2012; Wang et al., 2016; Yang, Khang, Chun, Harper & Lynch, 2012). Many other studies focus on the gender gap or other life expectancy issues, again in different parts of the world (Al-Ramadhan, 2008; Auger, Feuillet, Martel, Lo, Barry & Harper, 2014; Auger, Harper, Barry, Trempe & Daniel, 2012; Hosseinpoor, Lee, Lynch, Mathers & Abou-Zahr, 2012; Le, Ren, Shen, Li & Zhang, 2015; Rosella et al., 2016; Simmons, 2018; Trovato & Heyen, 2006; Trovato & Lalu, 1997; Trovato & Odynak, 2011; Vaupel & Romo, 2002; Waldon, 1983; Waldon, McCloskey & Earle, 2005; Yang, Khang, Chun, Harper & Lynch, 2012).
In these works a decomposition of age and cause-specific mortality contributions to changes in life expectancy is performed. In our work, we apply the same methodology to create deeper knowledge on the dynamics behind life expectancy changes, not only because the analysis covers a very long period of time, but mostly because more than 20 age groups and 20 mortality chapters, as defined by the International Classification of Diseases, are under study. Three developed countries with significant historical differences with respect to mortality (France, Czech Republic and the United States) haven been chosen as case studies, to make direct comparisons possible. The research focuses not only on quantifying the changes in LE, but also on estimating simultaneously the contributions attributable to each of the different age groups and mortality chapters, in an exhaustive and in depth way and for over four decades. We expect our paper to enhance the understanding of mortality and longevity differences and their origin, the evolution of the observed patterns as time goes by, and the historical change in the decomposition of these patterns.
In the following sections, we analyze *in depth and for a 42-year period* the changes in LE. To achieve this, mortality variations are decomposed considering age, cause of death (CoD) and the relationship between them for different nations, selected because of three major reasons: they belong to the small group of countries with CoD information available in the Human Mortality Database (HMD); they cover the entire range of gross national income of this group; and they have populations with very different sizes.
The information available in the Cause of Death Database (CoDD) goes from 1959 to 2013 for USA, 1958 to 2015 for France, and 1968 to 2015 for Czech Republic. In order to make the results comparable, a common time interval is necessary. Furthermore, it was important to break the timeline in three shorter periods of the same length, to better capture the evolution of the phenomenon in study. As a result, the analysis goes from 1970 to 2013, dividing the time horizon from 1970 to 1984, from 1985 to 1998, and from 1999 to 2013.

2. Background, Data and Method

In general, the concept of life expectancy is one of the most popular to use when analyzing mortality, so it is normally taken as an indicator of human health due to its capacity to "summarize mortality in a single measure" (Auger, Feuillet, Martel, Lo, Barry and Harper 2014). In this sense, whether a researcher uses this indicator or any other, it has become evident that mortality improvements are real, leading people to live longer.
Global LE for both sexes went from 66.5 years in 2000 to 72 years in 2015, (World Health Organization, 2019). According to United Nations (2019), it increased from 64.2 years in 1990 to 72.6 years in 2019 and is expected to increase further to 77.1 years in 2050. While considerable progress has been made in closing the longevity differential between countries, large gaps remain. In 2019, LE in the least developed countries lags 7.4 years behind the global average, due largely

to persistently high levels of child and maternal mortality, as well as violence, conflict and the continuing impact of the HIV epidemic. Moreover, the number of people in the world who were 60 or older has doubled when compared to 1980, and it is expected that by 2050 16% of the world population will be aged 65 or more (9% in 2019), i.e., by 2050 one in six people in the world will be over age 65 (16%), up from one in 11 in 2019 (9%), cf United Nations (2019).

Following the same sources, regions where the share of the population aged 65 years or over is projected to double between 2019 and 2050 include Northern Africa and Western Asia, Central and Southern Asia, Eastern and South-Eastern Asia, and Latin America and the Caribbean. By 2050, one in four persons living in Europe and Northern America could be aged 65 or over. In 2018, for the first time in history, persons aged 65 or above outnumbered children under five years of age globally. The number of persons aged 80 years or over is projected to triple, from 143 million in 2019 to 426 million in 2050.

Furthermore, there seems to be a growing interest in the so-called "Blue Zones", see Poulant, Buettner and Pes (2019), a selected group of places in the world with an extraordinarily high concentration of people living to ages over 100. According to the World Economic Forum (2017), Loma Linda in California (USA), Nicoya in Costa Rica, Sardinia in Italy, Icaria in Greece, and Okinawa in Japan are the members of this selective group that has driven researchers to try to understand the factors behind these high longevity levels.

In this context, actuaries have become protagonists in the search of solutions and contingency plans for countries to face the issues associated to having a much older population. The uncertainty of not knowing exactly how much further the improvements in mortality may go, and how deep the financial cost of the phenomenon may be, has received the name of Longevity Risk, one of the key factors in the actuarial scene nowadays. The Actuarial Association of Europe (2019) found that in this continent, in the context of the aging population, "costs are projected to rise in every country on health and long-term care spending. These projections depend not only on the population projections but also on how life expectancy increases translate into healthy life expectancy and how the demand for health and long-term care services evolve". Better understanding the drivers behind this extended longevity helps shed some light on the possibilities for the future, which allows systems to make more informed decisions.

To analyze mortality information from the HMD and CoDD, a programmed tool has been developed, the Mortality Analysis Calculator (MAC). MAC, which was created by Ugarte A for the Department of Research of the Society of Actuaries, proved to be a very effective instrument.

One of the main features of the Mortality Analysis Calculator is that it decomposes the changes in a mortality indicator by the contributions attributable per age group and mortality chapter, when applicable. In order to decompose the variations, the tool makes use of algorithms already present in the literature, relying mostly on the seminal contributions of Andreev, Shkolnikov and Begun (2002) and Arriaga (1984, 1989).

2.1 Decomposition of the changes in a mortality indicator per age group

Consider the changes between years t_1 and t_2 ($t_2 > t_1$) in a mortality indicator estimated for a specific age a. When computing the attributable contribution to changes associated to an age/age group, the algorithm presented by Andreev, Shkolnikov and Begun (2002) is used. The original paper presents the formula to decompose changes between two periods in time, but in general it

applies to compare two different "experiences" in an indicator - whether the change comes from time, gender or an ethnic group, for example. The notation presented here is slightly different from that used in the original paper, but the underlying principles remain intact.

Denote a mortality indicator - life expectancy in this case - for age *a* as Ind_a. Then the attribution of change in the mortality indicator between years t_1 and t_2 at age *a* associated to a contributing age *x* is

$$ {}^{a}_{x}\delta^{2-1} = \frac{l_x^2}{l_a^2}\underbrace{(Ind_x^2 - Ind_x^1)}_{Variation\ age\ x} - \frac{l_{x+1}^2}{l_a^2}\underbrace{(Ind_{x+1}^2 - Ind_{x+1}^1)}_{Variation\ age\ x+1}, \qquad (1) $$

where l_x^j represents the number of survivors aged *x* for year $t_j, j = 1,2,$ and Ind_x^j represents the level of the indicator for age *x* in year t_j.

As established by Andreev, Shkolnikov and Begun (1982) and Pressat (1985), the result of computing ${}^{a}_{x}\delta^{2-1}$ for the decomposition by age does not necessarily have to be the same as that of $-{}^{a}_{x}\delta^{1-2}$, so they suggested replacing ${}^{a}_{x}\delta^{2-1}$ with

$$ {}^{a}_{x}\delta = 0.5\left({}^{a}_{x}\delta^{2-1} - {}^{a}_{x}\delta^{1-2}\right) \qquad (2) $$

to obtain the attributable contribution coming from age *x* to the change in the indicator for age *a*, so that

$$ (Ind_a^2 - Ind_a^1) = \sum_{x=a}^{\omega} {}^{a}_{x}\delta. \qquad (3) $$

In the calculations that follow (2) and (3) will be used.

2.2 Decomposition of changes associated to causes of death

In this paper we also compute the contribution of the evolution of causes of death in the mortality indicators. Similar to the previous section, consider ${}^{a}_{x}\delta$ as the contribution to change attributable to age *x* in the mortality indicator at age *a* between years t_1 and t_2. Assume that the environment is affected by *n* diseases, so that we denote the change in the indicator at age *a* between years t_1 and t_2 due to disease *i* ($i = 1,2,3,\dots,n$) as ${}^{i}_{a}\alpha^{2-1}$. Following the reasoning in Arriaga's method, the change associated with disease *i* is

$$ {}^{i}_{a}\alpha^{2-1} = \sum_{x=a}^{\omega} {}^{a}_{x}\delta\ {}^{i}\Lambda_x^{2-1},\ {}^{i}\Lambda_x^{2-1} = \frac{{}^{i}q_x^2 - {}^{i}q_x^1}{q_x^2 - q_x^1}, \qquad (4) $$

where ${}^{i}q_x^k$ denotes the mortality rate associated with disease *i* for age *x* during year t_k. Similarly, q_x^k represents the total mortality rate for age *x* (i.e. including all *n* diseases) during year t_k.

Analyzing the formula, it becomes evident that it distributes the changes in the indicator attributable to the different ages involved using the changes registered in mortality rates per cause. In this sense, ${}^{i}\Lambda_x^{2-1}$ is just the proportion of the overall change in mortality for age *x* that was registered between times t_1 and t_2 that is attributable to cause *i*.

The underlying assumption is that the contributions to changes associated to a cause are directly proportional to the variations registered in the respective mortality rates. Then, clearly,

$$ \alpha_a^{2-1} = \sum_{i=1}^{n} {}^{i}_{a}\alpha^{2-1} = \sum_{i=1}^{n}\sum_{j=a}^{\omega} {}^{a}_{j}\delta\,{}^{i}\Lambda_j^{2-1} \qquad (5) $$

is the overall change in the mortality indicator for age *a* between years t_1 and t_2.

3. Breaking Life Expectancy at Birth from 1970 to 2013

LE shows remarkable evolution in France, Czech Republic and the United States. In all three countries the values of the indicator have increased as mortality dynamics evolve at different stages of human life and the effect of diseases vary in time. We will present next the decomposition of changes in LE per age group and the contributions attributable to the different mortality chapters, calculated using equations (2)-(5).

3.1 Life Expectancy at Birth in France

France has experienced a sustained growth in LE in the period of interest. This indicator went from 68.4 years for males and 75.8 years for females in 1970 to 78.8 years and 85.1 years (respectively) in 2013. This represents a change of 10.4 years for males and 9.3 years for females in the entire period. These changes, however, did not occur in a "uniform" manner and can be explained in different ways along this time interval.

3.1.1 1970-1984

During this term, females experienced a bigger increase in their LE, and registered a total change of 3.54 extra years against 2.77 extra years for males. Per age group, the changes experienced in LE during this period are characterized by a very important increase due to mortality changes at early ages. For example, the contribution to the change attributed to the first year of life alone amounts to around 29% of the total change for males and 19% for females. In general, during this time period, when considering the changes attributable to ages younger than 65, mortality changes in these age groups contributed with almost 64% of the total increase (1.76 years) in the case of males whereas for females they amount to 51% (or 1.81 years). In the case of males, estimations show that only 1 year is attributable to changes in mortality at ages 65 and older (out of the 2.77 years), while the number increases to 1.73 years when considered the total change of 3.54 years for females. From this information, it seems that women at older ages saw a much more significant improvement in their mortality prospects than men, who were experiencing a greater mortality enhancement at young ages.

When analyzing the results and estimated changes attributed to the different mortality chapters, estimations show that the most relevant increment in life expectancy, for both genders, took place due to improvements in Cerebrovascular Diseases (Mortality Chapter IX). The changes in mortality due to this group of diseases represented an estimated improvement in LE of half a year for males and 0.64 years for females, between 1970 and 1984. Changes in mortality due to Heart Diseases (Mortality Chapter VIII) also played a central role in improving the indicator for both genders, but the effect is much higher in the case of females since it is estimated that women gained over half a year in LE (against 0.35 years for males). Similar results are obtained for Mortality Chapter XIX, Ill-defined or Unknown Causes, registering an improvement of 0.52 years for females and 0.38 years for males.

Moreover, Mortality Chapter XX - External Causes - including death due to accidents, homicides, poisoning, and the like, contributes considerably to the improvement in LE for men (0.34 years), but not for women (0.14 years). Finally, it is worth noting that results show an important decrease in LE for males due to Chapter II, Malignant Neoplasm, which caused an estimated loss in life expectancy of 0.55 years for men. Table A.1 in the annex shows all the details of the composition

of changes in life expectancy per cause of death. Sources of all figures and tables: Human Mortality Database, Cause of Death Mortality Database and MAC.

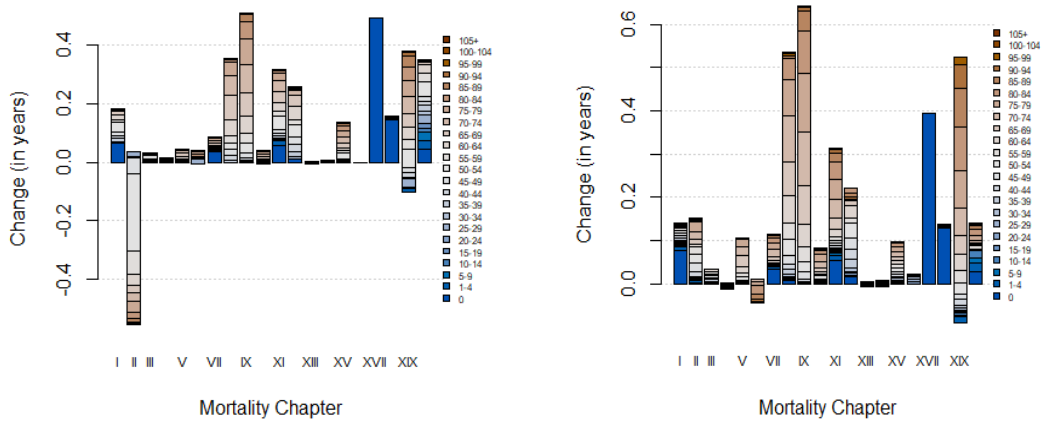

Fig. 1 Changes in LE per CoD and Age, 1970-1984 (France, males *vs.* females)

Figure 1 shows the estimated changes in LE per mortality chapter for the time interval being analyzed. The overall size of the bars represents the total variations estimated (axis *y*) for the mortality chapters (axis *x*). Every bar is divided in smaller segments with changing colors, representing where the overall change comes from in terms of contributing age groups. When a particular bar has a section in both the positive and negative quadrants, it shows that some ages contributed to a decrease in life expectancy for that mortality chapter whereas other age groups contributed to a gain. An example of this is Mortality Chapter XIX for females (with an overall gain of 0.525 years).

3.1.2 1985-1998

Contrary to what happened in the previous term, from 1984 to 1998 LE increased more for males than for females in France (with increments of 3.58 years for men and 3.06 years for women). The variation in LE attributable to each age group suffered several changes in structure: the contribution attributable to the first year of life decreased greatly in both absolute and relative numbers and represented less than 9% of the overall change in both genders. Moreover, between 1984 and 1998, the structure of changes is inverted per gender: the total change in LE for men coming from ages younger than 65 consists of 61% (2.18 years) of the total variation whereas 39% comes from ages older than 65. For women, it is the opposite, since 37% of changes (1.14 years) come from age groups younger than 65 and 63% from seniors.

Regarding gains and losses in LE, we can see that from 1984 to 1998 France experienced, with great success, improvements in the treatment of diseases of the Circulatory System, which caused Mortality Chapter VIII to improve the indicator in 0.72 and 0.73 years for men and women, respectively. This puts in evidence an improvement in this cause of death much more significant than the one registered in the previous 14 years. The estimated increases in LE attributable to Cerebrovascular Diseases, which had registered a very prominent role in the previous term for both genders, continue to be relevant. In this period, this mortality chapter placed itself as the second and third main cause contributing to the enhanced indicator, for women and men. The estimations of gains due to this chapter yield half a year increment in LE for males and 0.66 years for females.

The mortality experience registered during this period also suggests important improvements in deaths caused by external causes, completing the top 3 contributors per mortality chapter. In this case, the gain years in life expectancy are more relevant for men than for women. These three causes of death are responsible for about 52% and 59% of the overall change in life expectancy during this period. Figure 2 shows this and other results.

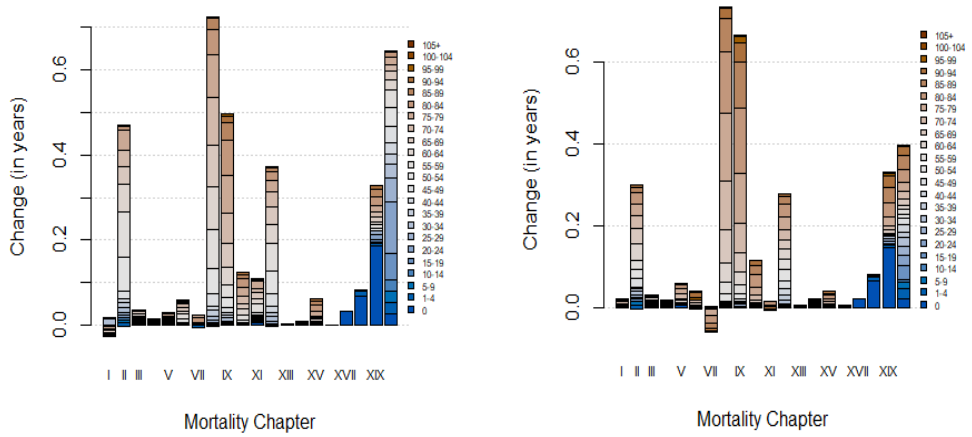

Fig. 2 Changes in LE per CoD and Age, 1985-1988 (France, males *vs.* females)

3.1.3 1999-2013

From 1999 to 2013, once again, the French population saw an important improvement in their LE. By the end of this period, like in the previous term, French men experienced a more significant increase than French women - men improved their LE in 4.05 years whereas women did so by 2.7 years. Moreover, not only did men see a more prominent improvement in the indicator for the second consecutive term, but also the difference when compared with the gains in the case of women are much more notable: 1.35 years higher than that of French women (as opposed to half a year in the previous term). This certainly contributed to a reduction in the gender gap.

The changes in LE during this period confirm the tendency detected previously: the improvements attributable to young ages start to lose relative importance as the mortality improvements start to come from the longevity of the elderly. During these 14 years, only 3% of the variation is attributable to changes in mortality of newborns for males (4% for females) whereas ages younger than 65 contributed with 47% of the overall change in the case of males and 30% in the case of females. Moreover, the variations attributable to senior ages amount to 2.1 years for males and 1.8 years for females. In this sense, the change in the structure becomes more relevant in the case of French men as they seem to keep up better with female mortality at older ages.

During these years, life expectancy was primarily improved due to the influence of Mortality Chapter II, Malignant Neoplasm, which generated an improvement of 1.14 years in LE for men. The evolution of mortality due to Heart Diseases continued to affect positively life expectancy for both genders (with an estimated attribution of 0.89 years of increase in the indicator for men and 0.78 years for women). Deaths due to external causes (Mortality Chapter XX) also helped to increase LE. Improvements related to Respiratory Diseases started to be more prominent during this term whereas causes such as Mental Disorders and Nervous System Disorders (Mortality Chapters VI and VII) caused subtle decreases in life expectancy.

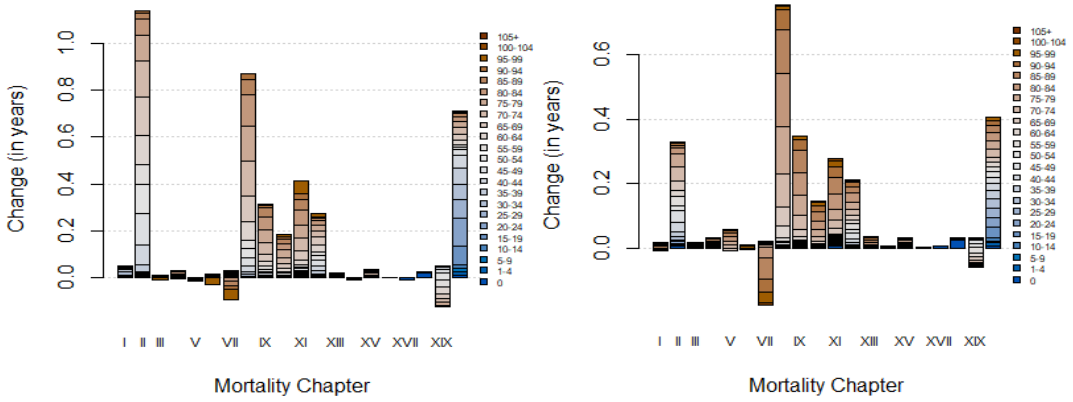

Fig. 3 Changes in LE per CoD and Age, 1999-2013 (France, males *vs.* females)

3.2 Life Expectancy at Birth in Czech Republic

In the case of Czech Republic, LE increased 9.03 years for males and 8.09 for females between 1970 and 2013, going from 66.04 years and 73.99 years for males and females, respectively, to 75.07 and 81.08 years. The causes of these variations, like in the case of France, seem to vary in time as mortality evolves per age and cause of death.

3.2.1 1970-1984

The change in LE in Czech Republic from 1970 and 1984 was very similar for both genders and reached 1.3 years in the case of males and 1.51 for females. Around a year of the change is estimated to have been generated by mortality changes in age groups younger than 65, which causes age groups over 65 to contribute in a much less significant manner during these years.

Mortality improvements in respiratory diseases are estimated to be among the main drivers of the increase for Czech Republic during this period for both genders, generating an estimated gain in LE of half a year for males and 0.43 years for females. Another main cause of death contributing to the enhancement of the indicator is also shared by both genders: mortality changes originating in Mortality Chapter XVII, Conditions of the Perinatal Period, which increased life expectancy in 0.36 and 0.33 years for males and females. All this variation is attributable to age 0. Improvements related to deaths caused by accidents, homicides, suicides, poisonings and the like (as defined in Mortality Chapter XX) contributed also in a great manner. This chapter is estimated to have generated 0.63 extra years of LE in the case of males (being the main cause explaining the increase in this case) and 0.19 extra years for females. Some chapters, however, are estimated to cause losses in LE for both genders during this time interval. Among them one finds Malignant Neoplasms and

Deaths related to Other Circulatory Diseases (Mortality Chapter X), estimated to have contributed to a loss in LE of 0.16 (males) and 0.1 years (females).

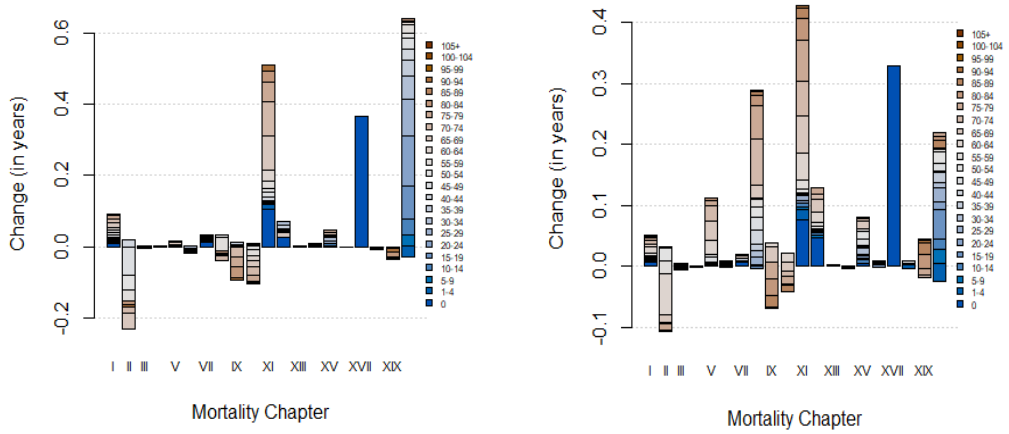

Fig. 4 Changes in LE per CoD and Age, 1970-1984 (Czech Republic, males *vs.* females)

3.2.2 1985-1998

Mortality improvements were much more significant during this fourteen-year period, which lead to a life expectancy increase of 3.71 years for males and 3.49 years for females. Again, mortality improvements for newborns are estimated to be the main driver in these changes, generating an estimated attributable LE of 0.72 years for males and 0.55 years for females. Despite this fact, age groups younger than 65 became, in relative terms, less "important" when compared to the previous period. Nevertheless, they continued to be the main driver in the change and their absolute contributions increased, generating 2.42 and 1.69 extra years in LE for men and women, respectively. This means that the contributions of changes in ages 65 and older represented only 35% of the variation for men but amount to 51% for women.

When analyzing the changes per mortality chapter, the estimated main contributors seem to be different from the ones in the previous period. In the case of males, mortality improvements in causes of death included in Mortality Chapter VIII, Heart Diseases, are the most relevant: they are estimated to have contributed with 1.10 years of extra LE. These improvements are registered mostly in ages from 45 to 74 years old. The influence of these groups is estimated to explain 0.83 years of the overall gains in this mortality chapter, showing that death rates associated to these causes improved greatly for adults mostly. Improvements in Cerebrovascular Diseases also seem to be central in the increase in LE. Their effect for men amounts to a gain of 0.67 years in the indicator. Respiratory diseases are also a major contributor in this case, generating 0.38 extra years of LE for males.

In the case of women, mortality improvements in Cerebrovascular Diseases are considered to be the main driver of the improvement with an estimated effect of 0.89 extra years in LE. It is worth noting that 0.69 years out of total improvement come from mortality changes registered at ages over 65. Heart Disease comes second and generated an estimated 0.80 extra years. Conditions of the perinatal period also played a central role and caused an estimated increased in the indicator of over a quarter of a year.

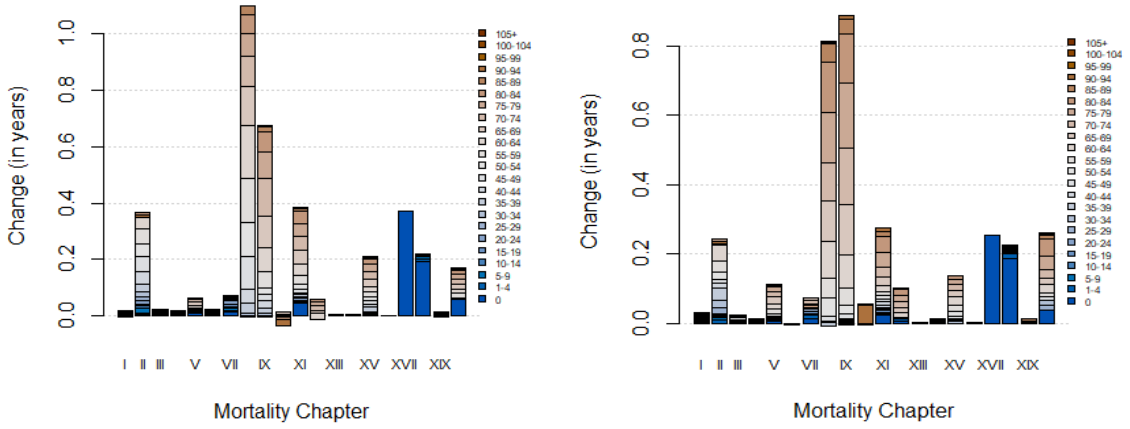

Fig. 5 Changes in LE per CoD and Age, 1985-1998 (Czech Republic, males *vs.* females)

3.2.3 1999-2013

From 1998 to 2013 LE in Czech Republic took another big leap (in fact the largest in the entire period for males). The increase in LE during this time was 4.02 years for males and 3.09 years for females. Despite having registered a lower improvement in mortality at birth, the contributions of age groups younger than 65 continue to be the most relevant in the case of males, representing a total gain of 2.28 years out of the overall change (or around 57%). In the case of females, the changes attributable to these age groups have lost importance in overall terms and amounted to less than 36% (over one year) of the total variation. This evidence shows that women were already experiencing major mortality improvements in senior ages while men were still experiencing major changes in younger age groups. In general terms, Czech Republic men seem to be slowly shifting to a pattern that should be more aligned with that of women in the years to come, but this shift seems to be happening at a much slower pace than with French men.

The effects registered per cause of death show subtle differences based on gender. Males increased their LE mostly due to improvements in mortality related to Malignant Neoplasms (generating 1.16 extra years out of which 64% is caused by age groups younger than 65). Heart Diseases also contributed greatly (0.89 extra years) whereas Cerebrovascular Diseases came third in importance (0.69 extra years).

For females, the main chapter contributing to changes is Cerebrovascular Diseases (0.93 additional years), followed closely by Mortality Chapter X, Other Circulatory Diseases (0.89 years). Malignant Neoplasms close the group of the three major contributors, generating an estimated increase in LE of 0.67 years. Together these three Mortality Chapters explain 70% of the overall improvement in the indicator for males and 82% for females. In Table A.2 in the annex the detailed results are presented.

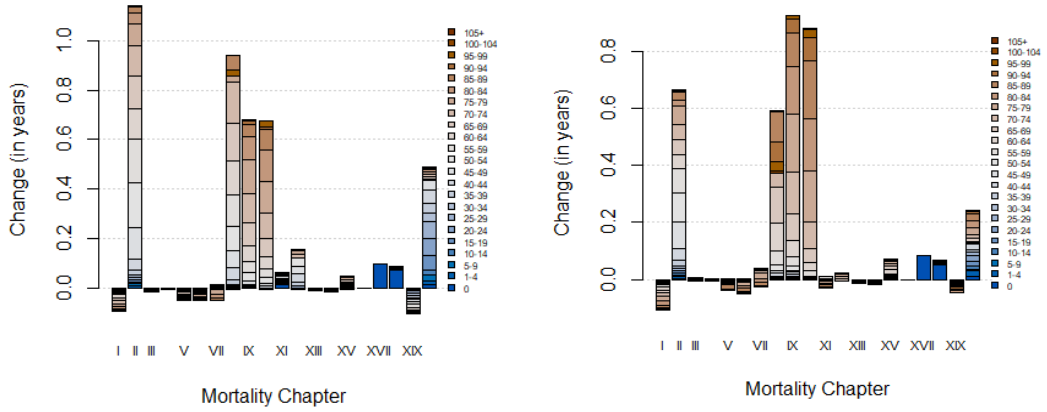

Fig. 6 Changes in LE per CoD and Age, 1999-2013 (Czech Republic, males *vs.* females)

3.3 Life Expectancy at Birth in the United States of America

The United States saw their LE grow from 67.02 years for males and 74.65 for females in 1970 to 76.6 years and 81.3 years in 2013. One remarkable aspect about these changes is that, out of the three countries being studied, U.S. was the country to decrease the most the gender gap during this time period. For now, just like in the case of France and Czech Republic, the focus will be placed on the sources of changes in LE.

3.3.1 1970-1984

LE in the United States experienced a great improvement from 1970 to 1984. The indicator for males increased 4.1 years and 3.52 years for females. The most relevant change in mortality, attributed to a single age group, was the one registered at age 0, which is responsible for an estimated increase in LE of 0.8 and 0.66 years for males and females, respectively. Mortality changes at the age groups younger than 65 are responsible for most of the improvement in the indicator for this period in both genders, representing a total increase of 3.11 and 2.11 extra years of LE for US men and women. In the case of senior ages, the evolution was much less expressive during this period and amounted to an improvement in the indicator of 0.98 and 1.4 years, respectively.

A big part of the positive experience in LE in the United States during this period is estimated to have come from the country's success in fighting Heart Diseases, generating a reduction in deaths high enough to increase LE by 1.47 and 1.25 years for males and females. In the particular case of US women, the mortality reductions in Cerebrovascular Diseases and in Conditions of Perinatal Period contributed to increase LE by 0.75 and 0.43 years, respectively. For males, a very relevant improvement comes from a reduction of deaths related to accidents, homicides, suicides, poisonings and the like, which generated an additional 0.74 years of LE. Changes in mortality in conditions associated to perinatal period also became a major contributor in case of men. The estimated decomposition of the changes in LE per Mortality Chapter, for all chapters, is presented below.

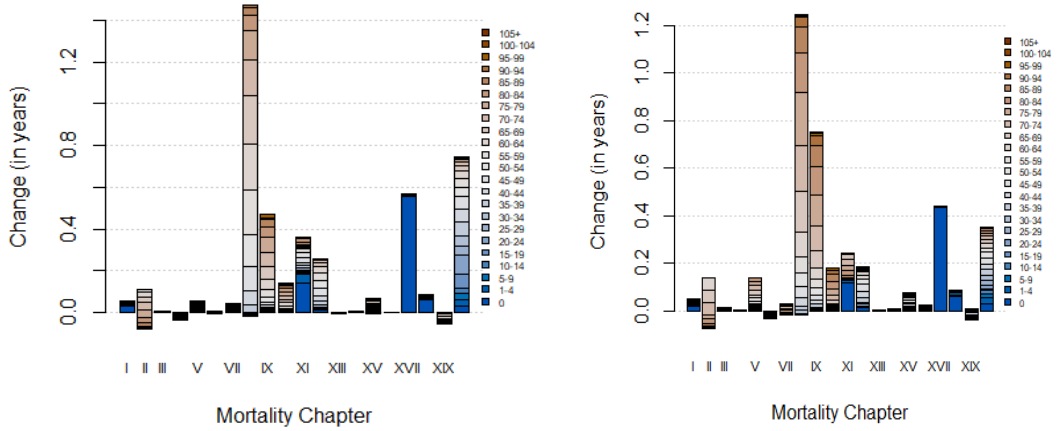

Fig. 7 Changes in LE per CoD and Age, 1970-1984 (USA, males *vs.* females)

3.3.2 1985-1998

This period was characterized by more modest increases in LE (2.69 year increase for males and 1.26 extra years for females). Out of the overall 2.69 additional years estimated for males, 1.66 years are attributable to mortality improvements registered for ages below 65. For females, these age groups represented 0.84 additional years of LE, out of the total 1.26 years. Because of this, during this time period, most improvements in LE are estimated to be generated by these younger age groups, representing in both genders over 60% of the overall change.

In general terms, the major improvement in LE, related to a mortality chapter, was gained in men due to a reduction of deaths caused by Heart Diseases (generating an increase of around 1.5 years). For females, the attributable effect of Mortality Chapter VIII is also the most relevant (one year in this period). Another relevant gain in the indicator is estimated to have happened in the case of men, due to a reduction in the death rates associated to Mortality Chapter XX.

It is worth noting that Mortality Chapter XI, Respiratory Diseases, was responsible for a decrease in LE for females in the United States from 1984 to 1998, generating a reduction in the indicator of around a quarter of a year. This phenomenon explains a part of the advantage in favor of males registered during this period, which - together with the stronger improvement in mortality related to heart disease registered for males - explains about 0.75 years of the additional LE gained by US men during this period, when compared to women.

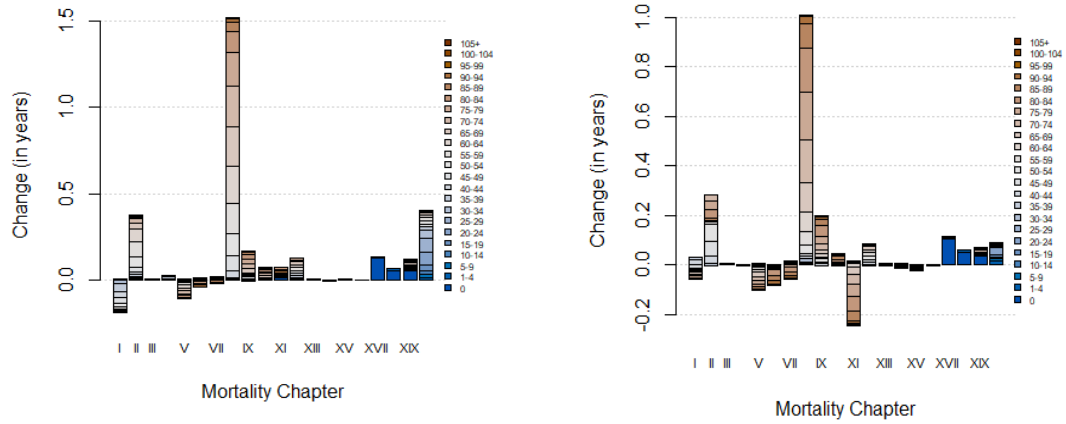

Fig. 8 Changes in LE per CoD and Age, 1985-1988 (USA, males *vs.* females)

3.3.3 1999-2013

In this period, increases in LE reached 2.8 and 1.9 years for males and females. These variations are much closer to those registered in 1970-1984. However, during these years, USA seems to have entered a new stage in their LE dynamics: one in which LE is driven by mortality improvements in senior ages, as treatments and prevention focuses more on retirees and individuals of more advanced ages. Mortality improvements in senior age groups are estimated to have contributed with 1.78 years of additional LE for males and 1.32 years for females. This represents 65% and 69% of the overall change and shows a total shift in the pattern found previously. The fight against Heart Diseases and Malignant Neoplasms seems to be the main drivers of the increase in LE during this new phase. These two mortality chapters are, for both genders, the two main sources of gains. In the case of Heart Diseases, they are estimated to have increased LE by 1.25 years for US females and 1.36 in the case of males. In the case of Mortality Chapter II, Malignant Neoplasms, the effect is very similar for both genders, generating a gain estimated in 0.74 extra years of life for females (and 0.77 years for males).

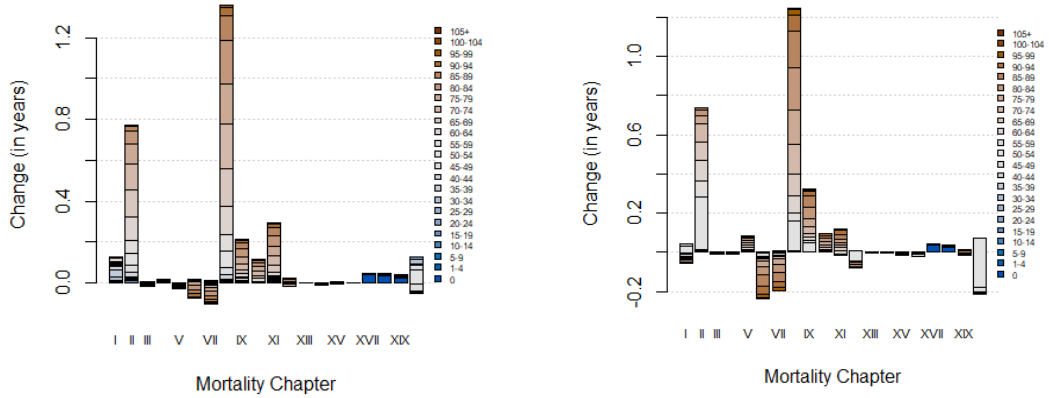

Fig. 9 Changes in LE per CoD and Age, 1989-2013 (USA, males *vs.* females)

The detailed numbers of the decomposition of changes in LE in the USA are presented in Table A.3 of the annex.

4. Conclusions

Judging by the findings in France, Czech Republic and United States, it seems that the evolution and increases in LE follows a tendency: improving mortality at birth is clearly an essential first step to enhance LE in any country. Once this is achieved, countries move to improve survival at younger ages (say ages younger than 65) so that mortality is reduced for these age groups. Finally, they have just one way to continue to a more "advanced stage": once they reach a "high enough" LE, improvements start to come from extending the life of seniors and reducing the effects of the diseases that affect them the most. It seems that women are the first segment of the population to reach this final stage in a country, but males are keeping up, seeing in general terms higher improvements in LE. France and United States seemed to be in this stage already for both genders by 2013. In the case of Czech Republic, women had reached this level while men still saw most increases in LE due to mortality changes in ages younger than 65.

Focusing only on four mortality chapters, one could explain at least 60% of the variations in LE in the three countries. No matter the geography or gender, it seems that increasing effectiveness to reduce mortality related to Heart Diseases, Malignant Neoplasms, Cerebrovascular Diseases and External Causes have become the key to maintain increasing levels of LE from 1970 to 2013. In the case of French males, the influence of the reduction in mortality rates due to Diseases of the Digestive System has also played a major role in this time interval, gaining an estimated 0.89 years during the period. In the case of Czech Republic, mortality chapter X has also become a very significant source of increases in life expectancy for females (0.90 years).

On one hand, it is relevant to point out that USA was the country to decrease the most the gender gap in LE, reducing the difference in the indicator between males and females in 2.86 years from 1970 to 2013. On the other, Czech Republic decreased the gender gap the least out of the three country and registered a change of less than a year. This phenomena will be analyzed more in depth in a work to follow.

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Annex

Table 1 - Decomposition of changes in LE, in years, per mortality chapter (France)

Mortality Chapters	1970-1984		1984-1998		1998-2013		1970-2013	
	Males	Females	Males	Females	Males	Females	Males	Females
I - Infectious diseases	0,1743	0,1324	0,0006	0,0191	0,0402	-0,0065	0,2151	0,1450
II - Malignant neoplasm	-0,5536	0,1482	0,4669	0,3001	1,1388	0,3398	1,0521	0,7881
III - Other neoplasm	0,0304	0,0342	0,0343	0,0271	-0,0101	0,0105	0,0546	0,0718
IV-Diseases of blood	0,0029	-0,0119	0,0145	0,0178	0,0423	0,0407	0,0597	0,0466
V- Endocrine/Nutritional	0,0415	0,1053	0,0289	0,0547	-0,0028	0,0568	0,0676	0,2168
VI - Mental disorders	0,0138	-0,0444	0,0537	0,0187	-0,0267	-0,0051	0,0408	-0,0308
VII - Nervous system	0,0866	0,1141	0,0001	-0,0585	-0,0942	-0,1758	-0,0075	-0,1202
VIII - Heart disease	0,3524	0,5272	0,7238	0,7337	0,8905	0,7844	1,9667	2,0453
IX - Cerebrovascular disease	0,5097	0,6421	0,4955	0,6651	0,3124	0,4751	1,3176	1,7823
X - Other circulatory diseases	0,0416	0,0805	0,1244	0,1169	0,1966	0,1447	0,3626	0,3421
XI - Respiratory diseases	0,3136	0,3125	0,1050	-0,0080	0,4249	0,2843	0,8435	0,5888
XII - Disease of digestive system	0,2464	0,1927	0,3726	0,2773	0,2797	0,2209	0,8987	0,6909
XIII - Diseases of the skin	-0,0056	-0,0057	0,0019	0,0048	0,0224	0,0364	0,0187	0,0355
XIV - Diseases of the musculoskeletal system	0,0025	-0,0058	0,0073	0,0198	-0,0064	0,0068	0,0034	0,0208
XV - Diseases of the genitourinary system	0,1371	0,0985	0,0617	0,0396	0,0438	0,0311	0,2426	0,1692
XVI - Complications of pregnancy/childbirth	0,0000	0,0222	0,0000	0,0049	0,0100	0,0036	0,0100	0,0307
XVII - Conditions of perinatal period	0,4930	0,3957	0,0319	0,0220	-0,0087	0,0059	0,5162	0,4236
XVIII - Congenital malformations	0,1586	0,1380	0,0817	0,0760	0,0371	0,0273	0,2774	0,2413
XIX - Ill-defined or unknown	0,3800	0,5249	0,3295	0,3316	-0,1064	-0,0525	0,6031	0,8040
XX - External causes	0,3449	0,1397	0,6456	0,3981	0,8622	0,4721	1,8527	1,0099
Total increase	2,7701	3,5404	3,5799	3,0608	4,0456	2,7005	10,3956	9,3017

Table 2 - Decomposition of changes in LE, in years, per mortality chapter (Czech Republic)

Mortality Chapters	1970-1984		1984-1998		1998-2013		1970-1984	
	Males	Females	Males	Females	Males	Females	Males	Females
I - Infectious diseases	0.0911	0.0505	0.0174	0.0308	-0,0882	-0,1046	0,0203	-0,0233
II - Malignant neoplasm	-0.1623	-0.0941	0.3554	0.2376	1,1585	0,6727	1,3315	0,8162
III - Other neoplasm	-0.0020	-0.0005	0.0215	0.0249	-0,0127	-0,0042	0,0068	0,0202
IV-Diseases of blood	-0.0015	0.0019	0.0159	0.0152	-0,0025	-0,0061	0,0118	0,0110
V- Endocrine/Nutritional	0.0015	0.1112	0.0613	0.1117	-0,042	-0,0372	0,0208	0,1857
VI - Mental disorders	-0.0172	0.0094	0.0206	-0.0009	-0,0451	-0,0505	-0,0417	-0,0420
VII - Nervous system	0.0259	0.0206	0.0581	0.0458	-0,0463	-0,0252	0,0376	0,0412
VIII - Heart disease	-0.0201	0.2883	1.0996	0.8077	0,8909	0,3888	1,9604	1,4848
IX - Cerebrovascular disease	-0.0866	-0.0689	0.6744	0.8859	0,6877	0,9325	1,2656	1,7495
X - Other circulatory diseases	-0.1019	-0.0290	-0.0140	0.0565	0,6627	0,8868	0,5368	0,9143
XI - Respiratory diseases	0.4918	0.4265	0.3788	0.2638	0,0529	-0,03	0,9236	0,6603
XII - Disease of digestive system	0.0491	0.1292	0.0583	0.1012	0,1766	0,0309	0,2639	0,2613
XIII - Diseases of the skin	-0.0001	0.0030	0.0034	0.0029	-0,0093	-0,014	-0,006	-0,0081
XIV - Diseases of the musculoskeletal system	0.0062	0.0010	0.0020	0.0147	-0,0129	-0,0174	-0,0047	-0,0017
XV - Diseases of the genitourinary system	0.0458	0.0776	0.2048	0.1374	0,0606	0,074	0,3012	0,2890
XVI - Complications of pregnancy/childbirth	0.0000	0.0095	0.0000	0.0043	0	-0,0009	0	0,0129
XVII - Conditions of perinatal period	0.3644	0.3278	0.3701	0.2552	0,098	0,0837	0,8325	0,6667
XVIII - Congenital malformations	-0.0010	0.0102	0.2168	0.2254	0,091	0,0509	0,2969	0,2865
XIX - Ill-defined or unknown	-0.0163	0.0440	-0.0022	0.0137	-0,0964	-0,0128	-0,1149	0,0449
XX - External causes	0.6333	0.1918	0.1676	0.2564	0,4966	0,2723	1,2876	0,7205
Total increase	1.3000	1.5100	3.7100	3.4900	4,0201	3,0897	9,0300	8,0899

Table 3 - Decomposition of changes in LE, in years, per mortality chapter (USA)

Mortality Chapters	1970-1984		1985-1998		1999-2013		1970-2013	
	Males	Females	Males	Females	Males	Females	Males	Females
I - Infectious diseases	0.0319	0.0225	-0.1847	-0.0595	0.0819	-0.0583	-0.0709	-0.0953
II - Malignant neoplasm	-0.0759	-0.0708	0.3567	0.1757	0.7711	0.7400	1.0519	0.8450
III - Other neoplasm	0.0058	0.0109	0.0047	0.0052	-0.0154	-0.0115	-0.0050	0.0046
IV-Diseases of blood	-0.0330	0.0007	0.0269	-0.0034	0.0190	0.0004	0.0129	-0.0023
V- Endocrine/Nutritional	0.0566	0.1378	-0.1100	-0.1036	-0.0141	0.0830	-0.0676	0.1173
VI - Mental disorders	-0.0047	-0.0308	-0.0396	-0.0845	-0.0762	-0.2340	-0.1205	-0.3494
VII - Nervous system	0.0137	-0.0147	-0.0195	-0.0582	-0.1003	-0.1962	-0.1061	-0.2691
VIII - Heart disease	1.4720	1.2454	1.5166	1.0075	1.3585	1.2445	4.3471	3.4974
IX - Cerebrovascular disease	0.4717	0.7503	0.1709	0.1979	0.2149	0.3214	0.8575	1.2696
X - Other circulatory diseases	0.1397	0.1804	0.0731	0.0461	0.1188	0.0977	0.3316	0.3242
XI - Respiratory diseases	0.3099	0.1306	0.0344	-0.2431	0.2973	0.1205	0.6417	0.0080
XII - Disease of digestive system	0.2539	0.1788	0.1286	0.0820	0.0189	-0.0427	0.4014	0.2181
XIII - Diseases of the skin	-0.0028	0.0006	0.0043	0.0068	-0.0002	-0.0037	0.0013	0.0037
XIV - Diseases of the musculoskeletal system	0.0042	0.0026	-0.0042	-0.0119	-0.0087	0.0044	-0.0087	-0.0050
XV - Diseases of the genitourinary system	0.0664	0.0625	0.0089	-0.0230	0.0040	-0.0007	0.0792	0.0387
XVI - Complications of pregnancy/childbirth	0.0000	0.0238	0.0000	-0.0026	0.0000	-0.0202	0.0000	0.0010
XVII - Conditions of perinatal period	0.5599	0.4336	0.1344	0.1131	0.0442	0.0414	0.7385	0.5882
XVIII - Congenital malformations	0.0870	0.0897	0.0666	0.0590	0.0474	0.0384	0.2010	0.1870
XIX - Ill-defined or unknown	-0.0008	0.0117	0.1229	0.0689	0.0318	-0.0127	0.1538	0.0679
XX - External causes	0.7446	0.3543	0.3991	0.0880	-0.0428	-0.2116	1.1009	0.2307
Total increase	4.1000	3.5199	2.6901	1.2602	2.7500	1.9001	9.5401	6.6802