DISABILITY FREE LIFE EXPECTANCY DECOMPOSITION: A COMPARATIVE ANALYSIS ACROSS EUROPEAN COUNTRIES

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Abstract. Life expectancies (LE) at birth and at adult ages have progressively increased in recent decades in Europe. LE is a quantitative indicator and therefore it provides a limited view of the status of the population, ignoring the weight and the effects that the health condition has on the years that remain to live. To address this issue, we refer to Disability Free Life Expectancy (DFLE) indicating the average number of years a person of a given age *x* expects to live in good health. In this paper we analyse the change in LE and DFLE at age 65 from 2004 to 2016 for a set of the most long-lived European countries, as well as for male and female populations in order to highlight gender differences. Then we quantify the extent by which age-specific mortality and morbidity contribute to changes in DFLE for understanding whether the trends observed are due to compression/expansion of morbidity or to variation in mortality patterns. This goal is important both for health policies planning and for sustainability of socio-economic and social security systems. DFLE is calculated using the Sullivan method, measuring disability in terms of the Global Activity Limitation Indicator (GALI). We refer both to step-wise and continuous change techniques for DFLE decomposition. Data sources are Human Mortality Database (HMD) for mortality rates and the European Health Life Expectancy Information System (EHLEIS) for prevalence rates. Results show that all the countries under examination present a stronger increase in LE at age 65 for men than for women. A positive variation in DFLE occurs for Belgium, Sweden, Norway, and Finland. A negative gap in DFLE is identified for Italy, Switzerland, and Spain, meaning that people lived longer but in poorer health conditions. Finally, age-specific mortality and morbidity contributions to the DFLE gaps are highlighted with an innovative visualization tool that allows to pursue a comparative analysis across countries.

1. Introduction

The aging of the population can be considered a success of the globalization, yet it represents an important challenge for governments especially with respect to retirement and welfare policies. For instance, the impact that the lengthening of life could have on the job market emerges when we observe the trend of the elderly dependency rate defined as the ratio between the population aged 65 and over, and the population in working age (15-64 years), multiplied by 100. Data for Italy (released by the National Institute of Statistics - ISTAT) record an acceleration in the increasing trend: specifically, from a value of 30 in 2004, to a value of 34,5 in 2016, up to a value of 37 in 2021.

Thus, it is equally important to value the elderly people, since they constitute a growing component of the population, and to take the longevity risk into account when designing welfare policies. From the individuals' point of view, aging can be perceived as a process that leads to uselessness. Therefore, a new rationale is advocated, based on the idea that the aging phenomenon can be an opportunity to find new ways to thrive and not only as a catastrophic event. In this framework, the study of the elderly of today (and even more of those of tomorrow) has to go beyond the quantitative perspective of age, using dynamic indicators that consider parameters that change over time, such as the state of health and socio-economic conditions. The World Health Organization (WHO) has introduced the term *active aging* understood as the "*process of optimizing opportunities for health, participation and security to gradually improve the quality of life as people get older*". The term "*active*" implies not only the ability to be physically involved but above all a constant participation in the social, economic, and cultural life (WHO, 2002).

Life expectancy (LE) is a widely used tool to assess the well-being of a population. It is a quantitative indicator and represents a measure of how long, on average, a person of a given age x can expect to live, assuming constant age-specific mortality rates; however, it does not give us any information on the quality of these years. The need arises to search for additional measures that could reveal the state of well-being of a population in qualitative terms. To meet this need, in the 70s Sullivan (Sullivan, 1971) proposed a method to calculate the number of remaining years, at a particular age, which an individual can expect to live in a healthy state.

When we talk about Healthy Life Expectancy (HLE) we refer to a family of indicators relating to life expectancy for a given state of health, the most common of which for studying the state of well-being at older ages is the Disability-Free Life Expectancy (DFLE). DFLE (called Healthy Life Years (HLY) according to the Eurostat definition) is a standardized indicator based on the study of limitations in carrying out daily activities. In recent years, many studies have been devoted to the

measurement of the components that determine the life expectancy in health. In particular, researchers have provided tools that allow to establish how much these components influence the differences in LE and DFLE for different populations, or for the same population at different times (Van Raalte and Nepomuceno, 2020). In this regard, the main interest lies in assessing the extent by which these variations are due to changes in morbidity or to changes in mortality (Vaupel, 1986). For this purpose, to the best of our knowledge there are two main methodologies: the step-wise decomposition algorithm (Andreev *et al*., 2002) and the continuous change technique (Horiuchi *et al*., 2008).

In this paper we contribute to the state of the art on the topics by presenting a comparative analysis of the evolution of DFLE at age 65, calculated by the Sullivan's method for a set of European countries selected among the most long-lived ones. Age 65 has been chosen since historically it is an approximate benchmark for retirement in several countries. In details, we first calculate the variation in both LE and DFLE from 2004 to 2016 and assess the evolution of the gender gap for both indicators. Some previous studies in this respect have been conducted for European countries by Robine *et al*., 2001, and for the United States in Crimmins *et al*., 1997. Then we quantify the age-specific contributions of morbidity and mortality to the gap in DFLE between the two time periods, for both male and female populations and for each country. Results are presented with simple yet original graphical tools.

The reminder of the paper is organised as follows: a brief introduction to LE and DFLE is provided in Section 2, where the Sullivan's method is also described; decomposition methods for DFLE gap are shortly recalled in Section 3. Section 4 provides results and comments related to the comparative analysis across the selected countries of the evolution in LE and DFLE gaps for male and female populations. Then a discussion on the decomposition of the DFLE gap follows. Finally, Section 5 summarizes results and provides concluding remarks.

2. Life Expectancy and Healthy Life Expectancy: definition and calculation

As explained in the previous section, LE at age x represents the expected number of years an individual aged x can live. The main differences among the several methods that can be used to calculate this measure concern the calculation of the probability of survival in the first year of life and the determination of the top age ω of the mortality table. Given these premises, the life expectancy at age x, $e_{x,}$ is defined by:

$$e_x = \frac{1}{l_x}\sum_{i=x}^{\omega} L_i \qquad (1)$$

where l_x is the number of survivors at age *x*, and for each age $i = x, \dots, \omega$, L_i denotes the total number of *person-years* lived by the individuals from age i to age $i+1$. For L_i calculation, it is generally assumed that the l_{i+1} survivors at age $i+1$ contributes with a whole year, whereas each of the d_i individuals who die within the age interval *(i,i+1)* contributes with half a year on average, so that $L_i = l_{i+1} + 0.5\ d_i$. For details and examples, see https://www.lifeexpectancy.org/lifetable.shtml.

Starting from the definition of LE as "*the average number of years remaining to live*", it is possible to divide these remaining years of life into years spent in good or ill health. The concept of healthy life expectancies as health indicators was introduced for the first time by Sanders in 1964 (Sanders, 1964). Then Sullivan in 1971 proposed a method for DFLE calculation which is the most popular and widely used still today to study the state of well-being at older ages. Sullivan's method assumes that life follows a one-way process from good health to death, passing through a state of ill-health.

DFLE is a standardized indicator based on the study of limitations in carrying out daily activities. For its determination by Sullivan's method, morbidity data as age-specific and health condition-specific prevalence rates are needed, along with age-specific mortality rates. In the following, we refer to the Human Mortality Database to obtain the mortality rates (HMD, 2023) and to the European Health Life Expectancy Information System (EHLEIS) for prevalence rates. In particular, disability is measured starting from the Global Activity Limitation Indicator (GALI) obtained by surveying the following question: *"Because of health problems, to what extent do you have limitations, which last for at least 6 months, in the activities that you usually carry out?".* Response options are: *"Serious limitations", "Minor limitations", "No limitations"*. These measurements are collected within the European Statistics on Income and Living Conditions survey (EU-SILC). Then, since Sullivan's Index requires a binary variable (presence/absence of disease, presence/absence of disability and so on), the response variable is dichotomized into two categories*: "No limitations"* and *"With some Limitations"*.

As a matter of fact, GALI is a subjective indicator: people affected by the same pathologies can report levels of different functional capabilities. For this reason, among others, its reliability can be argued (Berger *et al.*, 2015). Nevertheless, it allows to grasp how much the restriction in activities affects the physical and mental state of people and, to the best of the Authors' knowledge, there are no alternative indicators with some property. Most importantly, subjective evaluations play an important role in accounting for active ageing in the assessment of health of the elderly, circumstance that must be taken into consideration when investigating our topics.

Hereafter, for each age *x*, we set:

1. ${}_nL_x$ = the number of person-years lived in the age interval *(x; x+n)*, (usually *n=5* is set, apart from the first two and the last age intervals). This measure is obtained summing the total person-years L_y for each single age *y* in the interval *(x; x+n);*
2. ${}_n\pi_x$ = the prevalence rate in ill health for the age interval *(x; x+n).*

Then, life expectancy in bad health at age *x* (*Unhealthy*) can be calculated as:

$$e_x^U = \frac{1}{l_x}\sum_{i=x}^{\omega} {}_nL_i \times {}_n\pi_i \quad (2)$$

whereas Life expectancy in good health (*Healthy*) is obtained as:

$$e_x^H = e_x - e_x^U = \frac{1}{l_x}\sum_{i=x}^{\omega} {}_nL_i\ (1-{}_n\pi_i). \quad (3)$$

Note that other methods can be used for DFLE calculation such as the multistate methods (Saito et al, 2014), according to the data source available (panel or cross sectional). Some criticisms of Sullivan's model are due to the fact that the underlying assumptions limit the representation of people's functional status to prevalence rates influenced by past conditions instead of using measures such as incidence rates allowing to calculate a pure current proportion of unhealthy people. Anyway, it has been shown that the differences in estimates between Sullivan's method and methods using incidence rates (panel data) do not arise from the use of prevalence rates, but from the use of prevalence estimates: indeed, these are influenced by past conditions, in an open population. However, Sullivan's method provides good estimates if the changes in either prevalence and incidence rates are regular over the long term (Mathers and Robine, 1997). In addition, the simplicity as well as the ability to use easily accessible data such as prevalence data make it the most popular and widely used method.

3. Decomposing the gap in DFLE

Decomposition is a widely exploited methodology in Demography to study the gap in an index by analysing the contribution of the variation of each of its components to the overall change. The gap can refer either to the same population in different time periods or to different populations in the same time period.

In other words, the problem of decomposition results in the attribution of the observed difference between two aggregated indexes for two populations (or the same population at different times) to the contribution of the underlying parameters. In the case of the Sullivan's Index, the decomposition allows to know the

contribution given by the variations in mortality and morbidity to the gap observed between two indices. In this way we can understand whether the trends observed for life expectancy in health at a given age are due to a compression/expansion of morbidity or variations in mortality for subsequent age intervals.

Two decomposition methods have been proposed in literature for the Sullivan's Index. The former is the *step-wise decomposition* introduced in Andreev *et al*. (2002). This procedure replaces one at a time each of the parameters (age-specific contribution of mortality and morbidity in the present study) referring to one population (or time period) with the elements of the parameter vector from the second population (or time period). After each step, it recalculates the DFLE to estimate the contribution of the substituted parameter. The latter is the *continuous change* or *line integral model* developed by Horiuchi *et al*. (2008). It assumes that age-specific mortality and morbidity contributions change continuously along a hypothetical dimension, along which decomposition is performed based on multiple smaller time intervals. Then, the procedure estimates the variations needed by parameters to change the final aggregate value of DFLE from one population to another, or if we refer to the same population, from a time period to another. For more deepening on the topics, see also Van Raalte and Nepomuceno (2020).

To the best of the Authors' knowledge, the implementation of both methods has produced similar results in all demographic applications: therefore we can consider that there is no valid reason to prefer one methodology over the other.

For each population, the decomposition of the DFLE gap between the two time periods has been performed by means of the 'DemoDecomp' R package (Riffe, 2018).

4. A comparative analysis across EU countries.

In this section we first calculate the LE and the DFLE at age of 65 for male and female populations by the Sullivan's method for years 2004 and 2016 and for each of the selected countries. Time periods have been chosen on the basis of the available data from the EU-SILC survey. Then, we decompose the DFLE variation from 2004 to 2016 to determine the extent by which the change in each parameter (morbidity/mortality) contributes to the overall gap in the index.

We considered some of the most long-lived EU countries: Norway, Sweden and Finland for the Northern Europe, Belgium and Switzerland for the Central Europe, and Spain and Italy for the Southern part. Ages between 65 and 110 have been grouped into 5-year age intervals, with the addition of an open range one (85+): note that both e_x and $DFLE_x$ refers to the beginning of each age interval.

Table 1 shows that all the countries under examination present an increase in LE at age 65, stronger for men than for women. Belgium, Sweden, Norway, and Finland show a positive variation of DFLE, which is very marked for Norway and Sweden. Conversely, Italy, Switzerland and Spain present a negative gap in the DFLE, meaning that people live longer but the years lived without limitation have decreased.

Table 1 – *Gap in LE and DFLE at age 65 from 2004 to 2016, by country.*

	Female		Male	
Country	ΔLE	ΔDFLE	ΔLE	ΔDFLE
ITA	1	-2,25715	1,67	-1,22397
BEL	1,38	1,45967	1,82	1,66155
CHE	0,83	-3,14947	1,39	-2,22867
ESP	1,67	-0,7016	1,85	-0,07262
FIN	1,11	0,68061	1,58	0,95315
NOR	0,95	2,05546	1,92	2,8602
SWE	0,86	2,38447	1,62	2,87648

Figure 1 displays country-specific gender gap in LE and DFLE in 2004 and in 2016 as points in a scatterplot: by assessing the distance to the bisector line, results indicate that gender gap slightly reduced from 2004 and 2016 for all countries in a similar way, for DFLE to a greater extent than for LE.

In order to grasp the relative importance of DFLE compared to LE, Figure 2 displays the ratio between these indicators in 2004 and in 2016. It follows that overall, there is no relevant variations between men and female populations. Countries can be grouped in two sets: the 'continental' ones, for which DFLE increased relative to LE from 2004 to 2016 (standing over the bisector line), and the Scandinavian ones (except for Finland), for which DFLE decreased relative to LE between the two time periods (standing below the bisector line).

Figure 1 – *Gender gap in $DFLE_{65}$ and LE_{65} in 2004 and 2016, by country.*

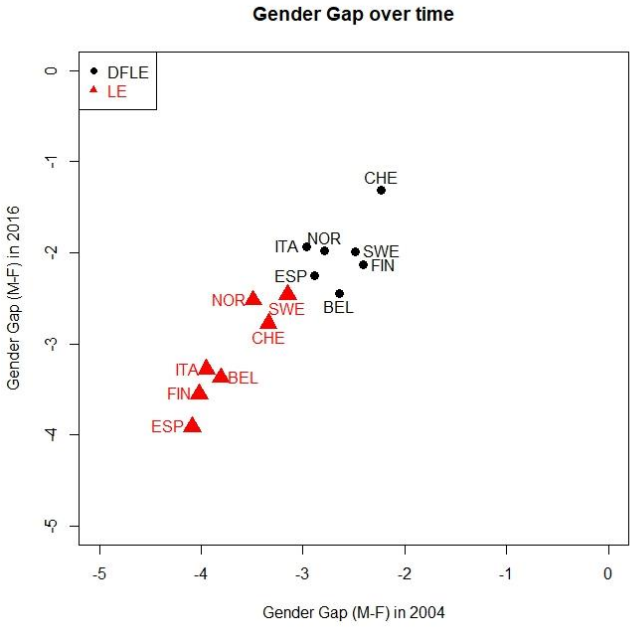
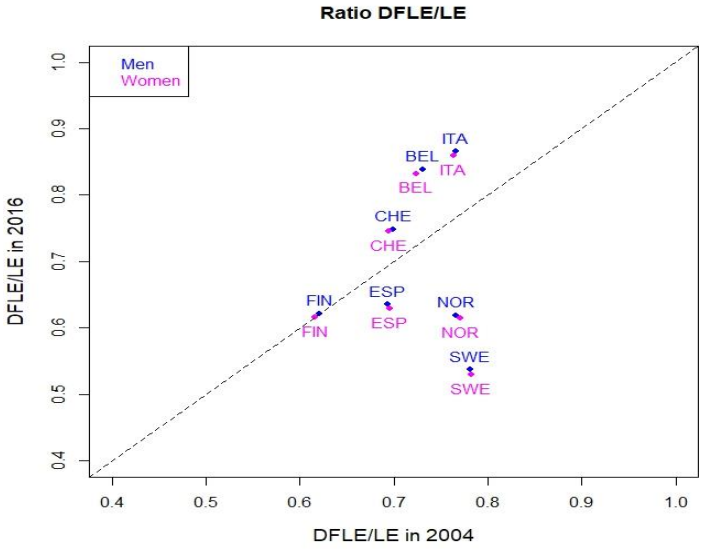
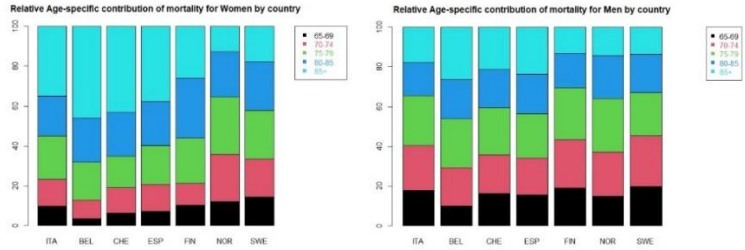


Figure 2 – *Ratio $DFLE_{65}/LE_{65}$ in 2004 and 2016, by country.*



For investigating to what extent mortality and morbidity have determined the overall variation in DFLE between 2004 and 2016, we performed the DFLE decomposition by the stepwise and the continuous change methods. As expected, we obtained similar results, so only those related to the stepwise method are reported. Figures 3 and 4 illustrate age-specific contributions of mortality and morbidity components to gap in DFLE at age 65 for women and men by country, relative to the total contribution of mortality and morbidity to DFLE gap, respectively. For mortality, the contribution of every age interval is positive, whereas for morbidity some negative values are observed. For this reason, Figure 4 considers the absolute value of age-specific contribution to morbidity, relative to their total. In order to preserve information about the sign of the contribution, dashed areas indicate negative variations.

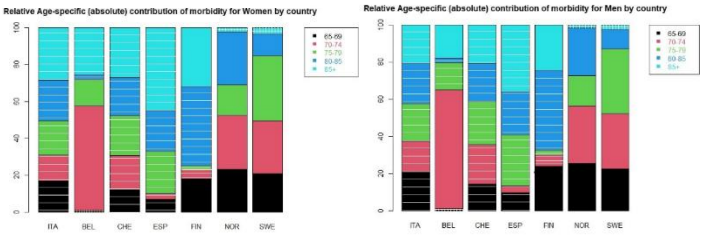
Figure 3 – *Age-specific contribution of mortality to gap in $DFLE_{65}$ by country.*



We can observe that the negative gap estimated for DFLE from 2004 to 2016 for Italy and Spain is mainly due to a significant worsening of morbidity (respect to the improvement in mortality) in all age groups for both men and women (especially in the 85+ range for women). The overall negative gap in the DFLE for Switzerland is due to a strong negative variation of the morbidity component compared to a lower improvement in mortality for all age groups, regardless of gender.

As far as Belgium, on one hand Figures 3 and 4 show that the positive DFLE gap for women is mainly determined by a strong improvement in morbidity in the 70-74 age group while for the 85+ age group mortality plays the main role. For the male population, instead, Figures 3 and 4 reveal that both morbidity and mortality improved, but mortality did so to a greater extent.

Figure 4 – *Age specific (absolute) contribution of morbidity to gap in $DFLE_{65}$ by country (dashed areas indicate negative variations).*



When we consider Finland, we observe that the positive gap in the DFLE is due to the improvement of mortality in all age groups and of morbidity in the 65-69 and 85+ ranges, despite the sharp worsening of morbidity in the 80-84 class for both males and females.

For Norway male population, we observe that the positive contribution of mortality is greater than that of morbidity in the 80-84 range; morbidity contributes negatively to the overall variation of the index only in the last age group. For females a similar conclusion can be drawn, with the difference that also in the 80-84 age group the morbidity contribution in the overall variation of the index is greater than that of mortality.

Finally, for Sweden we observe that, for both male and female populations, morbidity has contributed more strongly to the positive variation in DFLE with respect to mortality, which has improved in all age group. Only in the 85+ range a worsening of morbidity has been observed compared to an improvement in mortality, which is more significant for males than it is for females.

5. Concluding remarks

Given the longevity risk characterizing nowadays most of the developed countries, monitoring the evolution of life expectancy within the population is of foremost importance for public health, as well as for social security system and welfare, in order to promote also the so-called active ageing (Arriaga, 1984).

In this setting, the paper is framed within research on healthy life expectancy at older ages and its relative difference with life expectancy. A comparative analysis among a selection of long-lived EU countries and across gender allowed to reveal the extent by which mortality and morbidity improvements for age groups contribute to overall improvement in disability free life expectancy at age 65. Innovative

visualization of results of decomposition methods are proposed to foster monitoring of the evolution of these important demographic indicators over time and countries.

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