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THE ROLE OF EDUCATION FOR ASSESSING POPULATION HEALTH: AN ANALYSIS OF HEALTHY LIFE EXPECTANCY BY EDUCATIONAL ATTAINMENT FOR 16 EUROPEAN COUNTRIES

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Abstract

Healthy life expectancy (HLE) is a prominent summary indicator for evaluating and comparing the levels of population health status across Europe. Variations in HLE, however, do not necessarily reflect underlying differences in health and mortality levels among countries and are particularly sensitive when broken down by population subgroups. For instance, despite European countries showing large HLE inequalities by educational level, these countries are also highly heterogenous regarding their educational population composition, which most likely affects their HLE levels. We demonstrate how this compositional effect shapes HLE levels by providing HLE estimates of educational attainment and gender for 16 European countries using the Sullivan method. We use prevalence data about activities of daily living (ADLs) limitations from the European Union Statistics on Income and Living Conditions (EU-SILC) and mortality data from the Eurostat database. We then quantify the magnitude of educational inequalities based on the composite inequality index (CII). Finally, we express total HLE as the sum of education-specific HLEs, weighted by the educational population structure. As expected, we find large educational inequalities in HLE, with men's CII ranging from about 8.5 years in Portugal to approximately 3 years in Romania. For women, educational inequalities are slightly smaller. The decomposition reveals the population structure's strong effects on HLE, which can elicit misleading conclusions about people's health status and potentially turn HLE into an improper measure of educational differences as opposed to a measure of health gaps. For example, low-, medium-, and highly educated individuals in Portugal show more healthy life years than their counterparts in Poland. Still, Poland's total HLE value slightly exceeds that of Portugal, indicating favorable health and mortality conditions in Poland. However, Poland's greater relative number of highly educated individuals in its population is responsible for producing this higher total HLE value. We conclude that education is not only paramount for assessing health inequalities across European countries, but also the population composition by educational attainment, because it drives the differences in HLE levels.

Keywords

Health, mortality, educational inequalities, compositional effects, healthy life expectancy, life expectancy.

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The Role of Education for Assessing Population Health: An Analysis of Healthy Life Expectancy by Educational Attainment for 16 European Countries

Markus Sauerberg

1. Introduction

Health and mortality are well-documented as being strongly associated with socioeconomic factors, with individuals of higher socioeconomic status living longer and healthier lives than persons of lower socioeconomic status in both developed and developing countries (Mackenbach et al. 2017, Mackenbach et al. 2008, Preston and Taubman 1994, Beltrán-Sánchez and Andrade 2013). An individual's socioeconomic status can be measured through a multiplicity of factors, including income, wealth, education, and occupation. However, research consistently shows that, net of these other factors, educational attainment plays a prominent role in shaping health outcomes, since more educated individuals tend to avoid risky health behaviors (Brønnum-Hansen and Juel 2004, Cai et al. 2010, Pampel, Krueger and Denney 2010, Singer et al. 2019), are among the first to adopt and have access to medical technologies (Glied and Lleras-Muney 2008), and have lower levels of chronic and acute conditions (Castro 2012, Mirowsky and Ross 2003, Nusselder et al. 2005). Studies also demonstrate a strong educational gradient in both longevity and mortality compression, indicating that education attainment maximizes life chances by delaying the biological aging process (Brown et al. 2012). This evidence suggests that the relationship between education and population health might not only refer to simple correlations, but rather reflect a causal mechanism in which higher education directly translates into better population health through individual behavior and increased social capacity for population health (Davies et al. 2018, Brunello et al. 2015, Lutz and Kebede 2018, Fogel and Costa 1997). In addition, among all the socioeconomic factors, educational attainment has been identified as the single most important source of observable population heterogeneity that should be routinely added in any demographic analysis (Lutz and KC 2011). Consequently, research has consistently found substantial differences in terms of life expectancy (LE) as well as in the healthy life expectancy (HLE indicator) between educational subpopulations (Majer et al. 2010, Mäki et al. 2013), with educational inequalities in healthy life years surpassing those of total life expectancy (Crimmins and Cambois 2003).

Measures like life expectancy (LE) and healthy life expectancy (HLE) are well-known tools for assessing mortality and morbidity in Europe. While LE is a pure mortality indicator that reflects the expected number of *total life years*, HLE combines information on health and mortality to measure the expected number of *healthy life years* (Mathers 2002). In light of aging populations, HLE has become an increasingly relevant indicator of population health and sustainability level (Lutz, O'Neill and Scherbov 2001, Christensen et al. 2009). It directs health policies and measures health gaps between countries (Murray, Salomon and Mathers 2000). However, HLE indicators can limit cross-country comparisons due to their imperfect harmonization, i.e., differences in the collection of health data hinders the comparability of HLE estimates between countries (Ekholm and Brønnum-Hansen 2009, Brønnum-Hansen

2014). Thus, researchers have been working to better harmonize health data in order to measure population health across Europe more accurately (Bogaert et al. 2018, Jagger and Robine 2011). Further, Luy et al. (2020) show that variations in summary indicators such as LE or HLE do not necessarily reflect actual health and mortality differences over time or across countries. This is because several effects may potentially distort the comparability of HLE estimates, which particularly concerns population heterogeneity. Heterogeneity effects imply that members of a population do not all face the same health and mortality risks; therefore, a change in the population composition influences the HLE level (Guillot 2011). This has been shown to be especially important for education and its relationship to mortality and health, with evidence indicating that besides changing mortality, a large proportion of improvements to longevity might be arise from the changing population structure according to education level (Hendi 2017, Luy et al. 2019).

The aforementioned undeniable role of education in shaping health outcomes exemplifies how differences in the population composition by educational attainment are highly relevant for assessing population health on the basis of HLE. The HLE indicator can be seen as a population average, comprising several subpopulations with different health and mortality levels. Variations in HLE are therefore affected by differences in the population composition (i.e., the relative size of educational subpopulations in a given country) as well as by differences in the health and mortality levels (Vaupel and Canudas-Romo 2002). In other words, a country's HLE value might be comparatively high (or low) due to a higher (or lower) share of highly educated individuals as opposed to disparities in actual health and mortality levels.

In this paper, we derive gender-specific life tables on educational attainment for 16 European countries using Eurostat data. After combining the life tables with the prevalence of limitations in daily activities obtained from the EU-SILC 2016, we provide estimates of LE and HLE based on women and men's educational attainment in 16 European countries in 2016. The magnitude of educational inequalities in LE and HLE are measured using the composite inequality index (CII). Further, we express total HLE as the sum of the education-specific HLEs weighted by the educational population structure. This allows us to demonstrate how differences in the population composition affect HLE estimates in addition to differences in health and mortality levels. Finally, we discuss our results with respect to previous findings and summarize the main conclusions from this study.

2. Data and Method

2.1. Data

This analysis uses health and mortality data for European countries according to age, gender, and educational attainment. Since educational institutions and qualifications are difficult to compare across countries, different approaches have been introduced to measure educational attainment (Schneider 2010). In this analysis, we assess educational attainment according to the International Standard Classification of Education (ISCED). Individuals are defined as low educated when their highest level of attainment is lower secondary education or less (ISCED 0–ISCED 2). A medium education level includes upper secondary or post-secondary non-tertiary education (ISCED 3–ISCED 4). Those who attain tertiary education (ISCED 5–ISCED 8) are considered highly educated. The ISCED is suitable for the purpose of this paper, since Eurostat relies on this framework and provides several statistics, including health and mortality data, for discrete ISCED groups.

In our paper, health status refers to the observed prevalence of any reported, long-lasting daily living activity limitations, obtained from the European Union Statistics on Income and Living Conditions (EU-SILC). The Global Activity Limitation Indicator (GALI) is the official Eurostat HLE indicator[1] for monitoring health status, which defines individuals as healthy if they report no limitations at all. The GALI uses the following to determine such limitations:

> For at least the past 6 months, to what extent have you been limited because of a health problem in activities people usually do? Would you say you have been (1) severely limited, (2) limited but not severely, or (3) not limited at all?

The advantage of using the GALI instrument for estimating HLE is that it has been systematically assessed in order to obtain a harmonized health indicator, which enables comparing the level of population health over time and across European countries (Berger et al. 2016, Jagger et al. 2010, Van Oyen et al. 2006). While the harmonization is imperfect, GALI currently provides the highest degree of harmonization possible.

It should be noted that HLE is often used as an umbrella term, which includes several healthy life expectancy measures based on different health definitions (e.g., being disability-free, cognitively healthy, or active). The "Healthy Life Years" indicator (HLY) (e.g., Jagger and Robine 2011) defines health expectancy using the GALI as the underlying health indicator and is commonly used in EU policy and public health research. In order to avoid confusion, we do not distinguish between *HLE* and *HLY* and uses HLE consistently throughout this paper. In other words, we calculate and report HLY estimates in this paper, but nevertheless refer to them as HLE estimates.

This analysis uses mortality data from the Eurostat database[2], which are collected from national statistical institutes. Unfortunately, Eurostat does not provide complete period life

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1 https://ec.europa.eu/eurostat/cache/metadata/Annexes/hlth_hlye_esms_an1.pdf
2 https://ec.europa.eu/eurostat/data/database. A description of the metadata is given at https://ec.europa.eu/eurostat/cache/metadata/en/demo_mor_esms.htm.

tables stratified by level of education, which are required to estimate education-specific HLE indicators. However, Eurostat publishes age-specific estimates of remaining life expectancy by gender and educational attainment (as defined by the ISCED) for European countries that collect mortality data in this more detailed format. We derived the missing life table functions (i.e., the p_x, l_x, d_x, L_x, T_x functions) from their age-specific life expectancy estimates. Usually, the remaining life expectancy at a specific age x (e_x) is the outcome of a complete life table. In this paper, we use e_x to reconstruct the (complete) life table, i.e., we calculated the life table in reverse. After assuming that in each age interval x to $x+n$, people dying within this period live an average $\frac{n}{2}$ person-years ($a_x = \frac{n}{2}$), and using the life table function relationships (see Preston, Heuveline and Guillot 2001), we can express life table survivors l_{x+n} as:

(1) $$l_{x+n} = \frac{(l_x)^2 - 2 \cdot l_x \cdot T_x}{(e_x - e_{x+n}) 2 \cdot l_x - 2 \cdot T_x - l_x}$$

where l_x refers to the life table survivor at age x and T_x represents the number of person-years lived above age x, which is given by $T_x = e_x \cdot l_x$. Once l_x is estimated, the remaining life table functions can be easily derived, such as the probability of surviving to age x (p_x):

(2) $$p_x = \frac{l_{x+n}}{l_x}$$

Theoretically, equations 1 and 2 enable reconstructing life table functions based on e_x values (under the $a_x = \frac{n}{2}$ assumption). In practice, however, the reconstruction might require additional steps. For example, the e_x values provided by Eurostat have only one decimal place. This limits the accuracy of the l_x derivation and might result in constant l_x values for several ages. To overcome this issue, we fitted a non-parametric curve to the downloaded data and predicted e_x values with more decimal places.[3] In some cases, e.g., for the highly educated subpopulation in very low-mortality countries, the proposed derivation procedure still produces constant l_x values at young ages. We solved this issue by focusing on LE and HLE at age 30, which is not only favorable from a technical point of view, but also theoretically: Very young persons have not usually finished their educational attainment (Connelly, Gayle and Lambert 2016). A detailed description and evaluation of the estimation procedure using R code can be found in the Appendix.

2.2. Method

2.2.1. Estimating HLE with the Sullivan method

The most commonly used approach for extending LE to HLE is the Sullivan method (Sullivan 1971). It is based on the idea of applying the age-specific prevalence (proportions) of a population in an (un)healthy state to the age-specific person-years lived from the life table. This enables dividing total life years for each age interval into those spent in good and poor health. Summing up only the *healthy* person-years lived across all ages yields HLE at age x:

(3) $$HLE_x = \frac{1}{l_x} \sum_{x=0}^{\omega} (1 - {}_n\pi_x) \cdot {}_nL_x$$

[3] We used the loess() function in R.

with ${}_n\pi_x$ being the proportion (or prevalence) of individuals in poor health in the age interval x to $x + n$ and ${}_nL_x$ the number of person-years lived in the age interval x to $x + n$. The last open-age interval is represented by ω.

2.2.2. Approximating confidence intervals for HLE

Calculating ${}_n\pi_x$ for different educational groups and stratifying for sex reduces the number of observations in the survey data to a relatively small amount. Thus, information about uncertainty arising from the sample size is relevant for this analysis. Jagger, Hauet, and Brouard (2001) provide a guide for calculating the approximated variance of HLE_x. This approach ignores variance from the mortality data, which is usually justifiable—and in our case, even inevitable—since we do not have information about the number of persons dying in each age interval. Hence, we only report confidence intervals for HLE, but not for LE. The variance in healthy life expectancy at age x is estimated as:

(4) $$S^2(HLE_x) \approx \frac{1}{(l_x)^2} \cdot \sum_{x=0}^{\omega} {}_nL_x \cdot \frac{{}_n\pi_x \cdot (1 - {}_n\pi_x)}{{}_nN_x}$$

where ${}_nN_x$ is to the (unweighted) sample size in the age interval x to $x + n$. We used prevalence data aggregated in 5- year age intervals. Therefore, we transformed the single-age-specific life tables into abridged life tables with age intervals of the same length (i.e., 5-year age intervals). Next, we applied equation 4 in order to derive an estimate of the level of uncertainty in HLE from the prevalence data (Jagger, Hauet and Brouard 2001, p. 23).

2.2.3. Quantifying educational inequalities in HLE

The magnitude of inequalities between educational subpopulations can be quantified by calculating the gap between highly and low-educated subpopulations. This approach, however, neglects educational distribution in a population. Therefore, we follow Renard et al. (2019) and use the composite index of inequality (CII) as a summary measure of inequality. The CII accounts for population size and educational classes and has been used in other research that focuses on summary measures of socio-economic inequalities in health (Van Oyen et al. 2011). The CII is the sum of the weighted difference in HLE between the educational group with the highest level of HLE and the remaining educational subpopulations i:

(5) $$CII = \sum_{i=1}^{N} [HLE_x^{highest\ level} - HLE_x^i] \cdot w_x^i$$

with w_x^i being the relative size of the educational group i in a given population at age x.

2.2.4. Expressing total HLE as the weighted sum of education-specific HLEs

As mentioned above, total HLE for a given population comprises the HLE contributions for several subpopulations. We follow the approach introduced by Shkolnikov et al. (2001) in order to decompose HLE at age x into the specific contribution of each subpopulation i:

(6) $$Total\ HLE_x = \sum_{i=1}^{N} HLE_x^i \cdot \theta_x^i$$

with θ_x^i being the weight of the life table population group i at age x.

The life table population weights θ_x^i are derived by solving a system of linear equations based on information about the overall and education-specific HLE estimates as well as the proportions of each educational subpopulation on the total population (see Shkolnikov et al. 2001 for more details). In short, the method enables deriving life table population weights that satisfy equation 6, i.e., θ_x^i is chosen such that the sum of the weighted educational-specific estimates is equal to total HLE.

3. Results

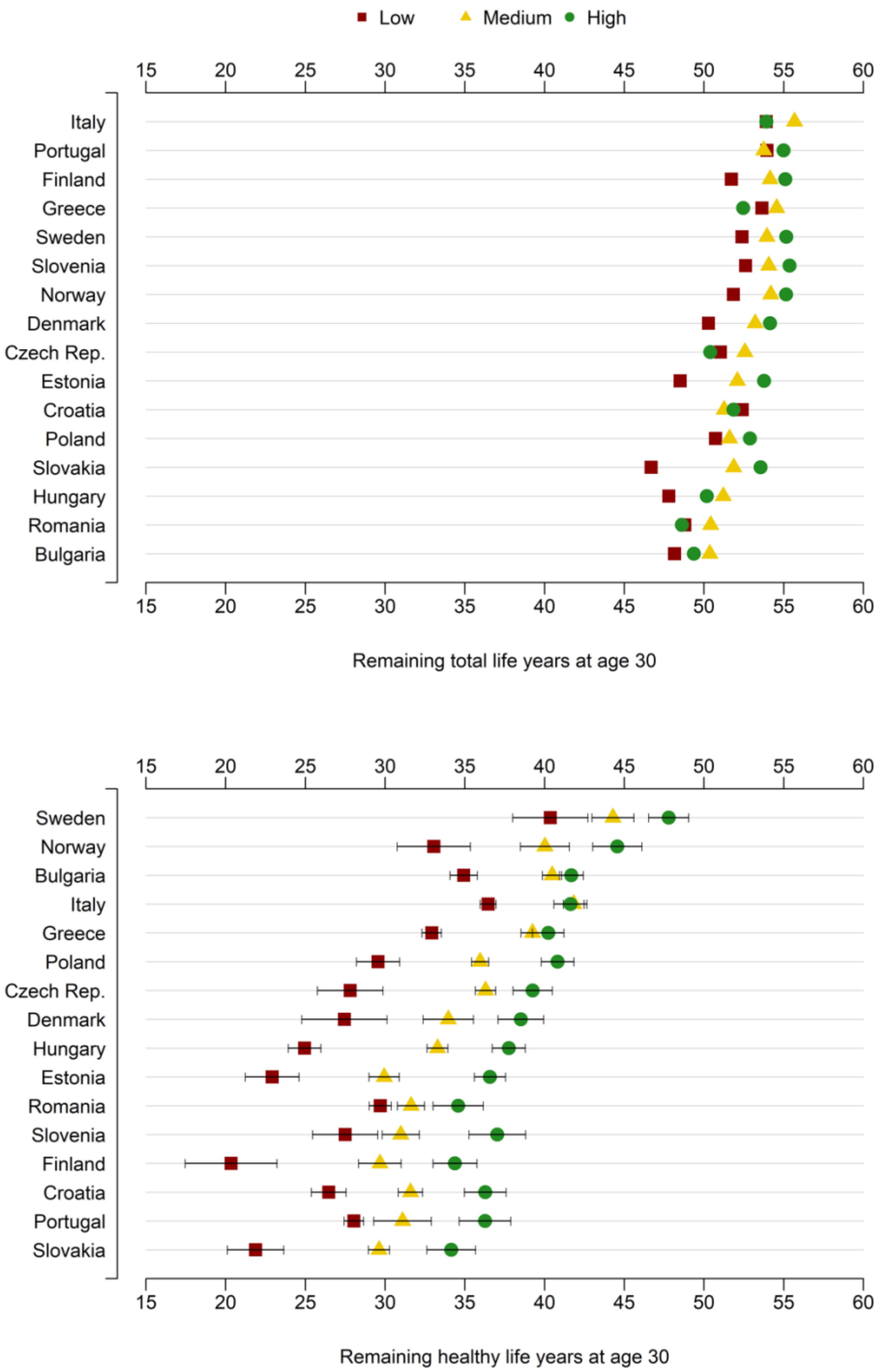
3.1. LE and HLE by educational attainment in 16 European countries

Figures 1 and 2 show life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) by educational attainment in 2016, stratified for sex. Three education-specific LE_{30} and HLE_{30} values are depicted for each country. In addition, 95 % confidence intervals are included for HLE_{30} to reflect the uncertainty in the health data (information on the uncertainty in the mortality data is not available and, therefore, confidence intervals for LE_{30} are not reported). The 16 countries are ordered by the country's LE_{30} and HLE_{30} rankings. Italy shows the highest LE_{30} among women and men, while Sweden is the top-ranked country in terms of HLE_{30} for both genders. Women and men in Bulgaria show the lowest observed LE_{30} level. The expected number of healthy life years measured through HLE_{30} is lowest in Slovakia (among women) and Estonia (among men). The high level of HLE_{30} in Sweden can be ascribed to an exceptionally low proportion of unhealthy individuals in its population. For example, the proportion of unhealthy Swedish men with a high education is about 6 percent, while the same proportion is about 20 percent in Slovakia (see table A1). Further, educational inequalities in LE_{30} are largest in Slovakia (6.9 years for women and 14.7 years for men), while the difference between highly and low-educated Italians is relatively small (0.02 among women 2.32 among men). In general, educational inequalities are more pronounced in HLE_{30} compared to LE_{30}, ranging from 4.9 years in Romania (women) to 15.5 years in Hungary (men). For most countries included in this study, the differences between the educational subpopulations are statistically significant. The only exceptions are women in Bulgaria, Italy, and Greece, where estimates about highly and medium-educated individuals do not differ significantly, as the corresponding confidence intervals overlap.

Table A1 provides information about the sample sizes, which range from 2,861 women and 2,864 men in Sweden to 20,910 women and 18,985 men in Italy. Contradicting our expectations, the highly educated subpopulation does not always show the highest estimate in LE_{30} (i.e., in Italy, Greece, Czech Republic, Croatia, Hungary, Romania, and Bulgaria medium- or even low-educated individuals perform better than the highly educated subpopulation in terms of LE). We will elaborate upon this in the discussion section.

Figure 1

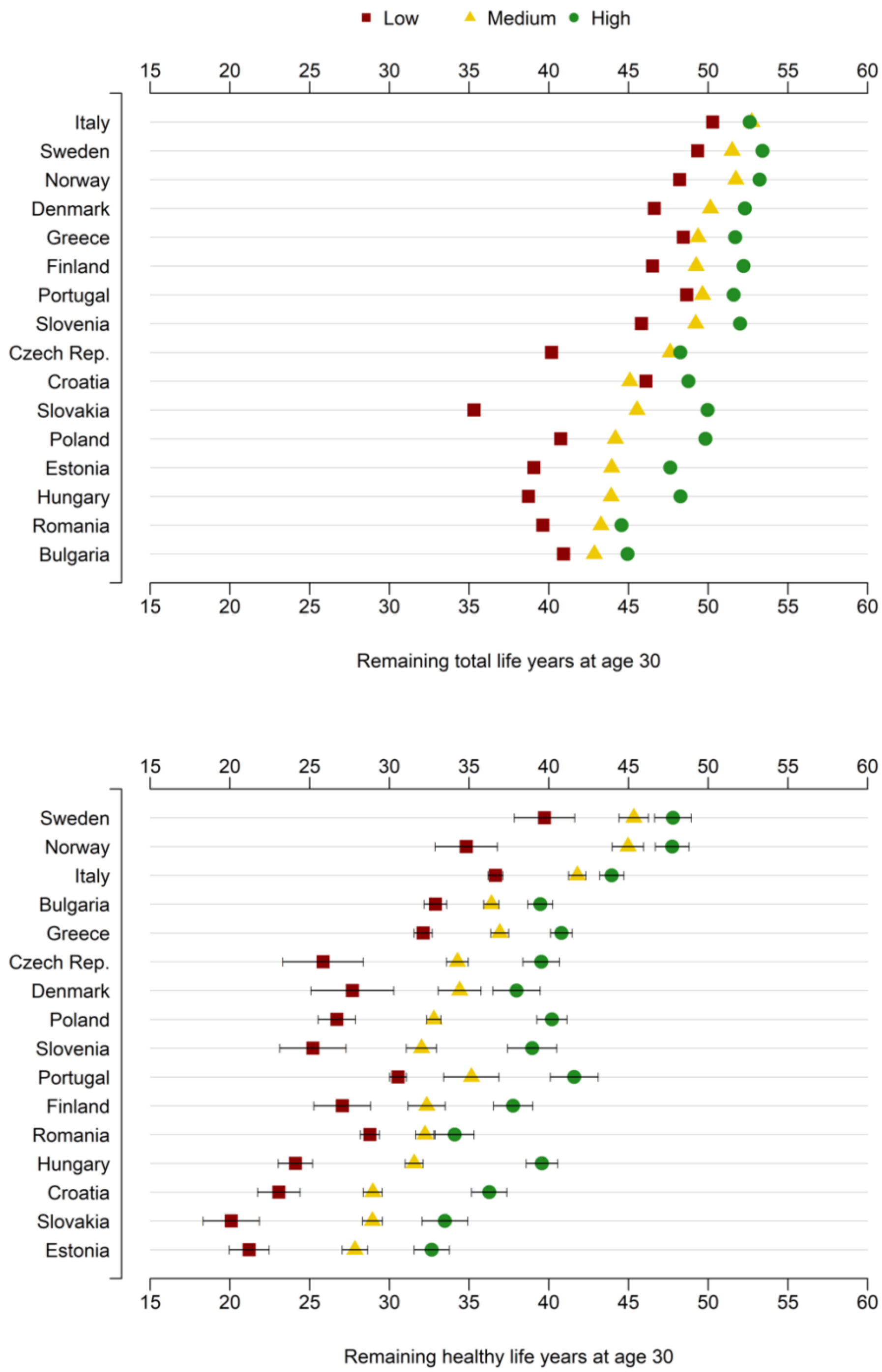
Life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) in 2016, with 95 % confidence intervals for HLE for 16 European countries, by educational level, females



Source: Own calculations, using data from EU-SILC 2016 and Eurostat database.
Note: Countries ordered according to decreasing values in LE_{30} and HLE_{30}. See Table A2 for the exact figures.

Figure 2

Life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) in 2016, with 95 % confidence intervals for HLE for 16 European countries, by educational level, males

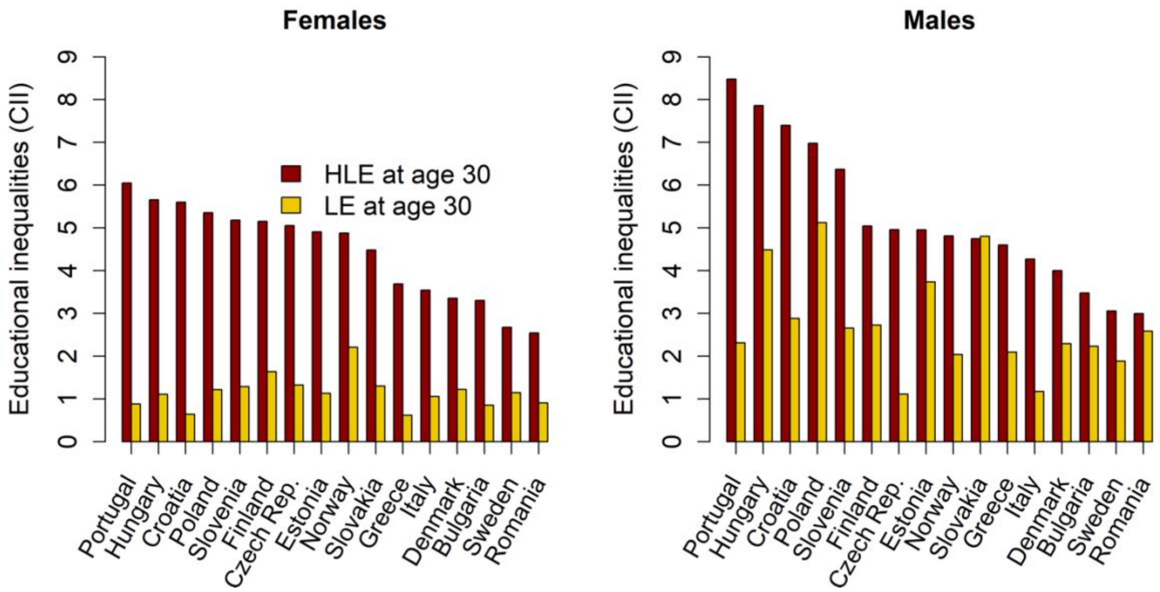


Source: Own calculations with data from EU-SILC 2016 and Eurostat database.
Note: Countries ordered according to decreasing values of LE_{30} and HLE_{30}. See Table A3 for the exact figures.

3.2 Educational inequalities in (healthy) life expectancy at age 30

The magnitude of educational inequalities is quantified through the CII and presented in figure 3 (stratified for sex). The countries are ordered by the size of CII for HLE_{30} in decreasing order. The variation between educational subpopulations in HLE_{30} is considerably large. Among men, CII ranges from about 8.5 years in Portugal to about 3 years in Romania. For women, the variation is slightly smaller, ranging from about 6 years in Portugal to about 2.5 years in Bulgaria. Note that CII accounts for the relative size of each educational subpopulation. The exact figures for the educational distribution are shown in table A1. The analyzed 16 European countries vary substantially in their educational composition. For example, about 42 percent of Estonian women are highly educated as opposed to about 13 percent in Romania. The high share of low-educated individuals explains why women and men in Portugal show the largest educational inequalities according to CII, even though the unweighted distance between the highly and low- educated subpopulation, shown in figures 1 and 2, indicate a somewhat moderate level. In general, inequalities in HLE_{30} exceed the those for LE_{30}, and men show higher educational inequalities in both LE_{30} and HLE_{30}. However, this pattern does not hold in every analyzed population. For example, men in Slovakia show a slightly higher CII in LE_{30} than in HLE_{30} (4.8 years compared to 4.7 years). Further, inequalities in HLE_{30} for women in Sweden slightly exceed CII for their male counterpart (about 3.6 years for women and about 3 years for men).

Figure 3
CII as a measure of educational inequalities in life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) for 16 European countries in 2016



Source: Own calculations using data from EU-SILC 2016 and Eurostat database.
Note: Countries ordered according to decreasing values of educational inequalities in HLE_{30}.

3.3 Decomposing total HLE_{30} in education-specific HLE_{30} estimates

As described in the methods section, total HLE can be expressed as the sum of the education-specific HLE estimates weighted by the population composition (see equation 6). Table 1 provides our results for 16 European countries stratified for sex. For example, the derived population weights for women in Bulgaria are 0.28 for highly educated, 0.46 for medium-educated, and 0.26 for low-educated individuals. Applying the population weights to the corresponding education-specific HLE_{30} estimates and summing them yields a total HLE_{30} of 39.38 years (0.28 * 41.68 + 0.46 * 40.47 + 0.26 * 34.93). This enables calculating the share of each education-specific HLE_{30} on total HLE_{30}. Using the example of women in Bulgaria again, medium-educated individuals make the greatest contribution to the total HLE_{30} level in 2016 (0.46 * 40.47 / 39.38 = 47 %), while the contributions from highly and low-education persons are considerably lower (29.58 % vs. 22.90 %). In contrast, total HLE_{30} for women in Finland, Estonia, and Denmark largely arises from the contribution of highly educated individuals (about 50 %). The difference between the Nordic countries and Bulgaria can be clearly attributed to differences in the population composition, i.e., HLE_{30} for highly educated women is assigned to a much lower population weight in Bulgaria compared to the Nordic countries (0.28 vs. about 0.5). Thus, the decomposition demonstrates the importance of differences in the population structure for the HLE estimation. It further reveals that comparing countries according to total HLE may be misleading. For example, total HLE_{30} for men is slightly higher in Poland compared to Portugal (33.35 years vs. 32.28 years). Yet, all three education-specific HLE_{30} estimates are larger in Portugal, i.e., the low-, medium-, and highly educated individuals in Portugal can expect more healthy life years than their counterparts in Poland. Therefore, it is the population composition—a greater relative number of highly educated individuals—that leads to Poland's favorable performance in terms of HLE_{30}. The same can be observed for women in Bulgaria and Italy. Comparing both populations according to education-specific HLE_{30} estimates indicates better population health in Italy. Again, the much larger share of low-educated individuals in Italy leads to a relatively higher total HLE_{30} value in Bulgaria (38.52 years vs. 39.38 years). Arguably, the influence of the population composition on HLE estimates can be seen as a distortion whenever we use the measure to compare levels of population health across countries. One way to eliminate this effect is by assuming a constant population composition by educational attainment for all analyzed countries. This standardization is presented in table A4[4]. According to the standardized HLE_{30} estimates, men in Portugal now show higher levels of population health compared to men in Poland (35.39 years vs. 32.95 years). Also, the previous, unexpected finding that women in Italy perform worse than women in Bulgaria in terms of population health disappears upon controlling for differences in the population composition (standardized HLE_{30} for Italian women is 40.22 years vs. 39.18 years for women in Bulgaria).

[4] Standardized HLE_{30} is estimated by assuming constant life table population weights (θi) for all 16 countries (see equation 6). We used the population composition by educational attainment of the EU-28 as the "reference" population. The exact life table population weights are 0.29 (low-educated), 0.45 (medium-educated), and 0.26 (high-educated).

Table 1

Life table population weights (θi), HLE_{30} by education, and contribution on total HLE_{30} in 2016

	Educational composition (θi)			HLE_{30} by education				Contribution to total HLE_{30} (%)			
Country	High	Medium	Low	High	Medium	Low	Total	High	Medium	Low	Total
Women											
Bulgaria	0.28	0.46	0.26	41.68	40.47	34.93	39.38	29.58	47.51	22.90	100
Czech Rep.	0.20	0.68	0.12	39.26	36.30	27.81	35.90	22.15	68.74	9.12	100
Denmark	0.45	0.41	0.14	38.51	33.96	27.45	35.10	49.19	40.00	10.81	100
Estonia	0.45	0.40	0.15	36.57	29.94	22.92	31.90	51.93	37.32	10.75	100
Greece	0.15	0.31	0.54	40.23	39.25	32.93	35.99	16.56	34.13	49.30	100
Croatia	0.14	0.48	0.38	36.28	31.59	26.46	30.33	17.23	49.88	32.89	100
Italy	0.10	0.29	0.61	41.63	41.83	36.46	38.52	11.03	31.02	57.95	100
Hungary	0.22	0.52	0.26	37.76	33.29	24.95	32.13	25.91	54.15	19.94	100
Norway	0.38	0.38	0.24	44.56	40.02	33.05	40.07	42.28	37.81	19.91	100
Poland	0.25	0.56	0.19	40.82	35.96	29.55	35.92	28.20	55.78	16.02	100
Portugal	0.17	0.19	0.64	36.26	31.10	28.04	29.99	19.98	19.91	60.12	100
Romania	0.18	0.36	0.46	34.58	31.63	29.70	31.27	19.93	36.05	44.02	100
Slovenia	0.22	0.48	0.30	37.04	30.98	27.50	31.26	26.03	47.34	26.63	100
Slovakia	0.20	0.62	0.18	34.14	29.62	21.88	29.16	23.75	62.95	13.30	100
Finland	0.47	0.41	0.12	34.38	29.67	20.34	30.78	52.42	39.79	7.79	100
Sweden	0.28	0.40	0.31	47.78	44.29	40.36	44.04	30.70	40.43	28.86	100
Men											
Bulgaria	0.20	0.54	0.26	39.47	36.40	32.89	36.11	22.01	54.51	23.48	100
Czech Rep.	0.18	0.73	0.08	39.53	34.27	25.84	34.53	20.90	72.88	6.22	100
Denmark	0.34	0.46	0.20	37.98	34.41	27.68	34.28	37.48	46.49	16.02	100
Estonia	0.30	0.51	0.20	32.65	27.84	21.21	27.98	34.81	50.40	14.78	100
Greece	0.18	0.41	0.42	40.79	36.92	32.12	35.61	20.22	42.33	37.46	100
Croatia	0.17	0.63	0.20	36.26	28.96	23.07	29.00	20.92	63.12	15.96	100
Italy	0.09	0.36	0.55	43.95	41.79	36.66	39.14	9.59	38.77	51.64	100
Hungary	0.19	0.61	0.20	39.57	31.55	24.11	31.62	23.77	61.36	14.88	100
Norway	0.32	0.43	0.25	47.74	44.96	34.83	43.28	35.27	44.34	20.39	100
Poland	0.20	0.64	0.16	40.20	32.79	26.71	33.35	24.56	62.97	12.48	100
Portugal	0.07	0.22	0.71	41.60	35.14	30.55	32.28	8.40	24.07	67.53	100
Romania	0.24	0.47	0.29	34.10	32.23	28.78	31.70	25.99	48.12	25.88	100
Slovenia	0.22	0.61	0.17	38.96	32.01	25.21	32.35	26.39	60.06	13.55	100
Slovakia	0.18	0.71	0.11	33.49	28.94	20.09	28.83	21.17	71.44	7.39	100
Finland	0.24	0.48	0.28	37.76	32.34	27.05	32.16	28.35	47.95	23.69	100
Sweden	0.25	0.50	0.25	47.79	45.33	39.73	44.55	26.85	50.99	22.16	100

Source: Own calculations, using data from EU-SILC 2016 and Eurostat database.

4. Discussion and Conclusions

In this article, we investigated the role of education in assessing population health across Europe according to the HLE indicator. While previous studies have mainly focused on issues connected to the imperfect harmonization of health survey data, we addressed how population composition impacts HLE estimation. As expected, we observed large educational inequalities in healthy life years, which substantially exceed inequalities in total life years. The greatest gap between low- and highly educated individuals was found among men in Hungary. While persons with low education can expect 24,11 healthy life years at age 30, HLE_{30} for highly educated individuals is almost 40 years. The educational differences in HLE are larger than for sex differentials, highlighting the relevance of explicitly including education in HLE analyses. Moreover, European countries differ considerably with respect to their educational population structure. For example, the share of low-educated women in Portugal is about 62 percent as opposed to about 20 percent in Poland. This points to the importance of differences in population composition for assessing population health. We expressed each total HLE_{30} as the sum of education-specific HLE_{30} and weighted by the population size to demonstrate how educational attainment affects population composition. For example, total HLE_{30} among men is higher in Poland than in Portugal (33.35 years vs. 32.28 years). However, looking at education-specific HLE_{30} values suggests that Portuguese men expect to live healthier lives than Polish men in all three educational subpopulations. It is, therefore, the larger number of low-educated individuals in Portugal that drives the comparatively low total HLE_{30} value. In this sense, a comparison of total HLE_{30} between Portugal and Poland reflects more differences in the educational population structure as opposed to inequality in people's health and mortality levels. Controlling for the effect of the population composition by educational attainment on HLE_{30} by means of standardization leads to a higher HLE_{30} value in Portugal compared to Poland. Thus, researchers and policy makers should be more aware of the fact that differences in HLE across Europe are not only driven by disparities in the health and mortality levels between countries, but also influenced by differences in the population composition by educational attainment.

The relationship between education and population health has been previously studied. Luy et al. (2019) have shown that the improvements in LE between 1990 and 2010 in Italy, Denmark, and the USA partly arose from an increasing proportion of higher educated individuals. In addition, Deboosere, Gadeyne, and van Oyen (2009) pointed to the importance of considering shifts in the population composition according to educational attainment in their analysis of how LE progressed in Belgium from 1991 to 2014. Likewise, Shkolnikov et al. (2006) emphasized how changes in the educational population structure played a role in mortality trends in Central and Eastern-Europe during the 1990s. Our findings suggest that changes in the population composition according to educational attainment might affect HLE trends more than LE trends, because educational differences appear much larger in HLE compared to LE.

Further, Jasilionis and Shkolnikov (2016) have argued that health and mortality levels for highly educated individuals may represent "vanguards" for the remaining population groups. In other words, the number of healthy life years for persons with high educational attainment can be interpreted in terms of the county's current potential health status. For example, the relatively large number of healthy life years for highly educated men in Portugal suggests a great potential for improving total HLE through educational expansion, which could even have implications for population forecasting in health and mortality. In contrast, Romania shows similar levels of HLE_{30} for all three educational groups, indicating that an external factor (e.g., a structural problem in the healthcare system that concerns all educational groups) may prevent Romanians from living long and healthy lives regardless of their educational attainment. Knowledge about educational differences in HLE is therefore vital for policy makers to address health interventions appropriately. While some countries can increase total HLE by reducing inequalities and promoting education, others need to target disadvantages in actual health and mortality levels.

There is also a technical advantage to estimating HLE by educational attainment. HLE levels and trends have been shown to be particularly sensitive to the underlying prevalence data, as opposed to mortality information (Sauerberg, Guillot and Luy 2020). In other words, the reliability of HLE estimates depends mostly on the accuracy of prevalence data. Health surveys, however, do not always appropriately reflect educational distribution in the actual population (Spitzer 2019). Our decomposition analysis suggests that even a small bias in educational distribution will result in a relatively large distortion to total HLE. Therefore, comparing HLE estimates by educational attainment might be more reliable, as it is less affected by a potential bias in the survey sample's educational composition.

This study has some limitations: First, we noted that the imperfect harmonization of health data affects how HLE can be compared across Europe (Ekholm and Brønnum-Hansen 2009, Jagger and Robine 2011). Additionally, changes to educational attainment classification might affect the results presented in this study. Eurostat used ISCED 1997 before 2014, which it replaced with ISCED 2011 afterwards. Looking at the LE_{30} time trend reveals that this classification change is associated with a drop in LE at age 30 for the highly educated subpopulation, while LE at age 30 increased for most analyzed countries in the low-educated group[5]. This might explain why we observe higher LE levels for low- or medium-educated individuals compared to highly educated persons in some countries, namely the Czech Republic, Hungary, Romania, Croatia, Bulgaria, Greece, and Italy. It should be noted that collecting mortality data by educational attainment is not mandatory in all European countries, which potentially biases our estimates of educational differences due to underreporting. In addition, the decomposition method applied in this study is based on a simplified solution for a rather complex relationship between total HLE_{30} and group-specific HLE_{30} (Shkolnikov et al. 2001). Nevertheless, a more sophisticated decomposition method might produce results with higher precision, but is unlikely to change the conclusions drawn from the analysis.

Despite the aforementioned limitations, our work shows how using total HLE can be misleading as a standalone tool to monitoring and comparing health status across different European countries. HLE differs considerably between educational groups, and European populations show large educational inequalities in terms of population composition. Relying exclusively on total HLE values cannot provide a comprehensive picture of population health across Europe. It is not inherently clear whether differences in total HLE reflect compositional effects or actual gaps in health and mortality levels. Additionally, the large educational

[5] The time trend is available in the Eurostat data:
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_mlexpecedu&lang=en.

differences in HLE bring into question whether it is reasonable to report HLE as an average over all educational subpopulations. Looking at education-specific HLE values provides a more meaningful picture of population health and helps policy makers better address health issues, i.e., it accounts for compositional effects, reveals the magnitude of actual health disparities, and informs about the size of inequalities in HLE between educational groups. Therefore, we suggest analyzing HLE separately for each educational subpopulation, whenever data allows. In case mortality data is not available in the required format, we recommend inspecting health survey data with respect to its educational variation, and to consider this information before interpreting HLE results.

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Appendix

Table A1
Limitations in daily activities (GALI) by educational level and educational distribution, by country and gender, in 2016

			Activity limitations (%)			Educational distribution (%)		
Country		*N*	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Bulgaria	Women	8257	29.61	15.59	10.59	29.68	44.87	25.45
	Men	7258	20.42	11.75	9.87	27.68	53.99	18.32
Czech Rep.	Women	6924	44.99	26.04	13.21	14.90	67.11	17.99
	Men	4590	28.63	25.00	14.43	7.98	73.49	18.54
Denmark	Women	3296	40.37	34.44	25.49	23.99	40.20	35.80
	Men	2956	34.26	29.11	24.19	23.04	45.73	31.23
Estonia	Women	6630	52.21	35.68	24.84	18.46	39.69	41.85
	Men	5805	40.44	28.51	24.92	22.07	50.40	27.52
Greece	Women	19581	46.00	15.29	11.21	40.31	36.62	23.08
	Men	18269	38.71	14.49	13.35	34.66	41.30	24.04
Croatia	Women	8869	57.00	25.13	17.47	34.12	48.00	17.88
	Men	7935	47.09	26.51	18.83	21.03	63.28	15.69
Italy	Women	20910	36.87	14.51	12.70	49.25	34.91	15.84
	Men	18985	27.35	12.24	10.68	47.26	38.21	14.54
Hungary	Women	8718	48.83	27.27	16.12	25.96	52.22	21.82
	Men	7045	32.42	22.90	13.15	18.96	61.48	19.56
Norway	Women	3313	31.43	24.03	14.70	29.24	37.18	33.58
	Men	3465	20.93	11.55	7.84	28.30	41.74	29.96
Poland	Women	13294	43.29	23.83	11.59	19.50	55.72	24.78
	Men	10941	30.53	21.03	11.03	16.52	64.11	19.38
Portugal	Women	12148	48.43	21.00	18.84	61.83	18.74	19.43
	Men	10532	34.95	16.07	13.78	64.28	21.27	14.44
Romania	Women	8308	39.53	24.83	15.36	50.62	36.29	13.09
	Men	7487	25.04	19.29	13.97	40.55	45.16	14.29
Slovenia	Women	4489	56.25	37.36	24.80	24.83	46.69	28.48
	Men	4096	41.96	29.03	20.62	15.69	60.68	23.62
Slovakia	Women	7498	53.54	32.22	16.76	16.87	62.12	21.01
	Men	6366	30.41	26.68	20.58	11.32	71.03	17.64
Finland	Women	5184	58.67	38.51	30.84	25.20	38.62	36.18
	Men	5363	45.12	26.94	23.21	22.98	47.64	29.37
Sweden	Women	2861	23.68	15.46	11.38	26.24	40.41	33.36
	Men	2864	18.81	10.55	6.48	22.55	50.65	26.80

Source: EU-SILC 2016 (own calculations).

Table A2

Life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) in 2016, using 95 % confidence intervals for 16 European countries, by educational level, females

	LE_{30}				HLE_{30} with 95% confidence intervals			
Country	Low	Medium	High	Total	Low	Medium	High	Total
Bulgaria	48.15	50.36	49.36	49.85	34.93 (34.07-35.79)	40.47 (39.88-41.07)	41.68 (40.93-42.43)	39.38 (38.99-39.77)
Czech Rep.	51.03	52.56	50.40	52.42	27.81 (25.76-29.86)	36.30 (35.67-36.93)	39.26 (38.03-40.49)	35.90 (35.38-36.42)
Denmark	50.28	53.21	54.14	52.82	27.45 (24.77-30.12)	33.96 (32.39-35.54)	38.51 (37.08-39.94)	35.10 (34.22-35.98)
Estonia	48.51	52.09	53.77	52.41	22.92 (21.24-24.60)	29.94 (28.99-30.89)	36.57 (35.60-37.55)	31.90 (31.31-32.48)
Greece	53.63	54.55	52.45	54.03	32.93 (32.32-33.53)	39.25 (38.53-39.96)	40.23 (39.24-41.21)	35.99 (35.68-36.30)
Croatia	52.40	51.26	51.85	52.11	26.46 (25.38-27.55)	31.59 (30.83-32.36)	36.28 (34.98-37.59)	30.33 (29.86-30.81)
Italy	53.90	55.67	53.92	54.71	36.46 (35.97-36.96)	41.83 (41.18-42.48)	41.63 (40.59-42.66)	38.52 (38.22-38.83)
Hungary	47.79	51.21	50.18	50.28	24.95 (23.92-25.98)	33.29 (32.63-33.94)	37.76 (36.72-38.79)	32.13 (31.68-32.59)
Norway	51.85	54.19	55.15	53.93	33.05 (30.76-35.35)	40.02 (38.49-41.55)	44.56 (43.02-46.10)	40.07 (39.20-40.94)
Poland	50.72	51.60	52.88	52.00	29.55 (28.21-30.90)	35.96 (35.42-36.50)	40.82 (39.80-41.84)	35.92 (35.53-36.30)
Portugal	53.95	53.74	55.00	54.15	28.04 (27.43-28.65)	31.10 (29.29-32.90)	36.26 (34.65-37.88)	29.99 (29.53-30.44)
Romania	48.79	50.42	48.61	50.09	29.70 (29.01-30.39)	31.63 (30.78-32.48)	34.58 (33.01-36.16)	31.27 (30.80-31.74)
Slovenia	52.61	54.06	55.37	53.95	27.50 (25.46-29.53)	30.98 (29.82-32.14)	37.04 (35.26-38.81)	31.26 (30.50-32.02)
Slovakia	46.68	51.86	53.55	51.49	21.88 (20.11-23.64)	29.62 (28.95-30.28)	34.14 (32.61-35.67)	29.16 (28.65-29.68)
Finland	51.72	54.14	55.10	54.06	20.34 (17.46-23.23)	29.67 (28.34-31.01)	34.38 (33.00-35.76)	30.78 (30.04-31.53)
Sweden	52.39	53.94	55.17	53.97	40.36 (38.01-42.72)	44.29 (42.97-45.61)	47.78 (46.53-49.03)	44.04 (43.26-44.83)

Source: EU-SILC 2016 and Eurostat database (own calculations).

Table A3

Life expectancy at age 30 (LE_{30}) and healthy life expectancy at age 30 (HLE_{30}) in 2016, using 95 % confidence intervals for 16 European countries, by educational level, males

	Life expectancy at age 30				Healthy life years at age 30 with 95% confidence intervals			
Country	Low	Medium	High	Total	Low	Medium	High	Total
Bulgaria	40.93	42.85	44.94	43.08	32.89 (32.18-33.60)	36.40 (35.92-36.88)	39.47 (38.69-40.25)	36.11 (35.76-36.46)
Czech Rep.	40.18	47.61	48.25	47.27	25.84 (23.32-28.37)	34.27 (33.59-34.94)	39.53 (38.38-40.67)	34.53 (33.95-35.10)
Denmark	46.62	50.13	52.29	49.89	27.68 (25.09-30.28)	34.41 (33.07-35.75)	37.98 (36.50-39.45)	34.28 (33.39-35.17)
Estonia	39.06	43.94	47.62	44.47	21.21 (19.96-22.46)	27.84 (27.04-28.64)	32.65 (31.56-33.75)	27.98 (27.43-28.54)
Greece	48.44	49.36	51.70	49.51	32.12 (31.55-32.69)	36.92 (36.36-37.48)	40.79 (40.11-41.47)	35.61 (35.32-35.90)
Croatia	46.10	45.08	48.76	46.35	23.07 (21.74-24.39)	28.96 (28.37-29.55)	36.26 (35.16-37.37)	29.00 (28.53-29.47)
Italy	50.28	52.73	52.60	51.48	36.66 (36.20-37.11)	41.79 (41.24-42.33)	43.95 (43.19-44.70)	39.14 (38.85-39.44)
Hungary	38.72	43.91	48.26	43.75	24.11 (23.03-25.19)	31.55 (31.00-32.11)	39.57 (38.58-40.56)	31.62 (31.18-32.06)
Norway	48.21	51.73	53.22	51.42	34.83 (32.88-36.78)	44.96 (43.98-45.94)	47.74 (46.68-48.80)	43.28 (42.59-43.98)
Poland	40.75	44.17	49.82	45.03	26.71 (25.54-27.88)	32.79 (32.34-33.24)	40.20 (39.25-41.15)	33.35 (32.99-33.72)
Portugal	48.65	49.63	51.60	49.15	30.55 (30.01-31.08)	35.14 (33.41-36.88)	41.60 (40.10-43.10)	32.28 (31.83-32.73)
Romania	39.63	43.27	44.56	43.25	28.78 (28.19-29.38)	32.23 (31.65-32.81)	34.10 (32.88-35.31)	31.70 (31.30-32.09)
Slovenia	45.81	49.21	51.99	49.04	25.21 (23.13-27.29)	32.01 (31.07-32.96)	38.96 (37.41-40.51)	32.35 (31.63-33.08)
Slovakia	35.31	45.53	49.96	45.19	20.09 (18.33-21.85)	28.94 (28.32-29.56)	33.49 (32.05-34.92)	28.83 (28.30-29.35)
Finland	46.51	49.24	52.22	49.48	27.05 (25.28-28.83)	32.34 (31.18-33.51)	37.76 (36.53-38.99)	32.16 (31.49-32.83)
Sweden	49.33	51.50	53.40	51.45	39.73 (37.83-41.63)	45.33 (44.41-46.25)	47.79 (46.63-48.94)	44.55 (43.91-45.20)

Source: EU-SILC 2016 and Eurostat database (own calculations).

Table A4
Standardized and original HLE at age 30 for 16 European countries in 2016

Country	Standardized HLE_{30}	Original HLE_{30}	Change in HLE_{30}	Change in Rank
Women				
Sweden	44.06	44.04	+0.02	1 → 1
Italy	40.22	38.52	+1.70	4 → 2
Norway	39.18	40.07	-0.89	2 → 3
Bulgaria	39.18	39.38	-0.20	3 → 4
Greece	37.67	35.99	+1.68	5 → 5
Poland	35.37	35.92	-0.55	6 → 6
Czech Rep.	34.61	35.90	-1.29	7 → 7
Denmark	33.26	35.10	-1.85	8 → 8
Hungary	32.03	32.13	-0.10	9 → 9
Romania	31.84	31.27	+0.57	11 → 10
Portugal	31.55	29.99	+1.57	15 → 11
Slovenia	31.54	31.26	+0.29	12 → 12
Croatia	31.32	30.33	+0.99	14 → 13
Estonia	29.63	31.90	-2.27	10 → 14
Slovakia	28.55	29.16	-0.61	16 → 15
Finland	28.19	30.78	-2.59	13 → 16
Men				
Sweden	44.34	44.55	-0.21	1 → 1
Norway	42.75	43.28	-0.54	2 → 2
Italy	40.86	39.14	+1.72	3 → 3
Greece	36.54	35.61	+0.92	5 → 4
Bulgaria	36.18	36.11	+0.07	4 → 5
Portugal	35.49	32.28	+3.21	10 → 6
Denmark	33.39	34.28	-0.90	7 → 7
Czech Rep.	33.19	34.53	-1.34	6 → 8
Poland	32.95	33.35	-0.40	8 → 9
Finland	32.22	32.16	+0.06	11 → 10
Slovenia	31.84	32.35	-0.51	9 → 11
Romania	31.71	31.70	+0.02	12 → 12
Hungary	31.48	31.62	-0.14	13 → 13
Croatia	29.15	29.00	+0.15	14 → 14
Slovakia	27.55	28.83	-1.27	15 → 15
Estonia	27.17	27.98	-0.81	16 → 16

Source: EU-SILC 2016 and Eurostat database (own calculations).
Notes: The population composition by educational attainment for the EU-28 serves as the "reference" population.
The exact life table population weights are 0.29 (low-educated), 0.45 (medium-educated), and 0.26 (highly educated).

Reconstructing Life Tables from e_x

Markus Sauerberg

10 11 2020

Guide for deriving education-specific life tables

The following code provides an example for calculating education-specific life tables when only the education-specific e_x values are known. In other words, the aim of the code is to calculate the life table backwards, namely from e_x to p_x. This is necessary because Eurostat does not provide education-specific life tables, but education-specific e_x values are available. Please note, the results in this example will differ from the results in the paper due to updates in the Eurostat database.

```
library(dplyr)
library(eurostat)
#please load these packages and download the data like this:
data <- get_eurostat("demo_mlexpecedu", time_format = "num")

#rename and redefine the file
data$isced11 <- as.character(data$isced11)
data$isced11 <- ifelse(data$isced11=="ED0-2", "lower", data$isced11)
data$isced11 <- ifelse(data$isced11=="ED3_4", "middle", data$isced11)
data$isced11 <- ifelse(data$isced11=="ED5-8", "higher", data$isced11)
data$isced11 <- ifelse(data$isced11=="TOTAL", "total", data$isced11)

data$age <- as.character(data$age)
data$age <- ifelse(data$age=="Y_LT1", "Y0", data$age)
data$age <- ifelse(data$age=="Y_GE85", "Y85", data$age)
data$age <- substring(data$age, 2)

data <- data[,-1]
colnames(data) <- c("sex","age","edu","country","year","ex")
data$age <- as.numeric(data$age)
#Filter for the year 2016, as we have done
data <- filter(data, year==2016)
```

The following function has the arguments "country.select", "edu.select" and "sex.select". Thus, the funcation allows to derive life tables for each educational level (high, middle, low, and total), for each country with available data (16 European countries), separated for men and women.

```
my.function <- function(country.select, edu.select, sex.select) {

    select.country <- arrange(filter(data, country==country.select ,edu==edu.select &
                                                   sex==sex.select),age)

#smooth to get more decimals by applying the loess function,
#then predict ex with more decimals
    grab.LE <- select.country$ex
    smooth.it <- loess(grab.LE~select.country$age, span=0.2)
```

```r
    predict.it <- predict(smooth.it, seq(0,85,1))
    select.country$ex.decimals <- predict.it

    LT.derive <- data.frame(Age=0:85)
    LT.derive$lx <- NA
    LT.derive$Tx <- NA

    LT.derive$ex <- select.country$ex.decimals
    LT.derive$lx[1] <- 100000
    LT.derive$Tx[1] <- 100000*select.country$ex.decimals[1]
#this loop refers to equation 1 in the paper
    for (j in 2:86) {

        upper <- (LT.derive$lx[j-1]^2)-2*LT.derive$lx[j-1]*LT.derive$Tx[j-1]
        bottom <- (LT.derive$ex[j-1]-LT.derive$ex[j])*2*
                   LT.derive$lx[j-1]-2*LT.derive$Tx[j-1]-LT.derive$lx[j-1]
        LT.derive$Tx[j] <- upper/bottom*LT.derive$ex[j]
        LT.derive$lx[j] <- upper/bottom

    }
#Checks if lx is monotonic decreasing, i.e., no resurrection in the life table
    lx.diff <- diff(LT.derive$lx)
    lx.diff <- round(lx.diff, 5)

    if (all(diff(lx.diff) < 0)) {

        px <- c(LT.frame$lx[-1]/LT.frame$lx[-86],0)

    }else{
#sometimes, it is not, so I force it =)
#please note, this occurs usually at very young ages and won't affect
#LE at age 30 or older
        lx.diff[lx.diff>=0] <- -runif(length(lx.diff[lx.diff>=0]), 1, 5)
        lx.monotonic <- cumsum(c(100000, lx.diff))
        px <- c(lx.monotonic[-1]/lx.monotonic[-86],0)

        }
#from here, the life table is constructed very standardly
    lx <- round(c(100000, (cumprod(px)*100000)[1:(length(px)-1)]))
    dx <- round(c(-diff(lx), lx[length(lx)]))
    LT.derive$lx <- lx
    LT.derive$dx <- dx
    LT.derive$px <- px
    Lx1 <- lx[-1]+0.5[-length(px)]*dx[-length(dx)]
    Lx.open <- LT.derive$Tx[1]-sum(Lx1)
    LT.derive$Lx <- round(c(Lx1, Lx.open))
    LT.derive$Tx <- rev(cumsum(rev(LT.derive$Lx)))
    LT.derive$ex.derived <- LT.derive$Tx/LT.derive$lx
    LT.derive$ex.original <- select.country$ex
    LT.derive$diff <- LT.derive$ex.original-LT.derive$ex.derived
    LT.derive$Country <- country.select
    LT.derive$Edu <- edu.select
    LT.derive$Sex <- sex.select
```

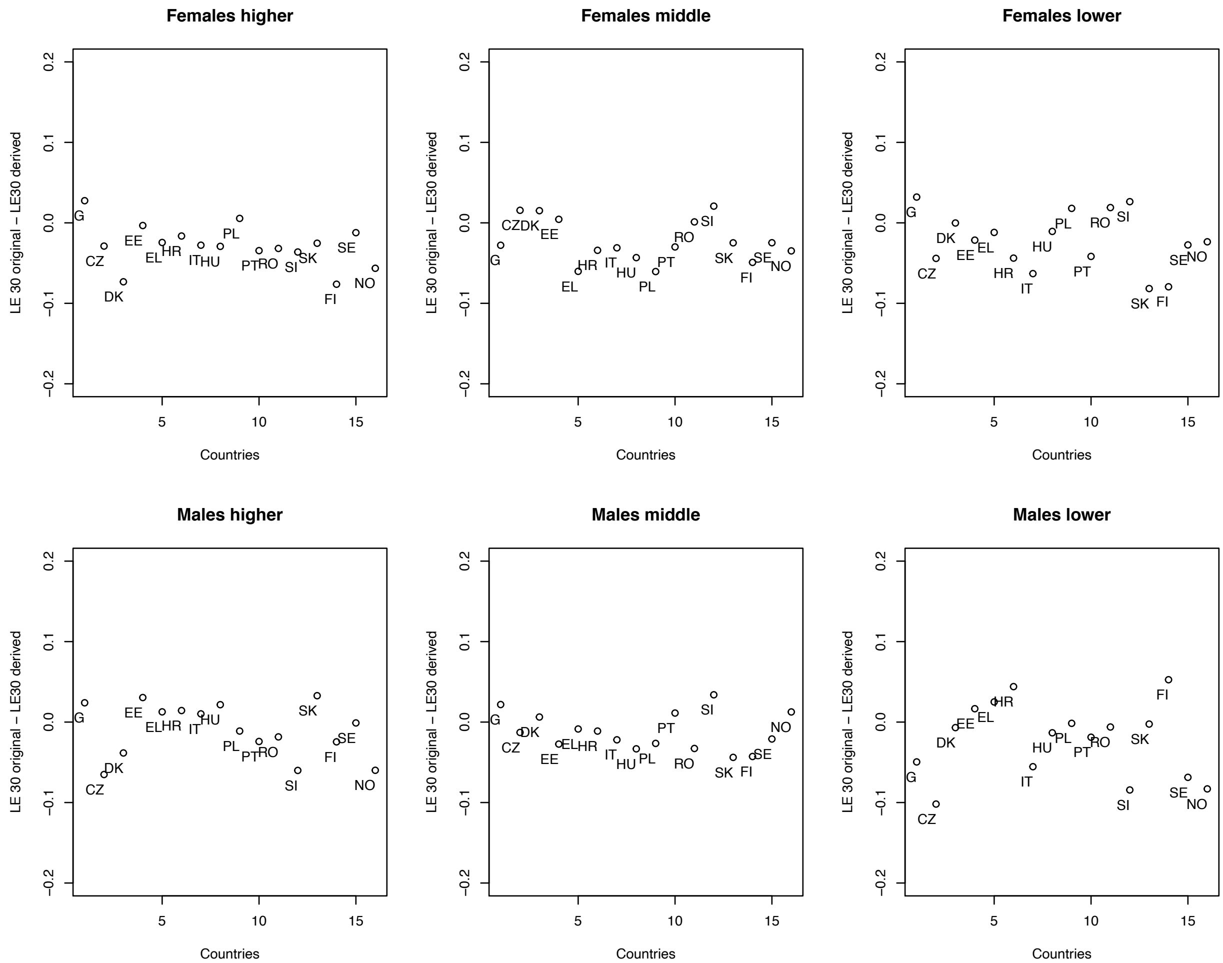
```
    return(LT.derive[,c("Country","Edu","Sex","Age","px","lx","dx","Lx",
                        "Tx","ex.derived","ex.original","diff")])
}
```

The following code applies the function to all 16 European countries by educational attainment, stratified by sex.

```
#these are the country codes
edu.countries <- c("BG","CZ","DK","EE","EL","HR","IT","HU",
                   "PL","PT","RO","SI","SK","FI","SE","NO")


###Females###
out.females <- c()

for (country.select in edu.countries) {

    for (edu.select in c("higher","middle","lower")) {

        out.females <- rbind(out.females,my.function(country.select, edu.select, "F"))
}
}


###Males###
out.males <- c()

for (country.select in edu.countries) {

    for (edu.select in c("higher","middle","lower")) {

        out.males <- rbind(out.males,my.function(country.select, edu.select, "M"))
}
}
```

Finally, I plot the difference between the original e_x and the derived e_x.

```
par(mfrow=c(3,3))
for (edu in c("higher","middle","lower")) {
    plot(1,1, type="n", xlim=c(1,16), ylim=c(-0.2,0.2),
         main=paste("Females",edu,sep=" "), xlab="Countries",
         ylab="LE 30 original - LE30 derived")
    points(1:16,out.females$diff[out.females$Edu==edu & out.females$Age==30])
    text(1:16,out.females$diff[out.females$Edu==edu & out.females$Age==30], 1:16,
         label=out.females$Country[out.females$Edu==edu & out.females$Age==30])
}

for (edu in c("higher","middle","lower")) {
    plot(1,1, type="n", xlim=c(1,16), ylim=c(-0.2,0.2),
         main=paste("Males",edu,sep=" "), xlab="Countries",
         ylab="LE 30 original - LE30 derived")
    points(1:16,out.males$diff[out.males$Edu==edu & out.males$Age==30])
    text(1:16,out.males$diff[out.males$Edu==edu & out.males$Age==30], 1:16,
         label=out.males$Country[out.males$Edu==edu & out.males$Age==30])
}
```



In my opinion, the differences are relatively small, and the results provide evidence for the method's accuracy.

Complete life tables by age and education (stratified by women and men)

This prints all the age- and education-specific life tables (the output it omitted).

```
library(knitr)

table.fun <- function(country.select) {

    print(
        kable(filter(out.females, Country==country.select & Edu=="higher"),
              digits=4, caption=paste("Life table for high-educated women in",
                                      country.select,", 2016",sep=" "))
        )
    print(
        kable(filter(out.females, Country==country.select & Edu=="middle"),
              digits=4, caption=paste("Life table for middle-educated women in",
                                      country.select,", 2016",sep=" "))
          )
    print(
        kable(filter(out.females, Country==country.select & Edu=="lower"),
              digits=4, caption=paste("Life table for low-educated women in",
                                      country.select,", 2016",sep=" "))
        )

    print(
        kable(filter(out.males, Country==country.select & Edu=="higher"),
              digits=4, caption=paste("Life table for high-educated men in",
                                      country.select,", 2016",sep=" "))
            )

    print(
        kable(filter(out.males, Country==country.select & Edu=="middle"),
              digits=4, caption=paste("Life table for middle-educated men in",
                                      country.select,", 2016",sep=" "))
            )
    print(
        kable(filter(out.males, Country==country.select & Edu=="lower"),
              digits=4, caption=paste("Life table for low-educated men in",
                                      country.select,", 2016",sep=" "))
            )
}

for (country in edu.countries) {
    table.fun(country)
}
```