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# Mortality Convergence in Europe? Spatial Differences in Life Expectancy Gains Between 1995 and 2019

MARKUS SAUERBERG , FLORIAN BONNET ,  
CARLO GIOVANNI CAMARDA  AND PAVEL GRIGORIEV 

*The conventional approach to gauging mortality convergence in Europe relies on life expectancy estimates ( $e^0$ ) at the national level. However, mortality can differ within countries significantly. To better apprehend whether Europe's mortality patterns have been converging or diverging over recent decades, we must shift our focus to regional mortality data. Using data from statistical offices, we present annual  $e^0$  estimates for 420 regions in 16 EU countries from 1995 to 2019. In our empirical analysis, we examined whether regions with initially high mortality levels caught up with low-mortality regions, and we investigated changes in the standard deviation of Europe's regional  $e^0$  distribution over time. Indeed, mortality variation has generally decreased from 1995 to 2019 due to larger gains in  $e^0$  for regions with initially high mortality levels. The convergence phase took place mostly during the first half of the entire time period analyzed. Over more recent periods, however, we observe more heterogeneity in the development of  $e^0$ . Some advantaged regions realized further gains in  $e^0$ , even as  $e^0$  improvements slowed for more disadvantaged regions. In conclusion, our analysis underscores the importance of addressing widening health inequalities. Policies should target disadvantaged regions to retard mortality divergence across Europe.*

## Introduction

Over recent decades, life expectancy has been rising throughout Europe generally due to improvements in living conditions, new medical technologies, public health policies, and changes in health behaviors (e.g., Meslé

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and Vallin 2002; Mackenbach 2020). Between the 1990s and 2019, central and eastern European countries typically started from lower life expectancy levels but showed larger gains compared to Western European countries.

After the dissolution of socialist regimes, the geographical distribution of mortality in Europe followed a distinct east–west gradient, with the highest mortality observed in the East. There are several reasons for the historical and partly persisting mortality divide, including less efficient healthcare system in former socialist nations (Nolte et al. 2002; Grigoriev and Pecholdová 2017), greater amount of psychological stress in these countries due to economic uncertainties and resulting detrimental health behaviors (Bobak and Marmot 1996; McKee and Shkolnikov 2001), and socioeconomic disparities in household income, unemployment rates, and educational attainment compared to the West (Richardson et al. 2013; Rosicova et al. 2009; Shkolnikov et al. 2006).

The Central-Eastern European (CEE) countries of the EU have experienced steep increases in life expectancy since the 1990s, largely attributed to the modernization of the healthcare system and improved access to medical innovations (Rychtarikova 2004; Bandosz et al. 2012; Jasilionis et al. 2011; Koppel et al. 2008). Additionally, factors such as improvement in general well-being, reduced psychosocial stress, improved dietary habits, and enhancements in road safety contributed to the progress (Bobak et al. 1997; Clark, Wildner, and Bergmann 2000; Meslé and Vallin 2002; Zatonski, McMichael, and Powles 1998). Access to modern medicine, preventive measures, and changes in health behavior have notably led to substantial reductions in initially high death rates from cardiovascular diseases.

Alcohol-related deaths and mortality from external causes have played a significant role in shaping overall mortality trends and patterns in the CEE region at both national and subnational levels (Rehm et al. 2007; McKee and Shkolnikov 2001; Grigoriev et al. 2020; Trias Llimos et al. 2017). Improved alcohol-control policies aimed at restricting affordability and availability of alcohol, as well as stricter penalties for drunk driving, have contributed to the positive mortality dynamics in the region (Lai and Habicht 2011; Jasilionis, Leon, and Pecholdová 2020).

Previous studies have found, however, that these achievements are not equally distributed across regions (Timonin et al. 2017; Diemer et al. 2022). Success or failure in reducing mortality has depended on the effective implementation of structural healthcare reforms (Jasilionis et al. 2011). Moreover, specific health policy measures, such as the regulation of alcohol and tobacco consumption, along with improvements in road safety and changes in diet have considerably influenced the spatial mortality pattern across Europe (Bonneaux et al. 2010).

While the catching-up process of populations with initially higher mortality rates might suggest mortality convergence, previous studies have found that variation in mortality between and within several European

countries has increased over time (see Hrzic et al. 2020, for a systematic literature review). Empirical evidence also indicates growing differences in mortality trajectories across Europe's regions. Recent studies have identified regional variation in changes in life expectancy in Belgium (Otavova et al. 2023), Germany (Van Raalte et al. 2020; Rau and Schmetzmann 2020; Hrzic et al. 2023), Finland and Sweden (Wilson et al. 2020), France (Bonnet and d'Albis 2020), the Netherlands (Janssen et al. 2016), and Spain (Bramajo, Permanyer, and Blanes 2023).

Levels and trends in life expectancy are typically closely linked to the socioeconomic situation of a given region (Macintyre and Ellaway 2003; Mackenbach et al. 2017; Lutz and Kebede 2018; Bonnet, d'Albis, and Thuilliez 2023). Particularly advantaged population groups, often referred to as "vanguard groups," with better access to health-related resources, tend to experience a more rapid decline in mortality rates compared to nonvanguard groups (Jasilionis et al. 2014). Diverging mortality trends should raise concerns for policymakers, as they suggest that not all regions have equally benefited from past health improvements, that is, structurally weak regions might be falling behind advantaged regions.

To mitigate spatial disparities in mortality levels, the European Union (EU) has allocated financial resources through the EU cohesion policy plan to help less-developed regions reduce still-persistent health gaps (European Commission 2023). Consequently, information about mortality trends at the subnational level is crucial for assessing progress in social cohesion. Furthermore, the period of this analysis (1995–2019) and the countries included in our study are particularly interesting in light of the EU's enlargement in 2004 to include several CEE countries. This raises the question of whether the addition of formerly socialist countries such as the Czech Republic, Hungary, Slovakia, or Slovenia in the context of the aforementioned EU cohesion policy plan, might have helped reduce inequalities in mortality across Europe (Hrzic et al. 2020). Examining regional life expectancy trends between 1995 and 2019 for nations belonging to both groups—those countries that joined the EU before 2004 and those that joined in 2004—provides an excellent opportunity for revealing a potential impact of EU expansion on mortality convergence.

Previous studies encountered challenges to appropriately examining mortality convergence in Europe because they often focused either on a limited selection of countries or considered only a relatively short period of time (Wilson et al. 2020; Bramajo, Permanyer, and Blanes 2023; Otavova et al. 2023). One significant challenge arises from revisions and changes in territorial units for population statistics, such as the Nomenclature of Statistical Territorial Units (NUTS), which makes estimating long time series of regional life expectancy in Europe extremely difficult. For instance, Richardson et al. (2013) examined regional inequalities in life expectancy for 13 European countries between 1991 and 2008. The authors pointed

to data limitations and comparability issues and addressed these challenges by first calculating life expectancy as three-year moving averages and then aggregating them into deciles based on their life expectancy value or household income. The Eurostat database provides regional mortality statistics without breaks in the time series for only three countries (Eurostat database 2023). Building on this dataset, the study by Hrzic et al. (2021) investigated mortality convergence between 1992 and 2016 for the Czech Republic, Hungary, and Poland at the NUTS-2 level, that is, based on data for 31 spatial units (8 units in the Czech Republic, 7 units in Hungary, and 16 units in Poland). The author noted data limitations due to changes in the NUTS classification and concluded the study with a call for improvements in the data infrastructure in the EU at the subnational level. Consequently, no study so far has examined mortality trajectories for individual regions across Europe.

## Materials and methods

### Data compilation, structure, and corresponding smoothed trend estimates

We use routinely collected death and population counts by age, sex, and region obtained from statistical offices. These data were either freely available for download from official web pages or were requested and, if necessary, purchased from the relevant statistical office. Since country-specific data differ in terms of length of the time series, size of regions, and format (i.e., single years of age or broad age groups with different open age intervals), we first had to harmonize them to ensure comparability. We used the NUTS classification provided by Eurostat and aggregated country-specific data accordingly by NUTS-2 or NUTS-3 levels. In the case of Germany, we followed the national classification “*Raumordnungsregionen*,” which splits Germany into 96 different regions (BBSR 2017). Due to territorial changes over time, we had to make minor adjustments to the official NUTS classification for Italy (see online supplementary Table A1 for details). We harmonized varying age intervals by using the `ungroup` package in R (Pascariu et al. 2018). This function allows the ungrouping of death and population counts into single ages based on a composite-link model (Rizzi, Gampe, and Eilers 2015). Because the model cannot accurately predict death counts at age zero, we estimated the number of region-specific and sex-specific deaths at age zero based on the corresponding share of deaths at age zero observed at the national level whenever data on the actual number of infant deaths by region was not available. The final harmonized dataset includes sex-specific death and midyear population counts for single age groups (0,1,2 ... 90+) in 420 regions. We selected the time span 1995–2019 because it is the longest available time series with data for almost all regions under study (without considering the pandemic years) except Slovakia, for which data

have been available only since 1996. Finally, we calculated period life tables to obtain life expectancy at birth ( $e^0$ ).

We assessed data quality by reaggregating region-specific counts back to the country level and comparing those figures with mortality data from the Human Mortality Database (HMD 2023). The differences between  $e^0$  calculated with our data and the corresponding  $e^0$  values based on data from HMD are generally minimal (the mean difference is 0.07 years, and the largest difference is observed for Slovakia before the year 2000, i.e., a maximum of 0.6 years observed for women in Slovakia in 1999). The deviation is larger among women, with greatest deviations for Portugal, Slovakia, and the Netherlands (mean differences, respectively: 0.22, 0.18, and 0.16 years). For men, the largest deviations are found in France, Slovakia, and Hungary (mean differences, respectively: 0.15, 0.15, and 0.14 years). Finally, all region-specific  $e^0$  trends have been visually inspected to ensure that there are no inconsistencies such as breaks in the time series that would make the choice of smoothing death rates over age and time unreasonable.

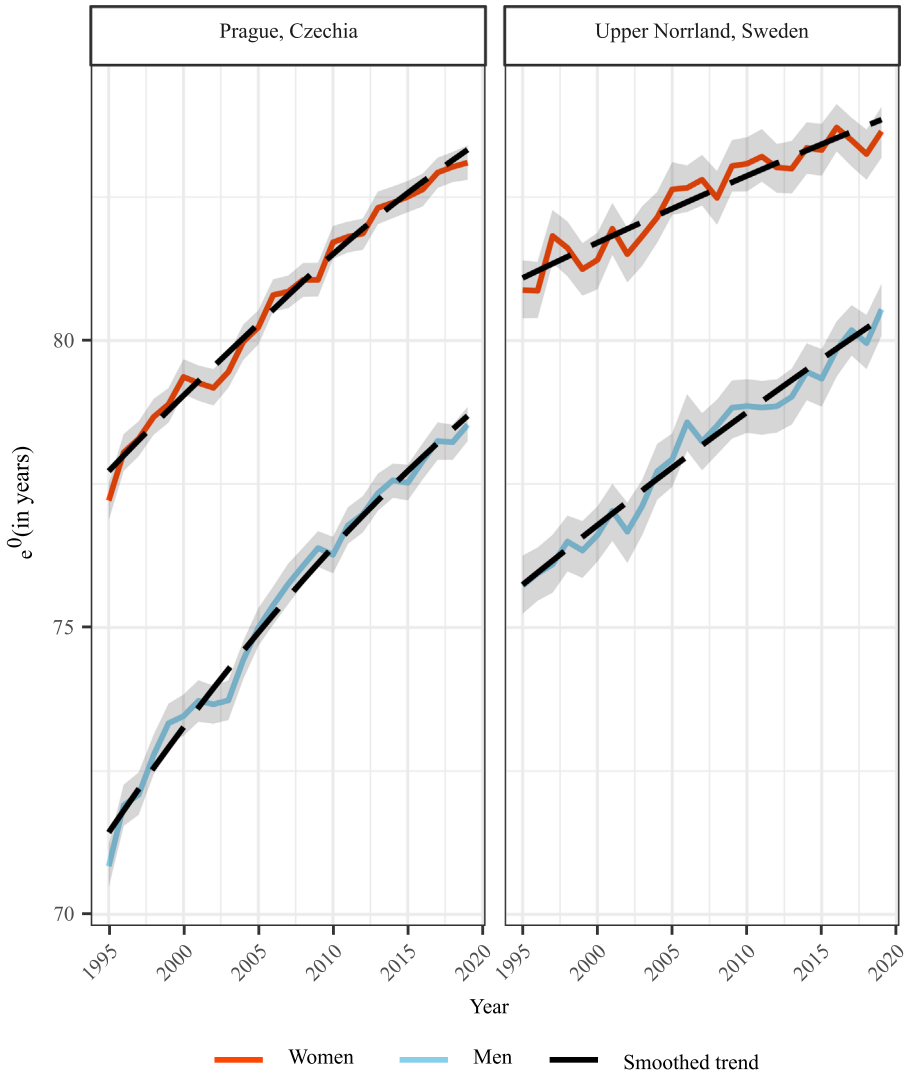
When analyzing subnational data, significant fluctuations in  $e^0$  may occur. To distinguish meaningful trends from random fluctuations in mortality, we smooth our data by CP-splines (Camarda 2019). This approach addresses mortality issues, particularly at age zero, and models data across age and time dimensions. Instead of directly modeling  $e^0$ , mortality is here integrated within a statistical framework, enabling us to derive  $e^0$  from estimated mortality rates.

Figure 1 serves primarily to demonstrate the efficacy of the smoothing method employed in capturing observed trends at the  $e^0$  level. The figure depicts  $e^0$  trends based on observed and smoothed data for Prague in the Czech Republic and Upper Norrland in Sweden. The gray-shaded area corresponds to the 95 percent confidence boundaries of  $e^0$  calculated from raw data (Chiang 1984). Smoothed  $e^0$  values (dashed line in black) lie mostly within the 95 percent confidence limits of the raw data and are depicted to evaluate the alignment of estimated  $e^0$  values with the uncertainty range of the observed data. Essentially, Figure 1 illustrates that by smoothing across both age and time (spanning 23 years), we ensure the robustness of our estimates. This approach accurately reflects the overall  $e^0$  pattern within a given region, primarily minimizing the impact of random variations resulting from the observation of a small number of deaths. The regional  $e^0$  values with 95 percent confidence intervals and the corresponding  $e^0$  values calculated from smoothed data can be found in the online repository <https://osf.io/z64a7/>.

### Measuring mortality convergence through beta- and sigma-convergence

The methodological framework designed to assess convergence between and within countries differentiates between two distinct types of

**FIGURE 1** Life expectancy at birth ( $e^0$ ) based on smoothed and observed data for two selected regions, 1995–2019



NOTE: Data are the observed life expectancy at birth estimates with 95 percent confidence intervals (gray-shaded band) and the corresponding life expectancy at birth estimates using smoothed age-specific death rates. Own calculations based on official data from statistical offices.

convergence: beta-convergence and sigma-convergence (see Table 1). In demographic and socioeconomic contexts, the former has been applied to various indicators, including  $e^0$  (Janssen et al. 2016), total fertility rate (Dorius 2008), and income per capita (Sala-i-Martin 1996). In accordance with Dorius (2008), we compute beta-convergence as the linear relationship between the annual relative change in life expectancy at birth and its

**TABLE 1 Summary of the beta- and sigma-convergence measurement**

Method	Short description	Statistical approach	Interpretation
Beta-convergence	It measures whether those regions with initially low $e^0$ levels have experienced larger gains in $e^0$ as compared to regions with rather high $e^0$ levels in the base year.	Regressing the change in regional $e^0$ on the regional $e^0$ level in the base year	<p>A positive sign on the <math>\beta</math> coefficient in the fitted regression model suggests larger gains in <math>e^0</math> for regions with higher <math>e^0</math> values in the base year                      → no beta-convergence</p> <p>A negative sign indicates that regions with initially lower levels in <math>e^0</math> experienced larger increases in <math>e^0</math> as compared to vanguard regions                      → beta-convergence</p>
Sigma-convergence	It measures the dispersion of the regional distribution of $e^0$ .	Examining time trends in standard deviation for regional $e^0$	<p>Increasing standard deviation for regional <math>e^0</math> over time indicates that <math>e^0</math> values have become more spread out                      → no sigma-convergence</p> <p>Decreasing standard deviation for regional <math>e^0</math> over time indicates <math>e^0</math> values have become more clustered around the mean                      → sigma-convergence</p>
Decomposition analysis for sigma-convergence	The exercise seeks to provide insights into the regions contributing to the change in standard deviation for regional $e^0$ between two points in time.	Using the stepwise-replacement algorithm (Andreev et al. 2002) to decompose the difference in standard deviation for regional $e^0$ between two points in time into the contributions of regions with different $e^0$ levels in the base year.	<p>Assuming mortality has been declining over time, the change in standard deviation for regional <math>e^0</math> is affected by the group-specific gains in <math>e^0</math>. For instance, larger <math>e^0</math> gains for regions that were already advantaged in the base year lead to an increase in variance.                      → No beta-convergence and no sigma-convergence</p> <p>Standard deviation for regional <math>e^0</math> decreases between two points in time whenever increases in <math>e^0</math> are found to be larger in the laggard group, that is, those regions with low <math>e^0</math> levels in the base year                      → beta- and sigma-convergence</p>



starting level. Let denote by  $e_{t,i}^0$  the smoothed life expectancy at birth value in year  $t$  for region  $i$ . The equation for beta-convergence, computed in the time interval  $[t, t + n]$ , is given by

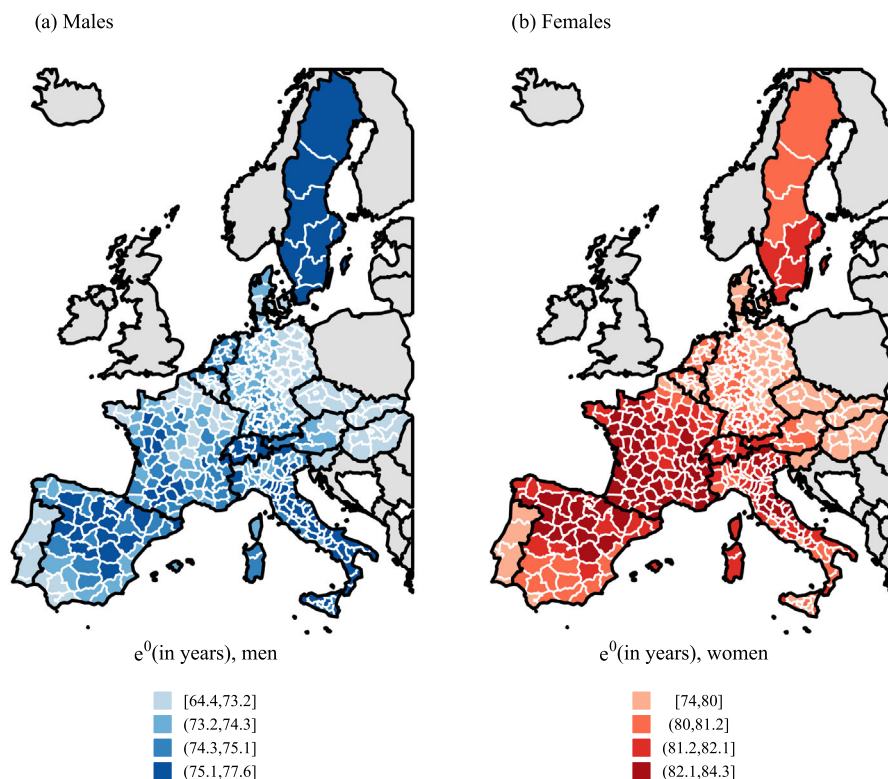
$$\Delta \ln(e_{t,i}^0) = \frac{\ln\left(\frac{e_{t+n,i}^0}{e_{t,i}^0}\right)}{n} = \alpha + \beta e_{t,i}^0 + \varepsilon_i, \quad (1)$$

where  $\ln$  is the natural log,  $\alpha$  is the intercept, and  $\varepsilon_i$  denotes the error term. The focal point of interest centers around the estimated slope, represented by  $\beta$ , which lends its name to the type of convergence. Convergence occurs with a negative  $\beta$  coefficient, that is, when the annual growth rate of  $e^0$  is larger for regions with initially low  $e^0$  levels. In contrast, a positive sign on the  $\beta$  coefficient indicates that those regions with comparatively high  $e^0$  levels in the baseline year experienced larger  $e^0$  gains over the analyzed time period. The level of  $\beta$  of the regression model can be interpreted as the magnitude of observed convergence or divergence.

In our study, we first look at beta-convergence for the whole period, 1995–2019. We then evaluate beta-convergence in five different periods: 1995–2000, 2000–2005, 2005–2010, 2010–2015, and 2015–2019. Equation (1) is a simple linear regression model that can be estimated either by ordinary least squares (OLS) or weighted least squares. In the latter setting, weights correspond to the proportions of individuals living in each spatial unit. While the population-weighted approach accounts for how many individuals are subjected to mortality changes, OLS treats each spatial unit equally. Our main results remain robust regardless of the choice of the estimation method (weighted vs. unweighted). For clarity and conciseness, we present unweighted results in the main text, while the corresponding weighted figures are available in the online supplement material. In addition, we checked the robustness of our results by using the absolute difference in  $e^0$ ,  $\Delta e_{t,i}^0 = e_{t+n,i}^0 - e_{t,i}^0$ , instead of focusing on the annual relative change in  $e^0$  (see left-hand side of Equation (1)). The regression results based on the absolute difference in  $e^0$  (population-weighted and unweighted) are very similar to the results presented in the main text and can be found in the online Appendix (Table A3) as well. Sigma-convergence reflects changes in the dispersion of the regional  $e^0$  distribution over time. When regional  $e^0$  values are more equally distributed at a second point in time as compared to the initial time period, we assume that sigma-convergence took place.

In this paper, we measure dispersion in the distribution of regional  $e^0$  in terms of time trends in the standard deviation (SD). Our statistical analysis includes time trends in SD for all 420 regional  $e^0$  estimates as well as country-specific SD using the regional  $e^0$  values for each of the 16 countries. We choose SD because it has a clear interpretation (the standard deviation

**FIGURE 2** Life expectancy at birth ( $e^0$ ) in 1995 grouped in terms of quartiles for women and men separately



NOTE: The map depicts the quartile distribution of life expectancy at birth estimates for 420 regions (Azores, Madeira, and the Canary Islands not shown) using smoothed data. Own calculations based on official data from statistical offices.

from the mean  $e^0$  value with life years as the unit) and can be calculated as an unweighted as well as population-weighted measure (Edwards and Tuljapurkar 2005; Timonin et al. 2017).

Finally, we examine which regions contributed most to the change in SD by applying the stepwise-replacement algorithm (Andreev et al. 2002) using the DemoDecomp package (Riffe 2018). This exercise helps us in examining whether the change in the variability of regional  $e^0$  is mainly due to changes in  $e^0$  for regions with initially high or low mortality levels. Accordingly, it makes sense to group our regions in terms of their  $e^0$  level in 1995. We use the quartiles of the regional  $e^0$  distribution in 1995 because four groups should be sufficient to cover the most important geographical variation in  $e^0$  across Europe. Also, the division of regions into four groups simplifies the interpretation. Indeed, regions joining the EU in 2004 as well as eastern Germany belong to the first quartile (see Figure 2). All statistical analyses were conducted in R (R Core Team 2023).

It is finally worth emphasizing that sigma and beta-convergence are not independent from each other. It has been shown, for example, that beta-convergence is a necessary condition for sigma-convergence (Gächter and Theurl 2011). In other words, the regional  $e^0$  distribution can only become more equal over time when laggard regions have experienced larger gains in  $e^0$  than vanguard regions. Yet, the relationship between beta- and sigma-convergence does not imply that beta-convergence necessarily results in sigma-convergence. Janssen et al. (2016) list several reasons why beta-convergence may not lead to sigma-convergence, including random fluctuations in the regional  $e^0$  estimation for the base or final year and differences in  $e^0$  trajectory between regions falling in the tail of the regional  $e^0$  distribution and regions which show  $e^0$  values closer to the mean. In these cases, it is possible to statistically measure beta-convergence without sigma-convergence. Accordingly, they sum up their discussion on the relationship between beta- and sigma-convergence by concluding: “The simultaneous study of both sigma and beta convergence is therefore necessary” (Janssen et al. 2016, 89).

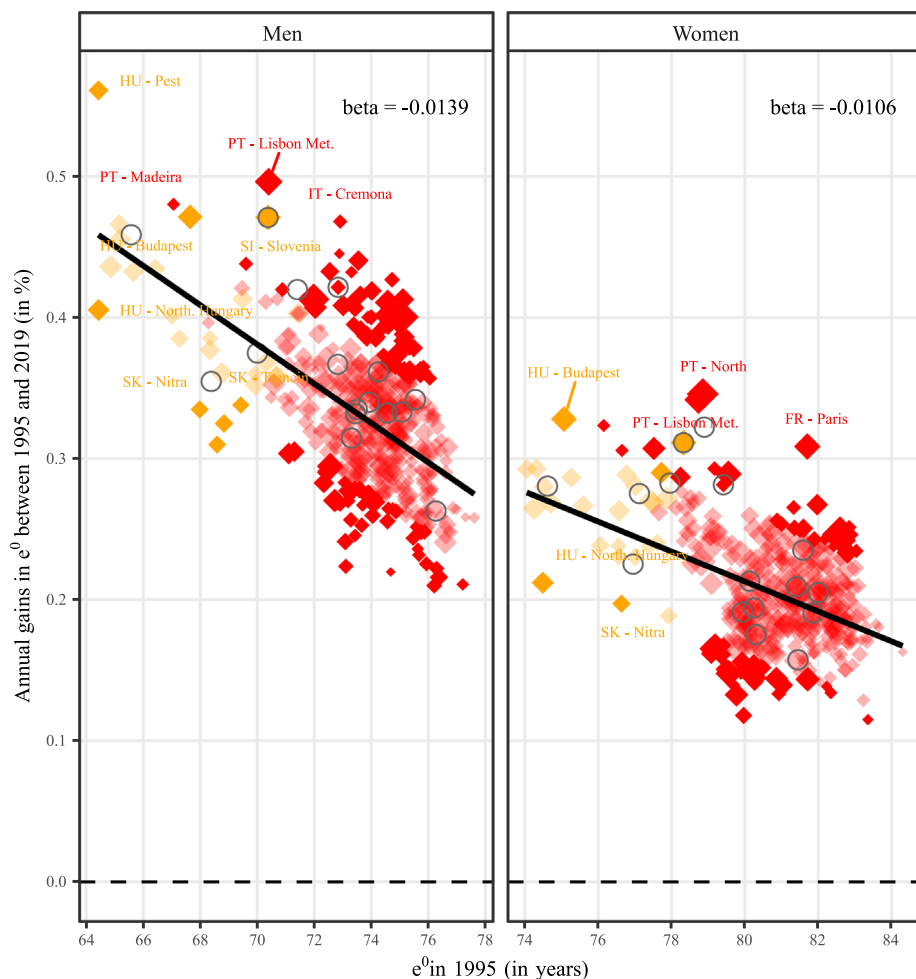
Previous work on mortality convergence in Europe by Hrzic et al. (2020, 2021) suggests the occurrence of beta-convergence without sigma-convergence. Yet, we have mentioned the data limitations of previous studies in the Introduction. In this paper, in addition to expanding the number of countries under analysis, we successfully address these data limitations as well. Using the smoothed  $e^0$  values instead of relying on raw estimates with potentially large random fluctuations and looking at the trajectories of the regions in the tails of the distribution, we aim to obtain a more comprehensive picture of the mortality convergence across Europe.

## Results

### Distribution of life expectancy at birth ( $e^0$ ) levels across Europe's regions in 1995

In the earliest year of the analyzed time period, Europe's mortality pattern can be described broadly by an east–west gradient with the lowest  $e^0$  levels observed in central-eastern Europe. Yet, the mortality map (Figure 2) reveals that Portugal, some regions in northern France, and Denmark show rather low  $e^0$  in 1995 levels as well. The most advantaged regions in terms of their mortality level can be found in parts of France, Italy, central Spain, and Switzerland. The geographical distribution of  $e^0$  is very similar for both sexes, but men show a considerably lower mortality level. Their values range from 64.4 to 77.6 years, while  $e^0$  estimates for women fall between 74.1 and 84.3 years. Accordingly, variation in  $e^0$  is slightly larger in the male population (distance in  $e^0$  is 13.2 years for men vs. 10.2 years for women).

**FIGURE 3** Annual rate of change (in percent) in life expectancy at birth ( $e^0$ ), regressed on life expectancy at birth in the base year, 1995–2019

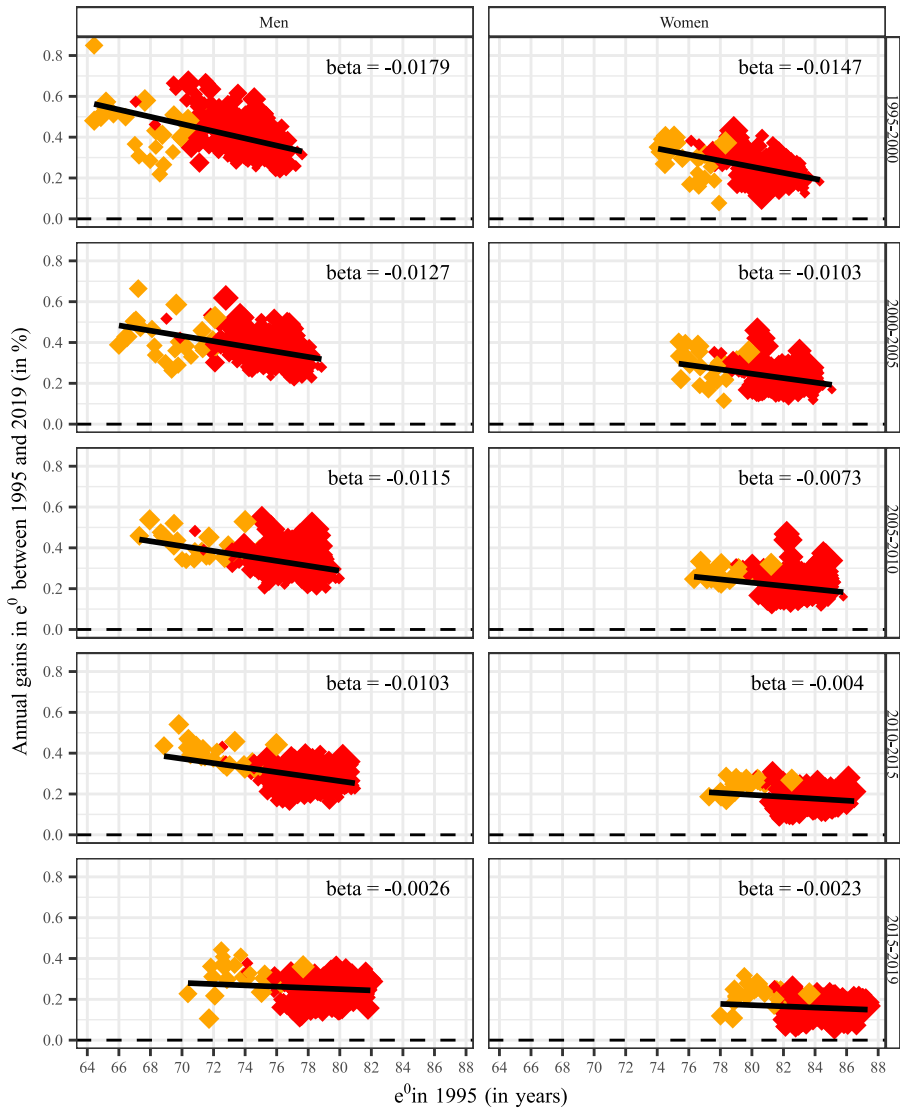


NOTE: Each square drawn in the figure refers to regional life expectancy at birth estimates using smoothed data, while the circles represent the corresponding national life expectancy at birth estimates. The yellow-colored squares depict regions that joined the EU in 2004, while the remaining regions are drawn in red. The size of each square is proportional to the region-specific population size. Transparent points depict regions with an absolute value of the difference between their observed growth rate and their expected growth rate defined by the regression line lower than 5 percent. The unweighted regression line (black line) is calculated from Equation (1). Own calculations based on official data from statistical offices.

### Beta-convergence: The catching-up of regions located in central-eastern Europe

Figure 3 presents the association between the initial  $e^0$  level and the annual rate of change in  $e^0$  for women and men between 1995 and 2019. The squares drawn in the graph correspond to the 420 regions. Regions joining the EU in 2004 are presented in yellow squares, and the remaining regions

**FIGURE 4** Annual rate of change (in percent) in life expectancy at birth ( $e^0$ ), regressed on life expectancy at birth in the base year in five different periods



NOTE: The same as in Figure 3.

in red squares. The size of each square is proportional to the region-specific population size. In addition, we include values for the whole country as circles. The beta-convergence models can be estimated for the shorter time periods 1995–2000, 2000–2005, 2005–2010, 2010–2015, and 2015–2019, as shown in Figure 4. Please note that Figures 3 and 4 refer to an unweighted estimation procedure using the  $e^0$  growth rates. In the online Appendix, Table A2 presents the corresponding unweighted and population-weighted

regression results while Table A3 shows the unweighted and population-weighted regression results using the absolute gain in  $e^0$  as the dependent variable. All versions of Figures 3 and 4 (using absolute  $e^0$  gains or the growth rate of  $e^0$  in an unweighted or population-weighted setting) can be found in the aforementioned online repository. The regression lines drawn into each scatterplot indicate which regions have experienced lower or higher  $e^0$  gains than expected from the fitted regression model. In other words, those regions located below the regression line can be seen as underperforming in terms of their past  $e^0$  gains and vice versa.

In 1995,  $e^0$  was comparatively low in eastern regions as most of the yellow points are located on the left-hand side of the graph (between 64 and 75 years for men and about 74–80 years for women). The annual rate of change in  $e^0$  over the period 1995–1999 is particularly large in several eastern and some southern regions such as Budapest, Slovenia, Lisbon, and Cremona in Italy. Yet, not all regions located in the east have experienced large gains in  $e^0$ , as we find also many yellow squares below the regression line, for example, the Žilina and Nitra regions in Slovakia as well as northern Hungary).

The fitted regression line has a negative slope, indicating that regions with initially lower  $e^0$  values show generally larger gains in  $e^0$  between 1995 and 2019. For women and men both, the  $\beta$  coefficient is statistically significant (see Table A2), providing empirical evidence for beta-convergence over the whole period 1995–2019. However, beta-convergence occurs more rapidly among men as indicated by the higher  $\beta$  coefficient.

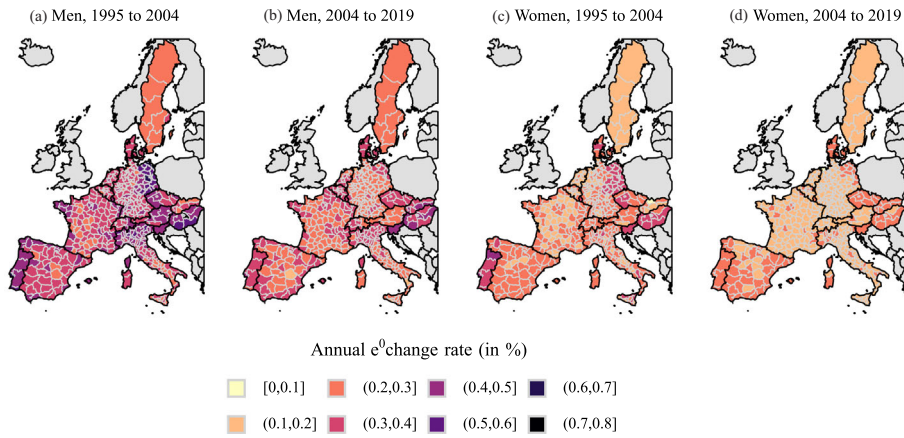
While the analysis suggests mortality convergence between 1995 and 2019, looking at specific periods reveals that most of the convergence occurred during the first half of the analyzed time span. Over the last two analyzed periods, the slope of the regression line is less steep and the estimated  $\beta$  coefficients are closer to zero. Further, coordinates for most of the regions have shifted from the upper left to the lower right over time, indicating that  $e^0$  gains are getting smaller with increasing  $e^0$  levels.

The catching-up of the CEE regions is apparent in Figure 4. The yellow-colored dots representing regions in central-eastern Europe move from below to above the regression line over time. Most European regions have already reached a high  $e^0$  level and further gains are difficult to realize, while regions in central-eastern Europe still have room for improvement.

It is not surprising to see consistently lower gains in  $e^0$  for women as compared to men because they started from a substantially lower mortality level. In other words, they have progressed further in the health transition.

The leveling off in  $e^0$  improvements over time is illustrated by the period-specific heatmaps of the annual rate of change in  $e^0$  (Figure 5). As expected, these maps reveal that the highest gains in  $e^0$  were observed in the first period (1995–2004) for regions in central-eastern Europe, namely regions located in eastern Germany, the Czech Republic, Slovakia, Hungary,

**FIGURE 5 Annual life expectancy at birth ( $e^0$ ) change rate for the periods 1995–2004 and 2004–2019**



NOTE: The map depicts the annual rate of change in life expectancy at birth estimates for 420 regions (Azores, Madeira, and the Canary Islands not shown) in two different periods using smoothed data. The annual rate of change is calculated as shown in Equation (1). Own calculations based on official data from statistical offices.

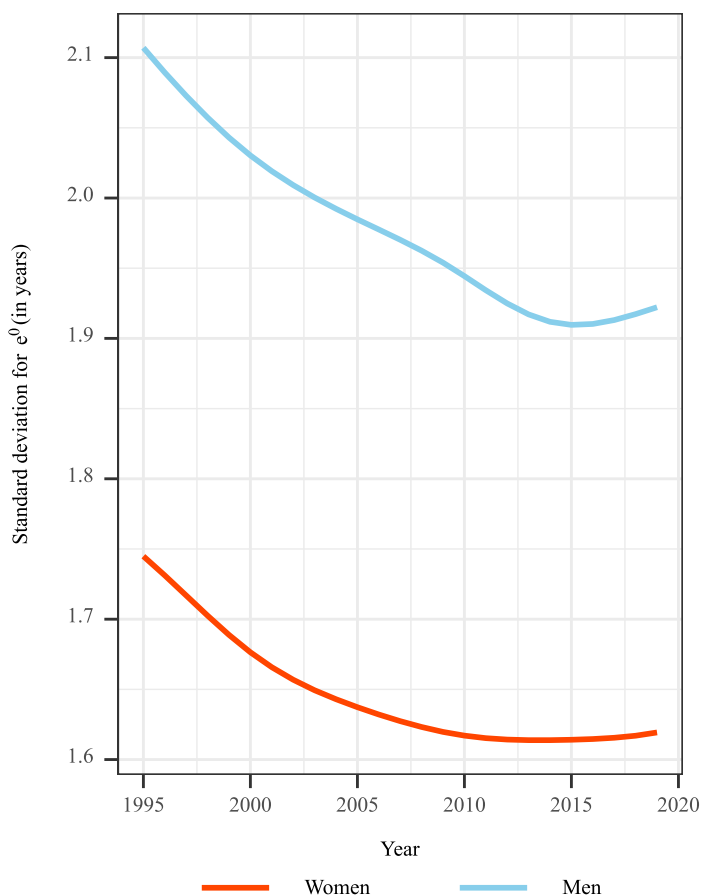
and Slovenia. Yet, not all regions in central-eastern Europe have followed the same trajectory. The group includes several regions with rather small  $e^0$  gains during the 1990s and early 2000s as well. Those regions have started to catch up in terms of their  $e^0$  levels only in the later periods as indicated by the yellow-colored dots drawn above the regression lines in Figure 4. Apart from the CEE countries, high  $e^0$  gains are also found in northern Italy, Portugal, Denmark, and Brittany (France). In general, improvements in  $e^0$  are considerably smaller for more recent years (the period 2004 to 2019).

In general, results hold for women and men alike. Yet, the magnitude of improvements in  $e^0$  is lower among women although differences by sex can be found in some countries. In Italy, for example,  $e^0$  gains are less concentrated in the north when looking at women, that is, improvements can be observed for southern regions as well. Finally, several regions in Spain have experienced above-average  $e^0$  gains among women, while  $e^0$  gains for Spanish regions are higher on average among men. Mortality maps for individual subperiods are presented in Figures A1 and A2 in the online Appendix.

### Sigma-convergence: Variation in regional life expectancy at birth ( $e^0$ ) decreases over time

Figure 6 depicts the time trend of SD between 1995 and 2019. While men show large reductions in SD between 1995 and 2015, women's decreases occurred mostly between 1995 and 2005. Since then, SD seems to have stagnated or even to have slightly increased. Variation in regional  $e^0$  de-

**FIGURE 6** Standard deviation in regional life expectancy at birth ( $e^0$ ), 1995–2019



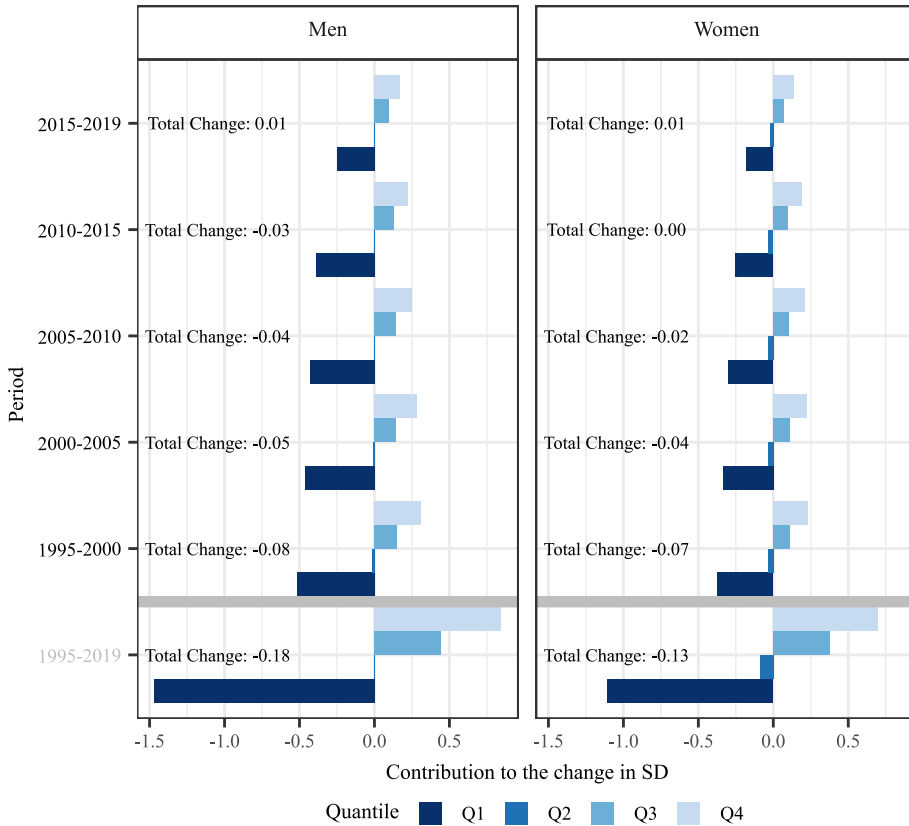
NOTE: Data are the unweighted standard deviation in regional life expectancy at birth estimates using smoothed age-specific death rates. Own calculations based on official data from statistical offices.

creased from 2.1 to 1.9 years among men, while women's SD dropped from 1.7 years to 1.6 years during the same period. The change in SD between 1995 and 2019 can be attributed mostly to the catching-up of regions with initially low  $e^0$  levels.

Figure 7 reveals the specific contributions to the change in SD between 1995 and 2019. For instance, regions that were in the first quartile in terms of their  $e^0$  level in 1995 (as shown in Figure 2) exhibit significant negative contributions to the change in SD. This suggests that their gains in  $e^0$  lead to a reduction in SD. In contrast,  $e^0$  gains for the other quartiles widened the distance between the vanguard and laggard regions, resulting in positive contributions. As we observe greater gains in  $e^0$  for laggard regions, the negative contribution of the first quartile group outweighs the positive



**FIGURE 7** Decomposition of the change in standard deviation for regional life expectancy at birth ( $e^0$ ) into the contribution of each quartile group

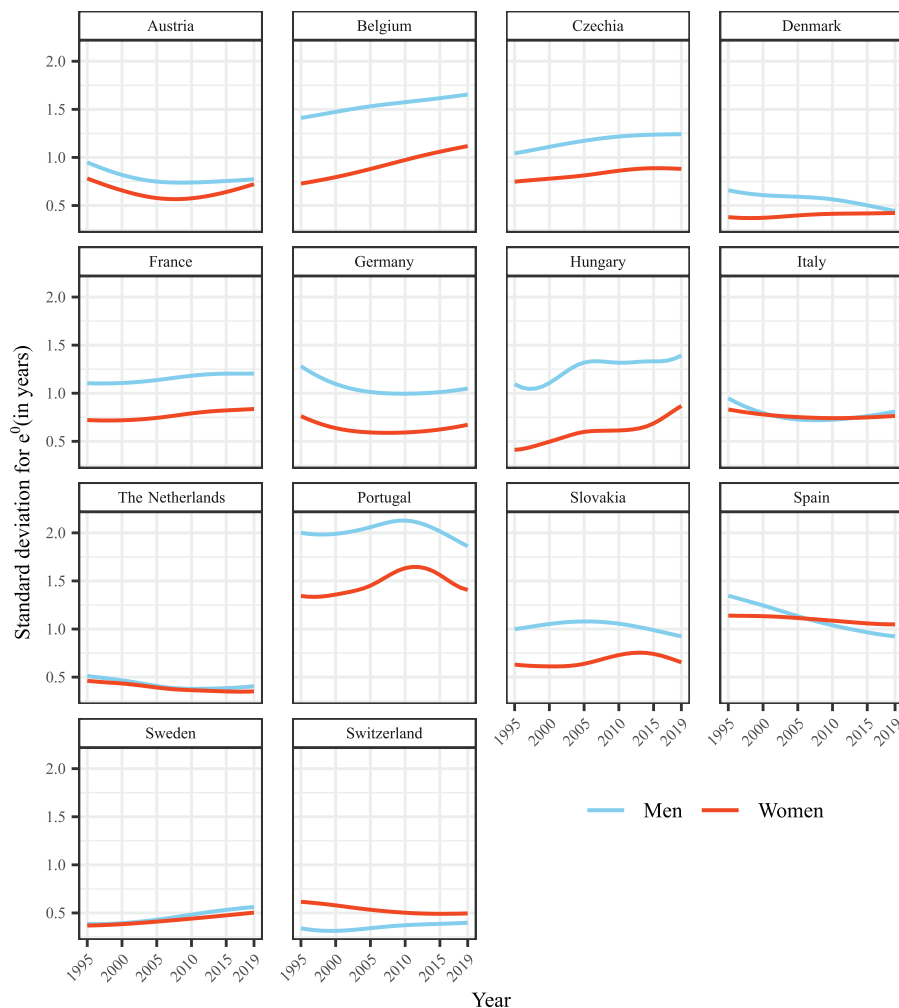


NOTE: The figure depicts the decomposition of changes in the unweighted standard deviation in regional life expectancy at birth using smoothed age-specific death rates for six different periods. The bars correspond to the contribution of each quartile (see Figure 2 for the quantile distribution of regional life expectancy at birth estimates). Own calculations based on official data from statistical offices.

contributions of all higher quartile groups, leading to a decrease in SD over time. Our results based on population-weighted SD are very similar as shown in Figures A3 and A4.

Finally, we have represented in Figure 8 the evolution of regional standard deviations for each country in our panel, for men (in red) as well as for women (in blue). This figure demonstrates that the evolution of regional disparities in longevity varies greatly from one country to another. Thus, there is a significant increase since 1995 in Hungary (+110 percent for women, +27 percent for men), Belgium (+53 percent for women, +17 percent for men), Sweden (+46 percent for men, +37 percent for women), the Czech Republic (+19 percent for men, +18 percent for women), and France (+16 percent for women, +9 percent for men). In other countries where we observe a decrease in disparities over the entire period, we can

**FIGURE 8 Standard deviation for regional life expectancy at birth ( $e^0$ ) from 1995 to 2019, by country**



NOTE: Data are the unweighted standard deviation for regional life expectancy at birth for each country. Life expectancy at birth is calculated from smoothed age-specific death rates. Own calculations based on official data from statistical offices.

nonetheless see an increase in recent years. This is the case notably for Austria, Germany, as well as Italy, Switzerland, and the Netherlands for men only. Finally, contrary to these worrying trends, a last group of countries still benefits today from convergence in terms of regional longevity: Spain since 1995 and Slovakia and Portugal only in recent years.

Interestingly, Figure 8 also reveals that regional disparities in longevity are much stronger among men than among women in most countries (Belgium, Czech Republic, France, Germany, Hungary, Portugal, Slovakia).

However, this observation does not hold for all: the gap between female and male standard deviations has significantly narrowed in other countries (Austria, Denmark), or has never existed since 1995 (Italy, the Netherlands, Sweden). In some extreme cases, the standard deviation is even higher for women than for men (Switzerland, Spain since 2007).

## Discussion and conclusion

### Summary of the main results

In our paper, we analyzed trends in regional  $e^0$  for 420 spatial units in 16 European countries between 1995 and 2019. We observed the largest  $e^0$  gains among regions with comparatively high mortality levels in 1995. These regions included not only those in formerly socialist countries but also parts of Portugal and Brittany in France. Additionally, we noted substantial increases in  $e^0$  among men in northern Italy. However, for women in northern Italy, their  $e^0$  was already relatively high in 1995, leaving less potential for further improvement. The timing of laggard regions catching up with vanguard regions in terms of their  $e^0$  levels can differ within countries. For instance, regions in Slovakia do not follow the same  $e^0$  trajectory over the observed time period. While some regions, such as Bratislava and its surroundings, showed exceptionally large  $e^0$  gains in the mid-1990s and early 2000s, other regions made little progress in reducing mortality during the same period. However, from 2005 onwards all Slovak regions started to increase their  $e^0$  levels substantially. Overall, we find clear empirical evidence supporting beta-convergence in Europe's regional  $e^0$  levels, particularly from 1995 to 2014 for men and from 1995 to 2009 for women.

The catching-up process for regions with initially high mortality levels has led to decreases in the variability of regional  $e^0$ . This process can be described as sigma-convergence. We can quantify the magnitude of sigma convergence by examining and decomposing changes in SD over time. Indeed, we observe sigma-convergence between 1995 and 2019. Yet, within-country variability increased for several European countries, so our results should not be interpreted as a general reduction in the dispersion of regional  $e^0$ .

### Interpretation

The CEE countries of the EU have experienced steep increases in life expectancy since the 1990s due to the modernization of the healthcare system and access to medical innovations, resulting in a reduction in the initially high levels of cardiovascular mortality (Meslé and Vallin 2002; Grigoriev and Pechholdová 2017). In addition, policy changes and more

investments in CEE countries during the EU pre-accession phase might have resulted in fast  $e^0$  growth and mortality convergence in the 1990s and early 2000s (Hrzic et al. 2021). Previous studies have primarily examined this process from the national perspective (Karanikolos, Adany, and McKee 2017; Mackenbach et al. 2013; Meslé and Vallin 2017). However, analyzing trends in regional  $e^0$  reveals that improvements in mortality are not always uniformly distributed within countries. For instance, we found that capital regions and surrounding areas, such as Prague and Bratislava, showed earlier and larger increases in  $e^0$  compared to other regions in the same country. This result can be attributed to the earlier onset of the cardiovascular revolution in urban areas, which were the first to benefit from the modernization of the healthcare system (Shchur et al. 2021; Timonin et al. 2020). Urban and rural areas differ in terms of their population composition by socioeconomic status, with urban areas typically attracting individuals of higher socioeconomic status. Improvements in socioeconomic conditions and higher proportions of those with higher education are important drivers for longevity gains. Accordingly, the regions showing progress in their economic development are also those with larger gains in  $e^0$  (Sauerberg et al. 2024). Individuals with higher educational attainment can be seen as the vanguard group in terms of adopting new medical knowledge and changing lifestyle habits, resulting in their advantage in reducing mortality (Lutz and Kebede 2018; Preston 1975; Mackenbach 2020; Jasilionis and Shkolnikov 2016; Shkolnikov et al. 2006).

Not just the former socialist countries exhibited relatively low levels of  $e^0$  during the 1990s, followed by remarkable mortality reductions, but we also observe a similar pattern for Portugal and parts of northern Italy (among men). In these regions,  $e^0$  lagged behind in 1995 but then increased strongly over time. It is important to note, however, that despite these improvements, the  $e^0$  level was still considerably higher than in the formerly socialist countries. We grouped regions in terms of quartiles for the regional  $e^0$  distribution in 1995. Due to the large variability in regional  $e^0$  during the 1990s, the first quartile includes a wide range of  $e^0$  levels (74–80 years for women and 64–73 years for men). The reason why Portugal transitioned from an underperforming country into an overperforming one is likely related to its slow educational expansion and high mortality from AIDS during the 1990s, followed by favorable mortality trends due to fewer ischemic heart diseases and low lung cancer mortality rates compared to other European countries (Mackenbach 2020).

In Italy, mortality levels were higher in the north than in the south during the 1970s and 1980s, especially among men (Caselli et al. 2003). The change in the geographical pattern, with the highest mortality levels in Italy shifted from the north to the south, has been ascribed to changes in death rates from lung cancer as well as ischemic heart diseases. The

less affluent southern regions might have initially excelled in primary and secondary prevention, but subsequently, the economically prosperous northern regions could more effectively reduce their initially high mortality level (Caselli et al. 2003). Consequently, we observe steep increases in  $e^0$  during the 1990s and early 2000s. In more recent years,  $e^0$  is even higher in the north as compared to the southern part of Italy.

Our results are consistent with those of Hrzic et al. (2020, 2021). We observe beta convergence, indicating a reduction in the disparities of regional life expectancy, but also increases in the dispersion of regional  $e^0$  within countries. For instance, we find significant regional disparities in  $e^0$  trends for Western Germany, France, Italy, and Sweden. The reasons for these inequalities in mortality are well-documented (Jasilionis et al. 2014; Meslé and Vallin 2002; Mackenbach 2013; Lutz and Kebede 2018). As mentioned above, gains in  $e^0$  are strongly linked to the development of socioeconomic factors such as income or educational attainment. Regions can show diverging mortality trends because they attract and select different groups of individuals. For instance, highly qualified individuals are more likely to relocate to economically strong regions such as Paris, Munich, or Stockholm, while those with lower qualifications are more commonly found in structurally disadvantaged regions. The observed increases in country-specific SD can be interpreted as a sign of widening socioeconomic inequalities, whereby a more privileged population group achieves mortality reductions steadily, while the disadvantaged group experiences stagnation and falls further behind.

The presented results suggest that trends in the national average  $e^0$  value can obscure important differences at the subnational level. For instance, while Sweden showed exceptionally low mortality levels in 1995, most Swedish regions were then continuously underperforming with respect to their  $e^0$  gains between 1995 and 2019. Only the Stockholm region managed to reduce mortality at a moderate pace over the analyzed time span. These gains are disproportionately reflected in the national-average  $e^0$  trend due to the high weight of the capital region which comprises about 20 percent of the population. In other words, recent trends in Swedish  $e^0$  can be mainly attributed to mortality reductions for individuals living in the Stockholm region.

Regardless of the initial mortality level of a region, we observe the pace of  $e^0$  gains slowing down over time. The decline in longevity improvements has been mentioned in the previous literature (Ho and Hendi 2018; Cardona and Bishai 2018; Carnes and Olshansky 2007). It should be noted, however, that the magnitude of  $e^0$  gains naturally declines with increases in the  $e^0$  level because progress in reducing age-specific death rates will result in a smaller number of additional life years as  $e^0$  increases (Keyfitz 1977; Pollard 1982; Arriaga 1984; Vaupel 1986). This relationship also implies that the observed slowing in  $e^0$  gains does not neces-

sarily mean that age-specific death rates have stopped declining further (Schoen 1976).

In light of these considerations, assessing the impact of the EU enlargement in 2004 on mortality convergence in Europe becomes a challenging task. Countries in central-eastern Europe have experienced their strongest  $e^0$  gains during the 1990s, while further increases in  $e^0$  after 2004 were substantially lower. The magnitude of both beta-convergence (measured through the regression slope) and sigma-convergence (measured through SD in regional  $e^0$ ) has been decreasing over time. In more recent periods, the  $e^0$  gains for laggard regions do not exceed the increases in  $e^0$  for vanguard regions, resulting in the stagnation of mortality convergence. Yet, the steady gains in  $e^0$  (even though slowly declining) for exceptionally low-mortality areas such as the Lake Geneva region in Switzerland, with a  $e^0$  value of almost 86 for women, may indicate that there is still potential for further mortality reductions in many European regions. Future mortality convergence or divergence might depend on whether Europe can transition from low to very low mortality levels uniformly or if further mortality reductions will be limited to the most privileged regions.

### Strengths and limitations

In this paper, we use a unique dataset which enables us to estimate annual life expectancy values for 420 regions in 16 European countries from 1995 to 2019. To the best of our knowledge, this is the first study providing such a long time series for regional life expectancy in various European nations. Still, our study is not free of data limitations. We could not obtain a comparable time series of regional  $e^0$  values from 1995 to 2019 for all EU member states. Countries such as Poland, Latvia, and Lithuania joined the EU in 2004 but are missing in our analysis. This is why our findings cannot be used to make generalizations about the impact of the EU enlargement on mortality convergence in Europe without caveat.

Previous studies have revealed that poor accounting for international and internal migration can limit the accuracy of population data at the subnational level. Issues related to population exposure, that is, the denominator of age-specific mortality rates, can result in biased mortality indicators (e.g., Jasilionis and Leinsalu 2021; Rees, Norman, and Brown 2004). However, this study mitigates such potential bias through several means. First, we mainly focus on changes, and unless this bias disproportionately affects only a few regions, the overall trends should remain accurate. Second, we smooth the actual data, which helps cancel out errors in specific years. Third, we concentrate on a summary measure like  $e^0$  and then compute country-specific variation measures of this metric. Thus, we can reasonably assume that errors in specific regions are offset by this double aggregation.

Furthermore, we chose to analyze the evolution of regional life expectancies in Europe only up to 2019. This decision, in addition to smoothing out mortality rates over time before calculating our regional life expectancies, is explained by our intention to analyze the structural changes in the convergence of living conditions in Europe, without dwelling on conjunctural mortality crises. However, the first studies on excess mortality related to Covid-19 in 2020 and 2021 show that the pandemic heavily affected CEE countries, especially in 2021, and thus likely led to a further increase in inequalities at both national and subnational levels (Schöley et al. 2022; Bonnet et al. 2024; Goldstein and Lee 2024). Future studies, focusing on the postpandemic period should soon reveal whether this anticipated upsurge in inequalities was a temporary phenomenon. What is already clear by now is that the COVID-19 pandemic has created additional obstacles in achieving longevity convergence in the foreseeable future.

## Conclusion

The regional mortality trends in Europe over the past decades have been characterized by two distinct processes. First, the catching-up process of regions in former socialist countries with initially high mortality has led to mortality convergence as well as decreases in the variability of regional  $e^0$ . These regions experienced significant reductions in death rates, primarily attributed to healthcare system modernization, access to medical innovations, and improved living conditions, resulting in steep increases in  $e^0$ .

Second, we observe large heterogeneity in the development of  $e^0$  for the other regions, leading to increases in the variability of  $e^0$  for many European countries. Whether a region succeeds or fails in achieving further mortality reductions depends on several factors, including differences in the socioeconomic situation of a given region or the efficiency of disease prevention and primary care. Our findings unveil a troubling truth: while certain regions flourish, others flounder, deepening health disparities across Europe. This underscores the critical need to address regional inequities in  $e^0$  trends, signaling a pressing urgency to combat the widening health divide in the region.

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## Conflict of interest statement

The authors have no relevant financial or nonfinancial interests to disclose.

## Data availability statement

The data and R code for this study are available on request from the corresponding author. Results and additional figures can be downloaded from <https://osf.io/z64a7/>.

## Ethics approval

This study does not involve human participants.

## Patient consent

This study does not involve human participants.

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