

Lifespan dispersion in times of life expectancy fluctuation: the case of Central and Eastern Europe

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Abstract

Central and Eastern Europe (CEE) have experienced considerable instability in mortality since the 1960s. Long periods of stagnating life expectancy were followed by rapid increases in life expectancy and, in some cases, even more rapid declines, before more recent periods of improvement. These trends have been well documented but to date, no study has comprehensively explored trends in lifespan variation. We improve such analyses by incorporating life disparity as a health indicator alongside life expectancy, examining trends since the 1960s for 12 countries from the region. Generally life disparity was high and strongly fluctuating over the period. For nearly 30 of these years, life expectancy and life disparity moved independently from one another, largely because mortality trends ran in opposite directions over different ages. Furthermore, we quantified the effect of mortality related to alcohol consumption on life disparity since 1994, which was substantial among the countries of the former Soviet Union and less important in Central European countries. Mortality patterns in CEE countries were heterogeneous and run counter to the common patterns observed in most developed countries. They contribute to the life expectancy-disparity discussion by showing that expansion/compression levels do not necessarily mean lower/higher life expectancy or mortality deterioration/improvements.

Introduction

The 20th century was marked by sizable improvements in mortality and health in most countries in the world (World Health Organization 2000). However, these improvements were unevenly shared in the second half of the past century, as parts of Central and Eastern Europe experienced an unprecedented period of stagnation and, in some countries, decrease in life expectancy at birth after 1960 (Human Mortality Database 2016). The long term combination of a failure to complete the epidemiologic transition by reducing cardiovascular diseases (Caselli et al. 2002), along with fluctuation in alcohol and violence, particularly in the countries of the former Soviet Union (FSU) (Bye 2008, Leon et al. 1997), led to lower levels of life expectancy and larger mortality inequalities in this region compared with western countries in Europe (Mackenbach et al. 2008). The high mortality among young men is at the heart of the unstable Eastern European trends in life expectancy (McKee and Shkolnikov 2001). For example, male life expectancy stagnated at a level between 65 and 70 years from the 1960s to the mid-1980s in most countries of the region. Russia experienced the lowest male life expectancy in the region over this period, which was followed by a brief period of sizable improvements in life expectancy due to Gorbachev’s anti-alcohol campaign (Leon and Shkolnikov 1998). After 1987 the mortality experiences in the region diverged. Life expectancy increased continuously in parts of Central Europe. The rest of the countries, particularly those from the former Soviet Union, experienced a pronounced period of deterioration up to the mid-1990s. Mortality increases among Russian and Latvian men were especially sharp, with life expectancy losses of around 7.5 years between 1987 and 1994, which led to levels not seen since the 1950s (Shkolnikov et al. 2001). Since the mid-1990s, life expectancy has mostly been increasing throughout the region, but at different rates. As a result, large regional differences in survival have emerged. For instance, the 2010 gap in male life expectancy between Slovenia and Russia was more than 13 years (Human Mortality Database 2016).

National trends in life expectancy are important and have been extensively studied in the region (Meslé 2004, Meslé et al. 2000, Rychtarikova 2004a, Shkolnikov et al. 2001; 2006, Leon 2011). Nonetheless, as an average, life expectancy conceals considerable heterogeneity in individual mortality trajectories (Edwards and Tuljapurkar 2005, Wilmoth and Horiuchi 1999). This age-at-death variation, hereafter referred to as life disparity or lifespan variation, is an important dimension of inequality as it summarizes this heterogeneity at the population level and uncertainty in the timing of death at the individual level. Until now, trends in lifespan variation have mostly been studied in the context of mortality decline at all ages (Edwards and Tuljapurkar 2005, Smits and Monden 2009, Vaupel et al. 2011). Alongside increases in life expectancy, ages at death have become more predictable (i.e. lifespan variation has decreased). This is because mortality decline over young ages has outpaced mortality decline at older ages, compressing most deaths into a narrower age window (Vaupel et al. 2011).

This need not be the case. At the subpopulation level, numerous instances have been documented of lifes-

pan variation increase occurring alongside increases in life expectancy (van Raalte et al. 2014, Sasson 2016, Seaman et al. 2016, Brønnum-Hansen 2017), mainly due to stalls in working age mortality decline occurring alongside continued old age mortality decline. To date, no comprehensive studies of lifespan variation have been undertaken under periods of life expectancy decline.

We complement the existing literature by focusing on the Central and Eastern European case, which shows atypical periods of mortality upheaval and substantial life expectancy fluctuation. This region is particularly interesting because its age pattern of mortality change was very different from that observed in western countries (Meslé 2004). Since the largest deviations in age-specific mortality occurred over working ages (Rehm et al. 2007), it is a priori unclear what the net effect would be on variability. We analyzed how lifespan variation has changed since the 1960s for 12 countries from this region and determined the ages and causes of death that contributed the most to the observed change in lifespan variation, with a particular focus on the impact of alcohol-attributable mortality.

Data & Methods

Dispersion measure & demographic methods

For each population, we investigated life expectancy and lifespan variation since birth. We decided not to analyze variability at death conditioned on survival to a childhood age, as previous studies have done (e.g. Edwards and Tuljapurkar (2005), Smits and Monden (2009)), because of the arbitrariness of choosing a starting age and because infancy and childhood are major contributors to lifespan inequalities that we did not want to overlook. We focused on five periods determined by trends of the coefficient of variation of male life expectancy. from 1960 to 1980 labeled “Stagnation”, “Improvements” from 1980 to 1988, “Deterioration” in 1988-1994, “Divergence between 1994 and 2000, and “Convergence” thereafter. Periods were determined using a divisive hierarchical estimation algorithm for multiple change points analysis¹The statistical break points were 1960, 1976, 1986, 1993 and 2001. We instead used complete decades or historical events which made the interpretation of the results easier, which were all within 3 years of the cut points. For example, the period 1960-1979 (complete years) included the two decades with no substantial changes in the coefficient of variation between life expectancies. The next break point (1986) was extended to 1988 to include completely Gorbachevs anti-alcohol campaign, which was implemented in the period 1985-1988. The following break point was used exactly since it allows the period 1988-1993 to include the dissolution of the Soviet Union in late 1991 and the largest drops in life expectancy in Russia, Latvia, Estonia, Lithuania, and less marked in Ukraine, Belarus, and Bulgaria in 1992-1993. Finally, the year 2001 was changed to 2000 to start with the 21st century.

Several dispersion measures have been proposed to analyze lifespan variability (van Raalte and Caswell

¹Using the package `ecp` in *R*

2013, Wilmoth and Horiuchi 1999). In this article, we use life disparity (e^\dagger) as a dispersion indicator (Vaupel and Canudas-Romo 2003). It is defined as the average remaining life expectancy when death occurs; or life years lost due to death. For example, when death is highly variable, some people will die well before their expected age at death, contributing many lost years to life disparity. When survival is highly concentrated around older ages, the difference between the age at death and the expected remaining years decreases, and life disparity gets smaller. It can be expressed as

$$e^\dagger = \int_0^\omega d(a)e(a)da \quad (1)$$

where $d(a)$, ω and $e(a)$ are the deaths distribution, the open-aged interval (110+ in our case), and remaining life expectancy, respectively.² We selected this measure because of its easy public health interpretation, which equals the average life expectancy losses attributable to death (Shkolnikov et al. 2011), and its decomposable and additive properties (Zhang and Vaupel 2009). The e^\dagger measure has the additive property that, once it has been decomposed by age between two periods, the sum of every age-specific contribution to the difference is the total change in e^\dagger between these two periods. These properties allow us to quantify the impact of mortality at different ages, and from different causes, and to separate ages that decrease lifespan variability from those that increase it by using demographic methods (Zhang and Vaupel 2009, Shkolnikov et al. 2011). An important attribute of e^\dagger is the so-called threshold age at which mortality improvements have zero effect on lifespan variation (Zhang and Vaupel 2009). Progress in saving lives below this age reduces variation (also called premature deaths), whereas progress above this age increases variation in lifespans (Vaupel et al. 2011).

The decomposition method used in this paper is based on the line integral model Horiuchi et al. (2008). Suppose f (e.g. e^\dagger) is a differentiable function of n covariates (e.g. each age-cause specific mortality rate) denoted by the vector $\mathbf{A} = [x_1, x_2, \dots, x_n]^T$. Assume that f and \mathbf{A} depend on the underlying dimension t , which is time in this case, and that we have observations available in two time points, t_1 and t_2 . Assuming that \mathbf{A} is a differentiable function of t between t_1 and t_2 , the difference in f between t_1 and t_2 can be expressed as follows:

$$f_2 - f_1 = \sum_{i=1}^n \int_{x_i(t_1)}^{x_i(t_2)} \frac{\partial f}{\partial x_i} dx_i = \sum_{i=1}^n c_i, \quad (2)$$

where c_i is the total change in f (e.g. e^\dagger) produced by changes in the i -th covariate, x_i . The c_i 's in equation (2) were computed by numerical integration following the algorithm suggested by Horiuchi et al. (2008). This method has the advantage of assuming that covariates change gradually along the time dimension.

We decomposed mortality by single age, period and cause of death. For the age-cause decomposition we used the 5-year age group mortality rates from the Human Cause-of-Death Database (2016). All the calculations were performed using R (R Core Team 2000) and are fully reproducible with the available code

²The discrete formula from lifetable functions used is $\sum_{x=0}^{109} [d(x)(e(x) + a(x) * [e(x+1) - e(x)]) + d(110+) * e(110+)]$

and additional information³.

The close relationship with other lifespan variation indices, such as Keyfitz’s life table entropy (Vaupel and Canudas-Romo 2003), and the high correlation between them suggests that conclusions would likely be the same regardless of the measure chosen (van Raalte and Caswell 2013, Vaupel et al. 2011, Wilmoth and Horiuchi 1999).

Data

We used all-cause death counts, population exposures and period life tables from the Human Mortality Database (2016) for 12 countries from 1960 to the most recent year available in the data set. The countries included in the study were from what will subsequently be referred to as *Central Europe* (Bulgaria, Czech Republic, Hungary, Poland, Slovakia, Slovenia), *the Baltic countries* (Estonia, Latvia, and Lithuania), and *other FSU* (Belarus, Russia, Ukraine). Data for Slovenia was only available from 1983. The data are by single age, year, sex and country.

Cause of death data came from the newly developed Human Cause-of-Death Database (2016), which provides coherent cause-specific mortality data time series for eight of the countries in the study (Belarus, Czech Republic, Poland, Russia, Ukraine, Estonia, Latvia and Lithuania). For inclusion into the database, a universal and standardized methodology was undertaken to redistribute deaths between 104 disease categories in 5-year age groups. We used these data to get the cause-specific proportion by 5-year age groups. This has effectively eliminated ruptures surrounding revisions of the International Classifications of Disease (ICD), and substantially reduced cross-country comparability problems owing to different coding practices, particularly from the use of ill-defined and unknown causes. We truncated the cause-of-death analysis at age 85 because of classification quality and presence of comorbidities and focus on the period after 1994 because comparable information is available for the eight countries (Human Cause-of-Death Database 2016). Furthermore, we focus on this period because it coincides with the beginning of the divergence in Eastern European mortality trends, particularly between the former Soviet and Central European countries (Meslé 2004).

Cause of death classification

Injurious alcohol consumption has long been identified as a major determinant of premature mortality in Eastern European countries, particularly of the FSU (Leon et al. 1997, McKee and Shkolnikov 2001, Rehm et al. 2007, Grigoriev and Andreev 2015). We aimed to identify the effect of mortality related to alcohol consumption on lifespan variation from 1994 to 2010.

³Link to code removed to avoid identifying information

We grouped causes of death into four categories according to the degree to which they associate with alcohol consumption and abuse (for details on the ICD-10 codes for each cause, see Table 1). The categories are as follows: 1) Alcohol-attributable conditions (for example, mental and behavioral disorders due to use of alcohol, alcohol liver disease, accidental poisoning by alcohol); 2) Conditions amenable to alcohol consumption (such as cardiovascular diseases, and transportation accidents); 3) Other conditions susceptible to alcohol consumption (other external causes); and 4) all other causes (labeled as residual causes). The first category (alcohol-attributable conditions) refers to those health conditions that by the ICD definition identifies alcohol consumption as a necessary cause and that previous research has identified as wholly attributable to alcohol consumption (Rehm et al. 2010). We additionally include liver cirrhosis in this first category because around three-quarters of deaths from this cause in the region are thought to be attributable to alcohol (Rehm et al. 2003), and it is common practice to include it as a condition attributable to alcohol consumption (Rehm et al. 2003; 2010).

The second category, conditions amenable to alcohol consumption, pertains to conditions that are not wholly attributable to alcohol consumption, but that have been linked with alcohol consumption patterns. For example, heavy drinking is associated with physiological mechanisms that increase the risk of IHD and stroke death (Rehm et al. 2010). Similarly, alcohol consumption has been shown to have a causal impact on different injuries (Rehm et al. 2003). We focus on transport injuries because Latvia, Lithuania and Russian report the highest in Europe (Avenoso and Beckmann 2005) and recent developments in infrastructure and safety may have had an important impact in reducing transportation injuries in some countries (World Health Organization 2009; 2013). From this group of causes we are more interested in examining changing trends, which we expect to be more closely related to changing alcohol consumption patterns than the baseline levels, which have numerous determinants.

The third category, other conditions susceptible to alcohol consumption, includes the rest of external causes, such as self-inflicted injuries, and the rest of circulatory diseases. We analyze them separately to complement the broad categories of external causes included in the second category. Although additional rare causes of death can be linked to alcohol consumption, we do not include them in our study because their absolute contributions to mortality change are likely to be very small in the set of countries that we study (Grigoriev and Andreev 2015).

[Table 1 about here]

In what follows, we present our results on Central and Eastern European males only. Mortality change was larger and more abrupt among men, which more clearly illustrates the added value of looking to lifespan

variation in times of crisis. In most cases, trends were similar for both sexes, but the magnitude of change was less for females. Full results are presented in the supplemental material for females.

Results

Age specific rates of mortality improvement

For a descriptive look at age-specific mortality change over the period, we first examined the average annual rate of mortality improvement (Rau et al. 2013) with smoothed mortality surfaces (Camarda 2012) for males in the 12 Central and Eastern European countries 1. The respective values are expressed in percent. Little change or no improvement (-0.5% to 0.5%) is depicted in white. Improvement in mortality (i.e. mortality decline) is shown in blue and mortality increase in red. Darker tones mean major changes in mortality rates.

Almost every country experienced a near-continuous 20-year period of increasing mortality rates, from the mid-1960s to the mid-1980s. Mortality rate increases were mainly concentrated in the ages between 20 and 80 years. After 1985, the Baltic and other FSU countries experienced sizable reductions in mortality rates for a period of around 5 years. This was less evident in Central European countries, with the exception of Poland. Opposing this trend, in the early 1990s the same countries that had made the most progress in reducing mortality experienced intense mortality increases, particularly over working ages. Finally, since the mid to late 1990s trends in the region diverged: Central European countries experienced mortality reduction over nearly every age, as did the Baltic countries of Latvia and Estonia. Russia, Ukraine and Lithuania experienced a second sharp period of mortality increase over working ages in the early 2000s, while age-specific trends in Belarus fell somewhere in between the Baltic and other FSU countries. Since the mid-2000s, all countries have experienced mortality improvement.

[Figure 1 about here]

Trends in life expectancy and lifespan disparity

Figure 2 shows male e_0 and e^\dagger trends for Central and Eastern European countries from 1960 to the most recent year available. From 1960 to 1984 e_0 stagnated for most of the countries, some of them even experienced a slow and steady decline (e.g. Russia, Latvia, Estonia, and Ukraine). This period was followed by a notable increase in e_0 in the mid-1980s, closely corresponding to, although sometimes preceding, Gorbachev's anti-alcohol campaign shaded in red. However, after 1987 life expectancy among these countries started to diverge: Central European countries experienced a short period of stagnation or decline followed by an upward trend until the end of the study. The Baltic and other FSU countries experienced a marked decrease

in e_0 from 1988 to 1994. From that point on, e_0 improved everywhere, with the exception of Lithuania and the other FSU countries. These last countries exhibited a final decrease (Russia, Lithuania) or stagnation (Belarus, Ukraine) in life expectancy between 1998 and the mid-2000s, followed by sharp increases in the final period from the mid-2000s to the latest available year. Estonia experienced particularly rapid improvements in life expectancy since the mid 1990's, especially among women (appendix Fig xx).

Life disparity showed similar patterns of stagnation between 1960 and 1980 as was seen for e_0 . Russia and Lithuania exhibited the highest levels in this period, between 17 and 19 years lost due to death; while the Czech Republic presented the lowest level throughout the same years, between 13 and 14 years. Importantly, the Czech Republic was not the regional record e_0 holder during these years. Around the mid-1980s all countries experienced compression of mortality, i.e. decreases in e^\dagger , with the exception of Hungary. After 1991, Russia and the Baltic countries experienced significant increases in e^\dagger with the peak in 1994-1995. During this peak, the observed e_0 levels differed from historic levels observed when e^\dagger was equally high. Central European countries experienced continuous reductions in e^\dagger after 1994, whereas it was less systematic in Latvia and Lithuania. The rest of the countries also experienced declines after that year up to 2010-2014, but with greater fluctuation. Such declines, however, were not as steep as the e_0 increases in these countries.

[Figure 2 about here]

Absolute and relative changes in life expectancy and lifespan disparity

Contrasting the changing levels of e_0 and e^\dagger from Figure 2 suggests that in periods of stagnation and mortality upheavals similar levels of e_0 do not correspond to similar levels in e^\dagger . Therefore, we analyzed the direction and magnitude of change in the two measures.

Figure 3 shows absolute and relative yearly changes (first differences) in e_0 and e^\dagger for males by period. The periods are grouped by the changes in life expectancy trends depicted in Figure 2: stagnation⁴ from 1960 to 1980, improvements from 1980 to 1987, deterioration from 1987-1994, divergence from 1994-2000, and convergence over the period 2000-2010. If a negative relationship existed between e_0 and e^\dagger , changes would concentrate in the top left and bottom right quadrants. If points fall in the top right and bottom left quadrants, the relationship was positive. We focus on the latter changes and quantify their frequency in three different time periods relating to overall mortality trends. Grey dots correspond to a negative association between life expectancy and life disparity (e.g. increases in e_0 with decreases in e^\dagger), while red dots correspond to a positive association (e.g. increases in e_0 with increases in e^\dagger). Since Russia is both the largest country included in the analysis and the country with the most volatile mortality trends, we marked

⁴We labelled the period as “stagnation”, even though some countries experienced a steady decline, because the coefficient of variation of life expectancies during this period was stagnant.

its points in dark blue. Absolute changes (top panel) are easy to interpret since they reflect the changes in life expectancy and life disparity measured in years. However, since the maximum value of e_0 is much higher than the maximum value of e^\dagger , it is not surprising that changes vary more strongly on the e_0 axis than the e^\dagger axis. Therefore, it is also important to analyze changes in both measures in relative terms (bottom panel). This allows us to quantify the intensity of such changes.

During 1960-1980, almost one-third of the yearly changes in mortality resulted in e_0 decreases and decreases in e^\dagger , in both males (35.45%, 95% CI [29.13,41.78]) and females (32.73 [26.53,38.93]). These were mostly small changes corresponding to less than one year of life. Conversely, 20.00% [14.71,25.29] (males) and 24.55% [18.86,30.23](females) of e_0 increases corresponded to e^\dagger increase. This means that, by adding both quadrants, the measures in this period were moving in the same direction more than half of the time. A similar patterns is shown in the period 1980-1988. In 1988-1994, when most of the changes corresponded to substantial decreases in e_0 , the two indices moved in the same direction about a fifth of the time. Finally in the period 1994 onwards, characterized by mortality convergence, around a third of all points related to movements in the same direction for both measures.

Moreover, even when the two measures moved in the direction expected from a negative correlation, the magnitude of change in life expectancy did not reflect the same magnitude of change in life disparity. For example, Russia lost 3 years of male life expectancy (around 5%) between 1992 and 1993, while life disparity showed a much smaller increase (less than 2.5%). Most of the time, however, e^\dagger experienced larger relative changes than e_0 , evidenced by more movement along the horizontal than the vertical axis in the bottom panel of Figure 3.

[Figure 3 about here]

Age-specific decomposition

Figure 4 shows age-specific contributions to the change in e^\dagger for ages 5 and above⁵, respectively, by period (results for ages 0-4 depicted in Supplemental material Figure 7⁶). The periods are the same as in the previous Figure: stagnation (blue), improvements (green), deterioration (red), divergence (purple), and convergence (orange). The threshold age occurs around the age-groups where changes in lifespan variation are usually the lowest by period (e.g. Russia ages 55-59, Slovakia 65-69, Slovenia 70-74). Bars on the left (decreases in variation) come about from mortality decrease at young ages or increase at old ages, separated by this threshold age. Conversely, bars on the right (increase in variation) are produced by mortality increase

⁵For age-specific contributions to life expectancy, see the supplemental material.

⁶Declines in mortality below age 5 were the strongest age-category contributor to changes in life disparity over the period under study, with most of the decline occurring over the 1960-1980 period. For this reason they are plotted separately from other ages with a different scale used on the x -axis in the supplemental material. The decline was near monotonic in most countries, with only minor differences between countries, especially when compared to the much larger between-country differences at other ages.

at young ages or mortality decrease at old ages. If the colors are all lined up on one side it suggests that mortality changed in different directions for the different ages.

Over the long period of e_0 stagnation (blue), changes in e^\dagger were driven by **mortality increase at all ages above around age 20**, which expanded age at death variability in young-adult ages; and compressed variation at older ages in all countries⁷. It is worth noting that these changes **mostly** offset each other since the old age compression was comparable to the net expansion of mortality experienced by children and younger adults. In fact, in Bulgaria and Belarus, the compression caused by mortality increase over older ages was greater than the expansion made by mortality increase among younger ages. **Maybe put in a footnote here about improving data quality over time which might suggest that the 'increasing' mortality at older ages is an artifact** A similar pattern was observed during the period of e_0 deterioration **among Baltic and other FSU countries following the collapse of the FSU** (red). Lifespan variability mostly increased, which was explained by expansion of mortality at young and middle ages, alongside smaller compression at older ages during this period. **By contrast Central European countries experienced little change in mortality during this period.**

Opposing these trends, over the period of improvements **during the 1980s** (green), **the Baltic and other FSU countries** followed a western pattern with e^\dagger decreases mostly caused by mortality decline at younger ages outpacing mortality decline over older ages and leading to overall compression in mortality. Mortality change was smaller and the age patterns of change were more variable in Central European countries during this period. From 1994 onward (purple and orange), all countries experienced e^\dagger compression at younger ages and expansion at older ages overall. However in the early years (1994-2000), mortality increases at younger ages led to increases in e^\dagger in Russia, Ukraine and Belarus before reversing itself in recent years. Importantly, during this post-1994 period, mortality fluctuations at relatively young ages (20-50) had the largest impact on e^\dagger changes.

[Figure 4 about here]

Alcohol-related mortality and its contribution to changes in lifespan variability

Table 2 shows the net contribution of alcohol-related mortality to changes in life disparity for the most recent periods of divergence (1994-2000) and convergence (2000-2010). From 1994 to 2010 all the countries included in our study experienced decreasing e^\dagger . **Changes were minor in the other FSU countries but substantial in the Baltic region and in Central Europe.** Most of the declines observed were due to a decrease in mortality from external causes and birth conditions. Mortality attributable to alcohol produced mixed results. In some countries such as Estonia, Latvia, and Russia, these causes of death contributed to decreasing lifespan disparity over the full period 1994-2010. In Lithuania it first decreased e^\dagger in 1994-2000

⁷Data unavailable for Slovenia before 1983.

before increasing it in the later period, while the opposite was the case in Ukraine. Belarus was the only country that showed increases in life disparity caused by alcohol-attributable mortality. Finally, mortality attributable to alcohol had little impact on e^\dagger trends in Poland and the Czech Republic during these periods. Although cardiovascular diseases generally co-moved with causes attributable to alcohol, its older age profile of mortality meant that its overall impact on e^\dagger trends was often opposite. Finally cancers were comparatively less important in driving e^\dagger trends in the Baltic and other FSU countries, but were a leading cause of mortality compression over the entire period in Central Europe.

[Table 2 about here]

Figures 5 and 6 show how alcohol-related mortality contributed to the changing e^\dagger at different ages for a subset of Central and Eastern European countries⁸. The sum of the age-specific contributions by causes of death result in the values in Table 2. Red colors are related to causes attributable to alcohol consumption, orange refers to circulatory diseases and green to transportation accidents. Purple and blue colors relate to other external causes. Infectious & respiratory and cancers are depicted in pastel blue and magenta. The remaining causes and mortality at ages 85 and above are depicted in grey.

Results show that in Russia, Ukraine and Belarus e^\dagger stagnated between 1994 and 2000 because age-specific mortality change was small and uneven across ages. On the contrary, the Baltic countries experienced sizable reductions in mortality at all ages, and particularly strong compression of early adult mortality. These mortality reductions were primarily in causes amenable to alcohol, namely external mortality and transport accidents at younger ages, and circulatory diseases mortality at older ages. Causes directly attributable to alcohol consumption were also a strong contributor to mortality reduction between the ages of 20 and 60 in Lithuania. Poland and Czech Republic fell somewhere in-between the two other groups of countries, with reductions in circulatory diseases, but experiencing little change in external mortality.

From 2000-2010 all countries experienced improvements in survival and decreases in e^\dagger , particularly from causes amenable or susceptible to alcohol consumption. Most of the mortality compression below the threshold age occurred in early adulthood, particularly from external mortality. Conditions wholly attributable to alcohol consumption played a negligible role in e^\dagger compression or expansion over the period, with the exception of Lithuania, where it increased between ages 30 and 45. Above the threshold age, mortality was variable by cause. Reduction in mortality from conditions amenable to alcohol consumption (circulatory diseases and external causes) was considerable in Russia, Latvia and Estonia, but nearly absent in Ukraine, Lithuania and Belarus. Belarus experienced increases in transport accidents, and the other Baltic countries experienced increases in mortality unrelated to alcohol at older ages during this period. The opposing contributions from circulatory diseases in the Baltic countries might be an indication of improving diagnostic practices in the countries rather than real differences (Jasilionis et al. 2011).

⁸For age-cause-specific contributions to life expectancy in the same periods, see the supplemental material.

[Figures 5 & 6 about here]

Limitations

The limitations of our study should be mentioned. First, different measures of inequality differ from one other in formal properties and in the degree of their sensitivity to age-specific mortality change ([van Raalte and Caswell 2013](#)). Other authors have chosen measures of relative inequality, such as the Gini coefficient, Keyfitz’s entropy or the Theil index of inequality ([Shkolnikov et al. 2003](#), [Moser et al. 2005](#), [Smits and Monden 2009](#), [Colchero et al. 2016](#)). As a robustness check, we performed a sensitivity analysis replicating all the results shown in this study with the Gini coefficient following [Shkolnikov et al. \(2003\)](#) (see supplemental material). We did not find major differences with the results discussed in this article.

Secondly, estimating alcohol-attributable mortality is not straightforward. For one, unlike smoking, heavy alcohol consumption can have both immediate and cumulative impacts on mortality. In any period certain causes, for instance traffic accidents or alcohol poisoning, may change immediately in response to changing consumption patterns, while others, for instance liver cirrhosis, mainly reflect past consumption behaviour ([Menon et al. 2001](#), [Rehm et al. 2003](#)), and still others are such as IHD have been implicated in both immediate binge drinking mortality ([Kauhanen et al. 1997](#)) and elevated mortality risks from long-term heavy drinking ([Roerecke and Rehm 2014](#)). Thus using a cause of death based attribution method is only sensible in countries with relatively stable temporal patterns of alcohol consumption ([Kraus et al. 2015](#), [Martikainen et al. 2014](#)), which is certainly not the case in our study. An alternative is to derive alcohol-attributable mortality from follow-up longitudinal studies that report consumption patterns. Even if such surveys were available for some countries included in the study, self-reported alcohol consumption data are often biased and underestimate actual consumption because individuals forget drinking occasions, underrate drink size and are not able to remember the quantity of drinks in every drinking session ([Livingston and Callinan 2015](#), [Bellis et al. 2009](#)). A third commonly used approach is to link mortality with changes in alcohol sales ([Evgeny 2010](#)). A limitation to this approach is that the total alcohol consumption might not matter so much as the alcohol consumption behaviour. Indeed low levels of alcohol consumed at a regular basis may even be protective against mortality ([Bell et al. 2017](#), [Rehm et al. 2010](#), [Klatsky et al. 1974](#), [Roerecke and Rehm 2014](#)). Moreover, alcohol sales do not include homemade alcohol, which is substantial in the region ([Popova et al. 2007](#), [McKee et al. 2005](#)), and can be distorted by alcohol tourism ([Mäkelä and Österberg 2009](#), [Rabinovich et al. 2009](#)).

For these reasons, we took a more cautious approach that aims to at least partially attribute the changes in mortality trends to alcohol consumption without over or under-interpreting its absolute impact on mortality at any given time. Although the causal effect of alcohol is not clear in some conditions, such as accidents, violent deaths and IHD, we included them as “amenable to alcohol consumption”. Smoking-attributable

mortality is also high in the region (Ezzati and Lopez 2003) and could be a determinant of rising IHD and stroke mortality in some periods, yet we would not expect it to cause major departures in the slope or direction of change in mortality trends. On the other hand, departures from baseline alcohol consumption levels would increase or decrease mortality from these alcohol-amenable causes in comparison to the baseline period. In other words, when IHD, violent deaths and accidents all increase from one period to the next, it is strongly suggestive of increasing alcohol-related mortality and vice-versa.

There could be concerns with the quality of the data used in a comparative temporal setting. First, the FSU and Central European countries used a less strict definition of live births from the WHO, which had the result of depressing infant mortality levels (Aleshina and Redmond 2003, Unicef and others 2003). Following the transition to market economies, all countries eventually shifted to the WHO definition, although the timing of this shift differed between and within countries (Aleshina and Redmond 2003, Unicef and others 2003). Since indices of lifespan variation are comparatively more sensitive to changes in infant mortality than life expectancy (van Raalte and Caswell 2013), we investigated whether our results would be robust to mortality conditional upon survival to age 5 (or to an inflation of IMR before year 1990). While this created some differences in the direction of trends, particularly over the communist period where infant mortality decline was substantial, our two main conclusions from this period still held: (1) life expectancy and life disparity moved independently during the years before the fall of the Berlin wall, (2) trends in life disparity were especially driven by trends in early adult mortality. These results are available in the online Appendix.

Third, in the Soviet era ill-defined cardiovascular diseases were often classified as 'atherosclerotic cardiosclerosis', which was a subset of ischaemic heart diseases (Jasilionis et al. 2011, Shkolnikov et al. 2012) or stroke (need some ref here - Marketa? Mesle?). Different countries abandoned this practice at different rates, which has the effect of misclassifying deaths between the IHD, stroke and 'other circulatory disease' categories used in the present study. While some degree of misclassification within circulatory disease has been corrected by the Human Cause-of-Death Database (2016) team (Pechholdová et al. 2017), caution should be used in interpreting differences between these causes of death [anyone write about this for other FSU? Timonin? Grigoriev?] (Jasilionis et al. 2011). It is likely that this is less of a problem in Central European countries, which had already abandoned the Soviet coding practice by 1994, which is the start of our cause of death time series [haven't read this study—is this what they argue?] (Zatonski et al. 1998).

Fourth, there could be concern about data quality relating to high emigration throughout the post-Soviet period. However, robustness checks conducted for Poland and Czech Republic (Fihel2017) and the Baltic countries (Jasilionis et al. 2011) showed that underestimated emigration resulted in an overestimation of life expectancy of up to four months in Poland during the intense outflows following accession to European Union, but in other countries and periods was usually equivalent to less than one month.

Finally, data quality at older ages, i.e. Bulgaria and Russia (Timonin et al. 2017), are likely to present inaccuracies, even after standard demographic techniques were applied to mitigate them Human Mortality Database (2016). Do we want to write a paragraph and/or do any robustness checks here?

Discussion

The results derived from this study allowed us to analyze and compare long time series in life disparity for 12 countries from Central and Eastern Europe. They shed light into the determinants of variation in age at death across time and countries. In addition, we looked into the causes of death that were responsible for the major changes in lifespan variation in the region. This is the first comparative study of the region making use of the Human Cause-of-Death Database (2016). Over the study period, the acute mortality crises of the 1990s caused greater year-to-year fluctuation in lifespan variation than in life expectancy. Life expectancy and life disparity moved independently from one another, particularly during periods of life expectancy stagnation caused by uneven age-specific mortality change. Fluctuations in life disparity were, to a large extent, caused by fluctuation in mid-life mortality that was directly or partially attributable to mortality amenable to alcohol consumption, with different net effects depending on the country and time period.

Changes in life expectancy (e_0) and life disparity (e^\dagger)

Previous studies have found a close negative correlation between life expectancy and life disparity when measured over all ages (Wilmoth and Horiuchi 1999, Vaupel et al. 2011, Colchero et al. 2016). These studies were carried out over long periods of a hundred years or more, and mostly included Western countries with near-monotonic life expectancy increases. Importantly, two major phenomena were observed from the mid-nineteenth Century to the present: first was a drastic reduction of infectious disease mortality followed later by a major decline in cardiovascular disease mortality. These epidemiological changes can equally be considered as a redistribution of deaths from young to middle ages and later from middle to older adult ages (Robine 2001). In both cases, contemporaneous mortality decline over “younger” ages (defined as ages that compress mortality into a smaller age interval) outpaced decline over “older” ages (ages where mortality decline leads to deaths occurring over a larger age interval), which caused life disparity to decrease in lockstep with life expectancy increase.

Central and Eastern European countries run counter to this narrative. Although they too experienced the sharp declines in infectious disease mortality up to the mid-twentieth Century, mortality at mid-life stalled or even increased for most of the last half of the twentieth Century (McKee and Shkolnikov 2001), with no

appreciable declines in cardiovascular mortality until very recently (Caselli et al. 2002, Grigoriev et al. 2014, Meslé 2004, Timonin et al. 2017). As our results made clear, mortality change at different ages was far from even, with the result that changes in lifespan variation did not correspond in intensity or even direction with changes observed in life expectancy.

Moreover, by looking at long term trends in life expectancy and lifespan variation in the region, it was apparent that between-country differences in lifespan variation have and continue to be larger (in relative terms) than between-country differences in life expectancy (coefficients of variation for e_0 and e^\dagger in 2014 are 0.06 and 0.11, respectively). However, while mortality change after the break-up of the Soviet Union led to sharply diverging trends in life expectancy, divergence in lifespan variation between countries was less dramatic. This complements recent work by Timonin et al. (2016) who found that differences between geopolitical regions in life expectancy were more important than increasing within-region disparities in ages at death in driving life expectancy divergence in developed countries from 1970 to 2010.

From a public health perspective, these results are important because they disclose inequalities underlying population health that could not be identified by looking at life expectancy alone. As previously noted, the full distribution of deaths is characterized not only by the mean (life expectancy), but also by the dispersion in ages at death (Edwards and Tuljapurkar 2005). Periods of increasing lifespan variability underscore both a rise in within-group heterogeneity at the population level and increasing uncertainty about the timing of death at the individual level. Similar episodes have been found previously for some countries and they are seen as outliers that are not following the classic western trend (Wilmoth and Horiuchi 1999, Zhang and Vaupel 2009). For instance, stagnating or increasing lifespan variation has been seen alongside life expectancy increase among lower socioeconomic groups or regions in Europe (van Raalte et al. 2014, Brønnum-Hansen 2017, Seaman et al. 2016). In the United States, lower educated groups have experienced both life expectancy decreases and increases in lifespan variation (Sasson 2016). More recently, much attention has been paid to poor trends in mid-life mortality among white Americans, particularly females (Case and Deaton 2015, Montez and Zajacova 2013). As noted by Gillespie et al. (2014), the challenge of reducing young-adult mortality could anticipate a new pattern characterized by increases in lifespan inequality. Our results are further proof of the independence of the two measures during long periods with atypical mortality schedules and illustrate the need to monitor lifespan variation for a complete picture of population health.

Age-specific contributions to changes in e^\dagger

Life expectancy increases with mortality improvements at all ages. However, lifespan variation increases or decreases depending on the balance of saving lives at “younger ages”, which compresses mortality into a smaller age interval and at “older ages” where saving lives leads to greater variability (Zhang and Vaupel

2009, Gillespie et al. 2014). These properties indicate that life expectancy and lifespan variation have different sensitivities to mortality changes over the age-span (van Raalte and Caswell 2013). Typically, trends in lifespan variation are thought to be driven by changes in the “younger age” component of lifespan variation, with variation from the “older age” mortality component holding steady. For instance, Vaupel et al. (2011) found that old age life disparity was stable at between 2.5 and 8 years from the period 1840 to 2009 in countries of the Human Mortality Database (2016). Gillespie et al. (2014) showed that fluctuation in lifespan variation in Canada, Japan and the United States was almost entirely driven by younger ages. van Raalte et al. (2014) discovered that at similar life expectancy levels, Finnish occupational classes had similar older age lifespan variation, but varied widely in younger age lifespan variability over the time period 1971-2010. By contrast, in this study, we found highly fluctuating lifespan variation owed to fluctuation in both the younger and older age components. For instance, in Bulgaria during the 1987 to 1994 period, lifespan variation increased because of increased mortality at younger ages and continued mortality reduction at older ages. Can we find a better example here given the reviewers concern about old age mortality data in Bulgaria?

Below age 5 almost every country experienced sizable progress in averting deaths, particularly in the 1960 to 1980 period. These results are consistent with previous research documenting improvements in infant mortality and deterioration in young and middle-aged mortality leading to a substantial deterioration in the health status in the region (Chenet et al. 1996).

At the same time, our results revealed a paradox of sorts. On the one hand, between-country differences in lifespan variation were more stable than between-country differences in life expectancy. On the other hand, changes in lifespan variation were more sensitive to year-to-year mortality fluctuations than life expectancy, particularly when viewed on a relative scale. Measures of dispersion are more sensitive to mortality change in early mid-life than life expectancy (van Raalte and Caswell 2013). Mortality between ages 25 and 50 experienced larger changes in response to crises than older adult mortality over the period, seen clearly in Figure 1. This explains why life disparity showed greater year-to-year fluctuation than life expectancy. Meanwhile, mortality differences over older working ages and among the early retired have a larger impact on life expectancy than life disparity. This is because these ages are found on either side of the threshold age, with mortality declines (or increases) often offsetting each other, so that the net impact is no change in lifespan variation. As a result, the combination of mortality fluctuation over younger ages with growing mortality differentials at older adult ages can lead to widening between-country inequalities in life expectancy, alongside stable life disparity differences.

Cause-of-death contributions to changes in e^{\dagger} after 1994

The impact of alcohol on mortality has been extensively studied in Russia, which experienced the largest

mortality swings in the region (Leon et al. 1997, Rehm et al. 2007, Shkolnikov et al. 2013; 2001). Alcohol-related mortality is also known to have played an important role in mortality trends since the 1980s in the Baltic and other countries of the FSU (Rehm et al. 2007, Jasilionis et al. 2011), although its specific impact on lifespan variation has not been thoroughly investigated. To date, only Shkolnikov et al. (2003)’s study on Russia between 1979 and 1989 has analyzed the ages and causes of death contributing to changing lifespan variation in the region. They found that early-adult mortality compression during this period was attributed to a decrease in alcohol-related mortality as a consequence of Gorbachev’s anti-alcohol campaign. We extended this cause-of-death analysis to include more countries (Belarus, Czech Republic, Estonia, Latvia, Lithuania, Poland, Russia and Ukraine), and to specifically examine the impact of mortality amenable to alcohol consumption on lifespan variation in the 1994-2010 post-Soviet years. While 1994 was the height of the crisis following the dissolution of the Soviet Union, the years that followed were characterised by divergence in mortality coinciding with widely differing economic and political transitions to a market economy, and a more recent period of convergence with sustained mortality decline experienced by all countries in the region.

Fluctuating alcohol-related mortality was an important component of the moving life disparity trends in the countries of the former Soviet Union, although it occurred to different degrees in each region, and manifested itself in different causes. Over young ages, a large role was found for the reduction of external cause mortality including traffic accidents in the Baltic countries throughout the period, and in Russia, Belarus and Ukraine from 2000 onwards. At older ages, between-country differences in mortality reduction seemed to be driven by the extent of IHD and stroke mortality reduction. Overall, alcohol-related mortality (both increases and reductions) had its strongest influence in Russia, Latvia, Lithuania and Estonia, particularly over young-adult ages; while in Ukraine and Belarus the effect of alcohol-related mortality on changes in lifespan variation was less clear. ... Can we put Penina in here???? From this study, we cannot distinguish whether the impact of alcohol on mortality in the former group was stronger because initial consumption levels were higher, leaving more room for improvement, or whether it was because different alcohol consumption patterns emerged between countries in the 1990s and 2000s. Some evidence has shown that alcohol consumption patterns diverged in Russia and Belarus in the 1990s and early 2000s (Grigoriev and Andreev 2015). In addition, alcohol consumption is not the only factor that explains mortality trajectories in the region, or the difference between life expectancy and lifespan variation levels with western European countries. Other factors, such as environmental pollution, medical care, smoking behaviors and diet are important determinants of health outcomes in this region at least since 1970 (Bobak and Marmot 1996)

In contrast to the Baltic and other FSU countries, the smoother trends in life disparity found in Central Europe were driven by IHD mortality and non-alcohol related mortality. This is consistent with others who have argued that the steady post-1990 improvements in mortality in the region were attributable to a combination of improvements in medicine, a reorganization of the health care system, and general shifts toward

healthier behavior including improving diets and reductions in smoking (Pajak and Kozela 2011, Zatonski et al. 1998, Fihel and Pechholdová 2017, Cífková et al. 2010, Rychtarikova 2004b).

Preventing external mortality at young ages has been previously highlighted as an immediate factor to reduce differences in lifespan variability. Firebaugh et al. (2014) argued that allocating resources to reducing homicides in the American black population was more likely to narrow racial disparities in lifespan variation than tackling more common causes of death. In this sense, most reductions in life disparity in the region were caused by improvements in mortality at young ages after 1994, particularly in external causes and birth conditions. The decline in these causes of death also increased life expectancy (Trias-Llimós et al. 2017), and contributed toward convergence between countries in the region in lifespan variation, as we showed. This pattern differs from developed countries such as Canada, France, Germany, Japan, among others, where cancers and cardiovascular diseases helped the most to increase life expectancy since 1950, but they did not account for most life disparity reductions (Seligman et al. 2016).

Mortality associated to the most hazardous forms of alcohol consumption, such as alcohol liver disease or poisoning by exposure to alcohol, did not play a central role in the lifespan variation fluctuation. In part, this might be because these are small causes of death to begin with in comparison to much larger causes of death such as IHD or external cause mortality. Nevertheless, some countries, namely Lithuania, Russia and Latvia did show large mortality improvements in these conditions which caused compression of mortality at young ages. These differences have been pointed out previously as a partial explanation to different mortality trends in Lithuania and Belarus (Grigoriev et al. 2015).

Lifespan variation, in this case e^\dagger , is a measure of aggregate health inequality that reveals fundamental differences in levels and trends across the countries that we studied. Therefore, analyzing lifespan dispersion together with life expectancy contributes to a deeper understanding of the impact of changing mortality trends on population health. Our results show not only that Central and Eastern European countries experience higher lifespan variation and consequently experience greater fluctuation in the predictability of life compared to other populations, but that life expectancy and life disparity were able to move independently, particularly in periods of stagnation in life expectancy. These uncommon findings, opposing those observed in most developed countries, show that expansion (compression) levels do not necessarily mean lower (higher) life expectancy or mortality deterioration (improvements) when the yearly changes over time are taken into account.

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References

- Aleshina, N. and Redmond, G. (2003). *How High is Infant Mortality in Central and Eastern Europe and the CIS?* UNICEF.
- Avenoso, A. and Beckmann, J. (2005). The safety of vulnerable road users in the southern, eastern and central european countries (the sec belt). *Brussels: European Transport Safety Council*.
- Bell, S., Daskalopoulou, M., Rapsomaniki, E., George, J., Britton, A., Bobak, M., Casas, J. P., Dale, C. E., Denaxas, S., Shah, A. D., et al. (2017). Association between clinically recorded alcohol consumption and initial presentation of 12 cardiovascular diseases: population based cohort study using linked health records. *BMJ*, 356:j909.
- Bellis, M., Hughes, K., Cook, P., and Morleo, M. (2009). Off measure: how we underestimate the amount we drink. *Alcohol Concern, London*.
- Bobak, M. and Marmot, M. (1996). East-West mortality divide and its potential explanations: proposed research agenda. *BMJ: British Medical Journal*, 312(7028):421.
- Brønnum-Hansen, H. (2017). Socially disparate trends in lifespan variation: a trend study on income and mortality based on nationwide Danish register data. *BMJ Open*, 7(5):83–96.
- Bye, E. K. (2008). Alcohol and homicide in Eastern Europe: A time series analysis of six countries. *Homicide studies*, 12(1):7–27.
- Camarda, C. G. (2012). MortalitySmooth: An R package for smoothing Poisson counts with P-splines. *Journal of Statistical Software*, 50(1):1–24.
- Case, A. and Deaton, A. (2015). Rising morbidity and mortality in midlife among white non-Hispanic Americans in the 21st century. *Proceedings of the National Academy of Sciences*, 112(49):15078–15083.
- Caselli, G., Meslé, F., and Vallin, J. (2002). Epidemiologic transition theory exceptions. *Genus*, pages 9–51.
- Chenet, L., McKee, M., Fulop, N., Bojan, F., Brand, H., Hort, A., and Kalbarczyk, P. (1996). Changing life expectancy in central Europe: is there a Single reason? *Journal of Public Health*, 18(3):329–336.
- Cífková, R., Škodová, Z., Bruthans, J., Adámková, V., Jozífová, M., Galovcová, M., Wohlfahrt, P., Krajčoviechová, A., Poledne, R., Stávek, P., et al. (2010). Longitudinal trends in major cardiovascular risk factors in the czech population between 1985 and 2007/8. czech monica and czech post-monica. *Atherosclerosis*, 211(2):676–681.
- Colchero, F., Rau, R., Jones, O. R., Barthold, J. A., Conde, D. A., Lenart, A., Nemeth, L., Scheuerlein, A., Schoeley, J., Torres, C., et al. (2016). The emergence of longevous populations. *Proceedings of the National Academy of Sciences*, 113(48):E7681–E7690.
- Edwards, R. D. and Tuljapurkar, S. (2005). Inequality in life spans and a new perspective on mortality convergence across industrialized countries. *Population and Development Review*, 31(4):645–674.
- Evgeny, R. Y. (2010). Beverage-specific alcohol sales and violent mortality in Russia. *Adicciones*, 22(4).
- Ezzati, M. and Lopez, A. D. (2003). Estimates of global mortality attributable to smoking in 2000. *The Lancet*, 362(9387):847–852.
- Fihel, A. and Pechholdová, M. (2017). Between pioneers of the cardiovascular revolution and its late followers: Mortality changes in the czech republic and poland since 1968. *European Journal of Population*, 33(5):651–678.
- Firebaugh, G., Acciai, F., Noah, A. J., Prather, C., and Nau, C. (2014). Why lifespans are more variable among blacks than among whites in the United States. *Demography*, 51(6):2025–2045.

- Gillespie, D. O., Trotter, M. V., and Tuljapurkar, S. D. (2014). Divergence in age patterns of mortality change drives international divergence in lifespan inequality. *Demography*, 51(3):1003–1017.
- Grigoriev, P. and Andreev, E. M. (2015). The huge reduction in adult male mortality in Belarus and Russia: is it attributable to anti-alcohol measures? *PLoS one*, 10(9):e0138021.
- Grigoriev, P., Jasilionis, D., Shkolnikov, V. M., Meslé, F., and Vallin, J. (2015). Spatial variation of male alcohol-related mortality in Belarus and Lithuania. *The European Journal of Public Health*, page ckv060.
- Grigoriev, P., Meslé, F., Shkolnikov, V. M., Andreev, E., Fihel, A., Pechholdova, M., and Vallin, J. (2014). The recent mortality decline in Russia: Beginning of the cardiovascular revolution? *Population and Development review*, 40(1):107–129.
- Horiuchi, S., Wilmoth, J. R., and Pletcher, S. D. (2008). A decomposition method based on a model of continuous change. *Demography*, 45(4):785–801.
- Human Cause-of-Death Database (2016). French Institute for Demographic Studies (France) and Max Planck Institute for Demographic Research (Germany).
- Human Mortality Database (2016). University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany).
- Jasilionis, D., Meslé, F., Shkolnikov, V. M., and Vallin, J. (2011). Recent life expectancy divergence in baltic countries. *European Journal of Population/Revue européenne de Démographie*, 27(4):403.
- Kauhanen, J., Kaplan, G. A., Goldberg, D. E., and Salonen, J. T. (1997). Beer bingeing and mortality: results from the Kuopio ischaemic heart disease risk factor study, a prospective population based study. *Bmj*, 315(7112):846–851.
- Klatsky, A., Friedman, G., and Siegelaub, A. (1974). Alcohol consumption before myocardial infarction. Results from the Kaiser-Permanente epidemiologic study of myocardial infarction. *Annals of internal medicine*, 81(3):294.
- Kraus, L., Østhus, S., Amundsen, E. J., Piontek, D., Härkönen, J., Legleye, S., Bloomfield, K., Mäkelä, P., Landberg, J., and Törrönen, J. (2015). Changes in mortality due to major alcohol-related diseases in four Nordic countries, France and Germany between 1980 and 2009: a comparative age–period–cohort analysis. *Addiction*, 110(9):1443–1452.
- Leon, D. A. (2011). Trends in European life expectancy: a salutary view. *International journal of epidemiology*, 40(2):271–277.
- Leon, D. A., Chenet, L., Shkolnikov, V. M., Zakharov, S., Shapiro, J., Rakhmanova, G., Vassin, S., and McKee, M. (1997). Huge variation in Russian mortality rates 1984–94: artefact, alcohol, or what? *The lancet*, 350(9075):383–388.
- Leon, D. A. and Shkolnikov, V. M. (1998). Social stress and the russian mortality crisis. *JAMA*, 279(10):790–791.
- Livingston, M. and Callinan, S. (2015). Underreporting in alcohol surveys: whose drinking is underestimated? *Journal of studies on alcohol and drugs*, 76(1):158–164.
- Mackenbach, J. P., Stirbu, I., Roskam, A.-J. R., Schaap, M. M., Menvielle, G., Leinsalu, M., and Kunst, A. E. (2008). Socioeconomic inequalities in health in 22 European countries. *New England Journal of Medicine*, 358(23):2468–2481.
- Mäkelä, P. and Österberg, E. (2009). Weakening of one more alcohol control pillar: a review of the effects of the alcohol tax cuts in Finland in 2004. *Addiction*, 104(4):554–563.
- Martikainen, P., Mäkelä, P., Peltonen, R., and Myrskylä, M. (2014). Income differences in life expectancy: the changing contribution of harmful consumption of alcohol and smoking. *Epidemiology*, 25(2):182–190.

- McKee, M. and Shkolnikov, V. (2001). Understanding the toll of premature death among men in Eastern Europe. *BMJ: British Medical Journal*, 323(7320):1051.
- McKee, M., Sűzcs, S., Sárvány, A., Ádany, R., Kiryanov, N., Saburova, L., Tomkins, S., Andreev, E., and Leon, D. A. (2005). The composition of surrogate alcohols consumed in Russia. *Alcoholism: Clinical and Experimental Research*, 29(10):1884–1888.
- Menon, K. N., Gores, G. J., and Shah, V. H. (2001). Pathogenesis, diagnosis, and treatment of alcoholic liver disease. *Mayo Clinic Proceedings*, 76(10):1021–1029.
- Meslé, F. (2004). Mortality in Central and Eastern Europe: long-term trends and recent upturns. *Demographic Research*, 2:45–70.
- Meslé, F., Vallin, J., and Shkolnikov, V. (2000). Reversal of mortality decline: the case of contemporary Russia. *World Health Statistics Quarterly*, 51(2-4):191–206.
- Montez, J. K. and Zajacova, A. (2013). Trends in mortality risk by education level and cause of death among US White women from 1986 to 2006. *American journal of public health*, 103(3):473–479.
- Moser, K., Shkolnikov, V., and Leon, D. A. (2005). World mortality 1950-2000: divergence replaces convergence from the late 1980s. *Bulletin of the World Health Organization*, 83(3):202–209.
- Pajak, A. and Kozela, M. (2011). Cardiovascular disease in Central and East Europe. *Public Health Reviews*, 33(2):416.
- Pechholdová, M., Camarda, C.-G., Meslé, F., and Vallin, J. (2017). Reconstructing long-term coherent cause-of-death series, a necessary step for analyzing trends. *European Journal of Population*, pages 1–22.
- Popova, S., Rehm, J., Patra, J., and Zatonski, W. (2007). Comparing alcohol consumption in central and eastern Europe to other European countries. *Alcohol and alcoholism*, 42(5):465–473.
- R Core Team (2000). R language definition.
- Rabinovich, L., Brutscher, P.-B., de Vries, H., Tiessen, J., Clift, J., and Reding, A. (2009). *The affordability of alcoholic beverages in the European Union: understanding the link between alcohol affordability, consumption and harms*. RAND Corporation Santa Monica, CA.
- Rau, R., Bohk, C., Muszyńska, M. M., and Vaupel, J. (2013). Rates of mortality improvement on the lexis surface. Technical report, Max Planck Institute for Demographic Research.
- Rehm, J., Baliunas, D., Borges, G. L., Graham, K., Irving, H., Kehoe, T., Parry, C. D., Patra, J., Popova, S., Poznyak, V., et al. (2010). The relation between different dimensions of alcohol consumption and burden of disease: an overview. *Addiction*, 105(5):817–843.
- Rehm, J., Room, R., Graham, K., Monteiro, M., Gmel, G., and Sempos, C. T. (2003). The relationship of average volume of alcohol consumption and patterns of drinking to burden of disease: an overview. *Addiction*, 98(9):1209–1228.
- Rehm, J., Sulkowska, U., Mańczuk, M., Boffetta, P., Powles, J., Popova, S., and Zatoński, W. (2007). Alcohol accounts for a high proportion of premature mortality in central and eastern Europe. *International journal of epidemiology*, 36(2):458–467.
- Robine, J.-M. (2001). Redefining the stages of the epidemiological transition by a study of the dispersion of life spans: The case of France. *Population: An English Selection*, pages 173–193.
- Roerecke, M. and Rehm, J. (2014). Alcohol consumption, drinking patterns, and ischemic heart disease: a narrative review of meta-analyses and a systematic review and meta-analysis of the impact of heavy drinking occasions on risk for moderate drinkers. *BMC medicine*, 12(1):182.
- Rychtarikova, J. (2004a). The case of the czech republic: Determinants of the recent favourable turnover in mortality. *Demographic Research*, 2:105–138.

- Rychtarikova, J. (2004b). The case of the czech republic: Determinants of the recent favourable turnover in mortality. *Demographic Research*, 2:105–138.
- Sasson, I. (2016). Trends in life expectancy and lifespan variation by educational attainment: United States, 1990–2010. *Demography*, 53(2):269–293.
- Seaman, R., Leyland, A. H., and Popham, F. (2016). Increasing inequality in age of death at shared levels of life expectancy: a comparative study of scotland and England and Wales. *SSM-population health*, 2:724–731.
- Seligman, B., Greenberg, G., and Tuljapurkar, S. (2016). Equity and length of lifespan are not the same. *Proceedings of the National Academy of Sciences*, 113(30):8420–8423.
- Shkolnikov, V., Andreev, E., McKee, M., and Leon, D. (2013). Components and possible determinants of the decrease in Russian mortality in 2004–2010. *Demographic research*, 28(32):917–950.
- Shkolnikov, V., McKee, M., and Leon, D. A. (2001). Changes in life expectancy in Russia in the mid-1990s. *The Lancet*, 357(9260):917–921.
- Shkolnikov, V., Meslé, F., and Vallin, J. (2012). Data collection, data quality and the history of cause-of-death classification. In *Mortality and Causes of Death in 20th-Century Ukraine*, pages 121–130. Springer.
- Shkolnikov, V. M., Andreev, E. E., and Begun, A. Z. (2003). Gini coefficient as a life table function: computation from discrete data, decomposition of differences and empirical examples. *Demographic Research*, 8(11):305–358.
- Shkolnikov, V. M., Andreev, E. M., Jasilionis, D., Leinsalu, M., Antonova, O. I., and McKee, M. (2006). The changing relation between education and life expectancy in central and eastern europe in the 1990s. *Journal of Epidemiology & Community Health*, 60(10):875–881.
- Shkolnikov, V. M., Andreev, E. M., Zhang, Z., Oeppen, J., and Vaupel, J. W. (2011). Losses of expected lifetime in the United States and other developed countries: methods and empirical analyses. *Demography*, 48(1):211–239.
- Smits, J. and Monden, C. (2009). Length of life inequality around the globe. *Social Science & Medicine*, 68(6):1114–1123.
- Timonin, S., Danilova, I., Andreev, E., and Shkolnikov, V. M. (2017). Recent mortality trend reversal in russia: Are regions following the same tempo? *European Journal of Population*, 33(5):733–763.
- Timonin, S., Shkolnikov, V. M., Jasilionis, D., Grigoriev, P., Jdanov, D. A., and Leon, D. A. (2016). Disparities in length of life across developed countries: measuring and decomposing changes over time within and between country groups. *Population health metrics*, 14(1):29.
- Trias-Llimós, S., Kunst, A. E., Jasilionis, D., and Janssen, F. (2017). The contribution of alcohol to the East-West life expectancy gap in Europe from 1990 onward. *International journal of epidemiology*.
- Unicef and others (2003). *Social monitor, 2003*. UNICEF.
- van Raalte, A. A. and Caswell, H. (2013). Perturbation analysis of indices of lifespan variability. *Demography*, 50(5):1615–1640.
- van Raalte, A. A., Martikainen, P., and Myrskylä, M. (2014). Lifespan variation by occupational class: compression or stagnation over time? *Demography*, 51(1):73–95.
- Vaupel, J. W. and Canudas-Romo, V. (2003). Decomposing change in life expectancy: A bouquet of formulas in honor of Nathan Keyfitz’s 90th birthday. *Demography*, 40(2):201–216.
- Vaupel, J. W., Zhang, Z., and van Raalte, A. A. (2011). Life expectancy and disparity: an international comparison of life table data. *BMJ open*, 1(1):e000128.

- Wilmoth, J. R. and Horiuchi, S. (1999). Rectangularization revisited: Variability of age at death within human populations. *Demography*, 36(4):475–495.
- World Health Organization (2000). The world health report 2000: health systems: improving performance.
- World Health Organization (2009). European status report on road safety: towards safer roads and healthier transport choices.
- World Health Organization (2013). Global status report on road safety 2013: supporting a decade of action.
- Zatonski, W. A., McMichael, A. J., and Powles, J. W. (1998). Ecological study of reasons for sharp decline in mortality from ischaemic heart disease in Poland since 1991. *Bmj*, 316(7137):1047.
- Zhang, Z. and Vaupel, J. W. (2009). The age separating early deaths from late deaths. *Demographic Research*, 20(29):721–730.

Figures and tables

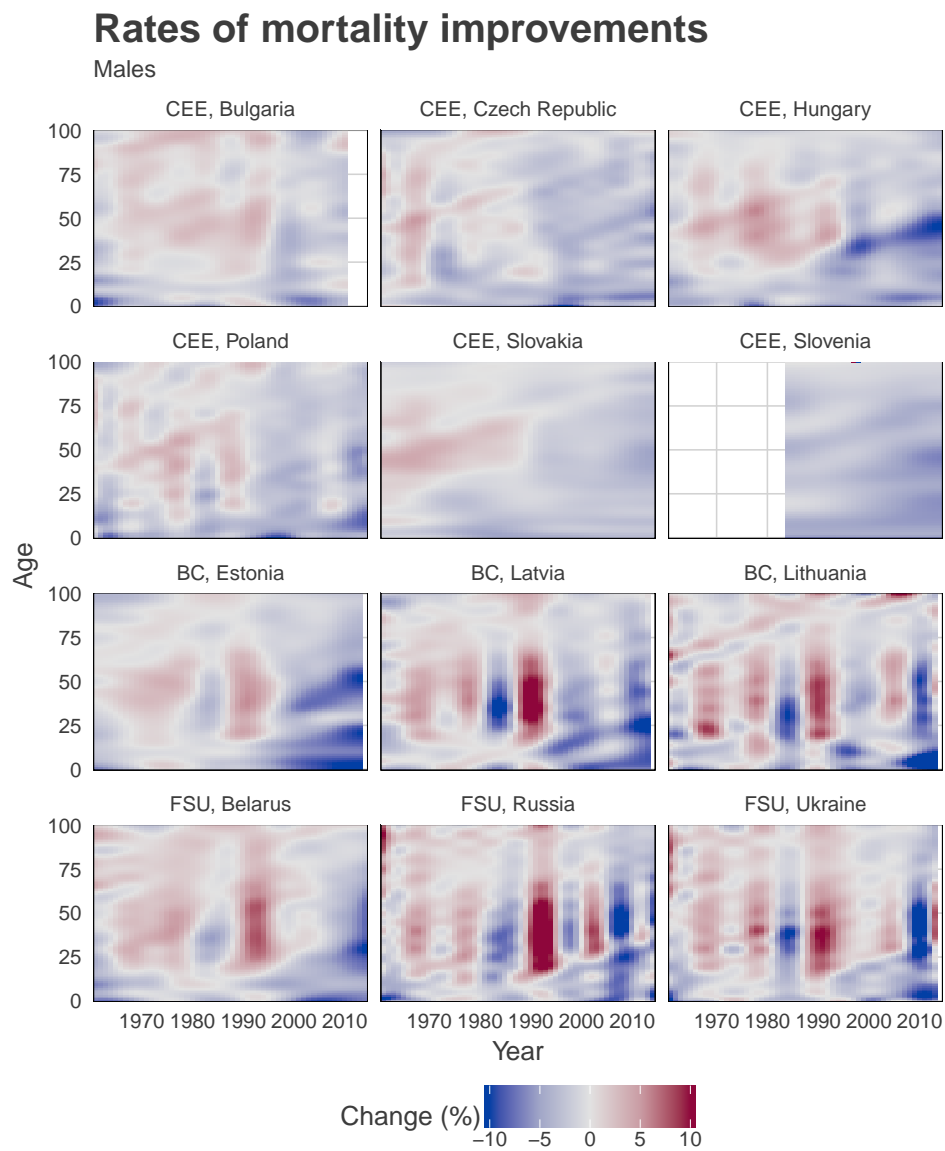
Table 1: Classification of causes-of death amenable to alcohol consumption

Category	ICD-10 codes
1) Alcohol attributable conditions	
Mental and behavioral disorders due to use of alcohol, alcohol liver disease and cirrhosis of the liver, poisoning by exposure to alcohol	F10, K70 & K74, X45
2) Amenable to alcohol consumption	
Cardiovascular diseases (Ischemic Heart Diseases, stroke, rheumatic heart diseases; essential hypertension; hypertensive disease; pulmonary heart diseases; non rheumatic valve disorders; cardiac arrest; heart failure; other heart diseases; sequelae of cerebrovascular disease; diseases of arteries, arterioles and capillaries, other circulatory diseases) and transport accidents	I20-25, I60-I67 & G45, I00-I09; I10; I11-I15; I26-I28; I34-I38; I46; I50; I30-I33, I40-I45, I47-I49; I51; I69; I70-I78; I80-I99, and V01-V99
3) Other conditions amenable to alcohol consumption	
Other external causes (Accidental exposure to smoke, fire and flames; accidental poisoning by other substance; suicide and self-inflicted injuries; assault; event of undetermined intent; complication of medical and surgical care, accidental falls, accidental drowning and submersion, other accidental threats to breathing, other accidents and late effects of accidents)	(X00-X09; ; X40-X44, X46-X49; X60-X84; X85-Y09, Y35, Y36; Y10-Y34; Y40-Y84, W00-W19, W65-W74, W75-W84, W20-W64, W85-W99, X10-X39, X50-X59, Y85-Y91, Y95-Y98)
4) Residual causes	
Rest of conditions and mortality above age 85	

Table 2: Cause-specific contributions to the change in e^\dagger for males, 1994-2000 & 2000-2010

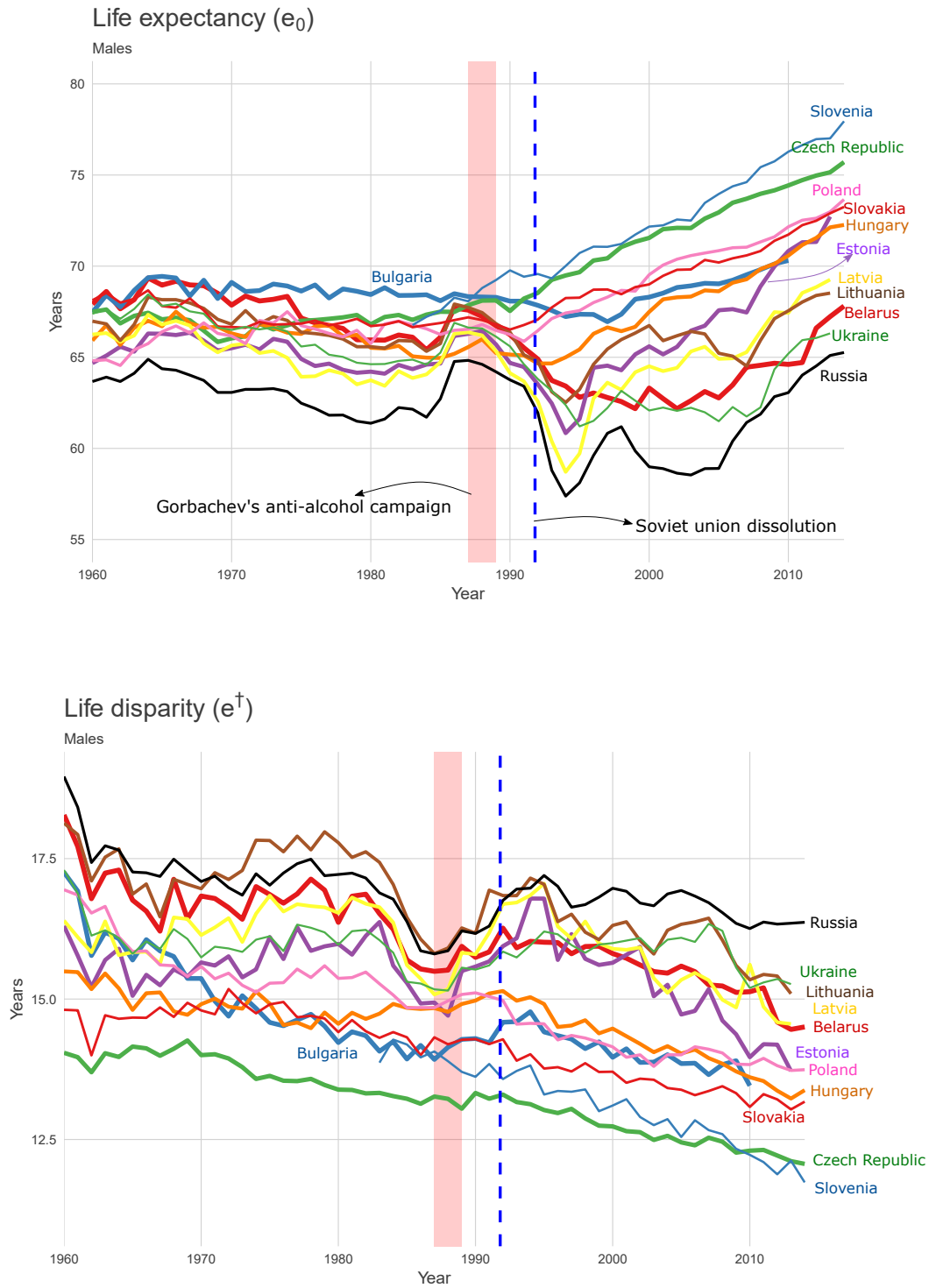
Period	Country	Attributable to alcohol	Circulatory	Other external	Transport accidents	Infect. & resp.	Cancers	Rest	Total
1994-2000	Belarus	0.03	-0.13	0.01	-0.03	0.01	-0.10	0.01	-0.20
	Czech Republic	0.01	-0.04	-0.09	-0.06	0.01	-0.16	-0.07	-0.40
	Estonia	-0.04	0.30	-0.78	-0.41	-0.01	-0.14	-0.03	-1.11
	Latvia	-0.11	0.15	-0.64	-0.14	-0.12	-0.09	-0.01	-0.96
	Lithuania	-0.28	0.21	-0.39	-0.04	-0.09	-0.15	-0.09	-0.83
	Poland	0.01	0.15	-0.18	-0.08	-0.07	-0.13	-0.11	-0.41
	Russia	-0.07	0.10	-0.02	-0.03	0.09	0.00	-0.08	-0.01
	Ukraine	0.04	-0.03	-0.04	-0.07	0.21	-0.02	-0.05	0.04
2000-2010	Belarus	0.02	-0.07	-0.33	-0.10	0.01	-0.02	-0.17	-0.66
	Czech Republic	-0.01	-0.00	-0.11	-0.14	0.00	-0.23	0.04	-0.45
	Estonia	-0.17	0.03	-0.60	-0.23	-0.14	-0.15	-0.41	-1.67
	Latvia	-0.01	0.17	-0.47	-0.34	-0.04	-0.02	0.43	-0.28
	Lithuania	0.05	0.12	-0.35	-0.21	0.01	-0.03	-0.53	-0.94
	Poland	-0.01	0.11	-0.06	-0.16	0.01	-0.16	-0.05	-0.32
	Russia	-0.06	0.28	-0.70	-0.10	-0.03	0.01	-0.12	-0.72
	Ukraine	-0.08	-0.09	-0.53	-0.04	0.05	-0.01	-0.10	-0.80

Figure 1: Male mortality surface showing rates of mortality improvements



Source: own calculations based on [Human Mortality Database \(2016\)](#) data. Note: The regular light -grey areas indicate no data available.

Figure 2: Trends in males life expectancy (e_0) and lifespan disparity (e^\dagger) for 12 Eastern European countries, 1960-2014



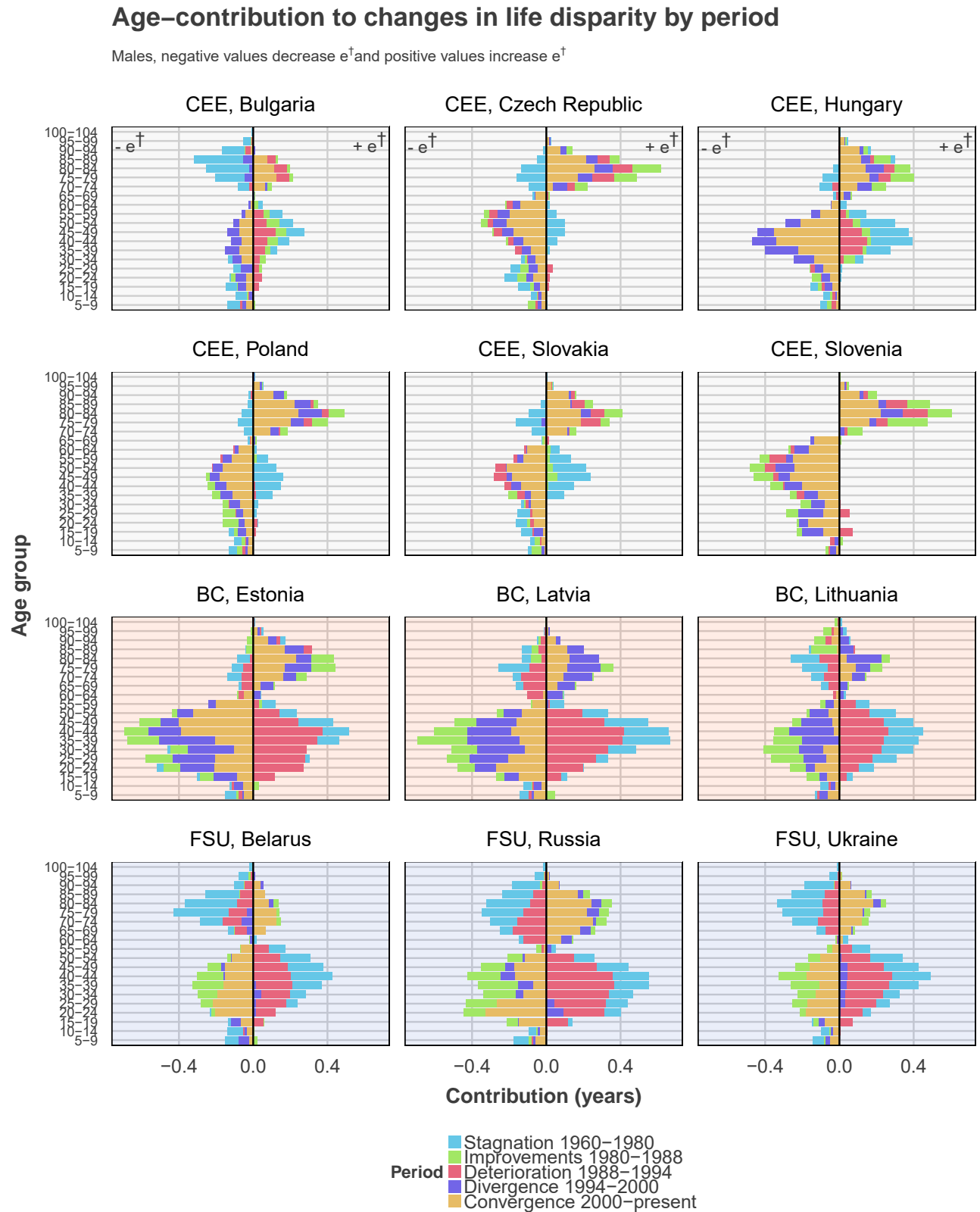
Source: own calculations based on [Human Mortality Database \(2016\)](#) data.

Figure 3: Absolute and relative yearly changes in life expectancy and lifespan disparity, 1960-2010



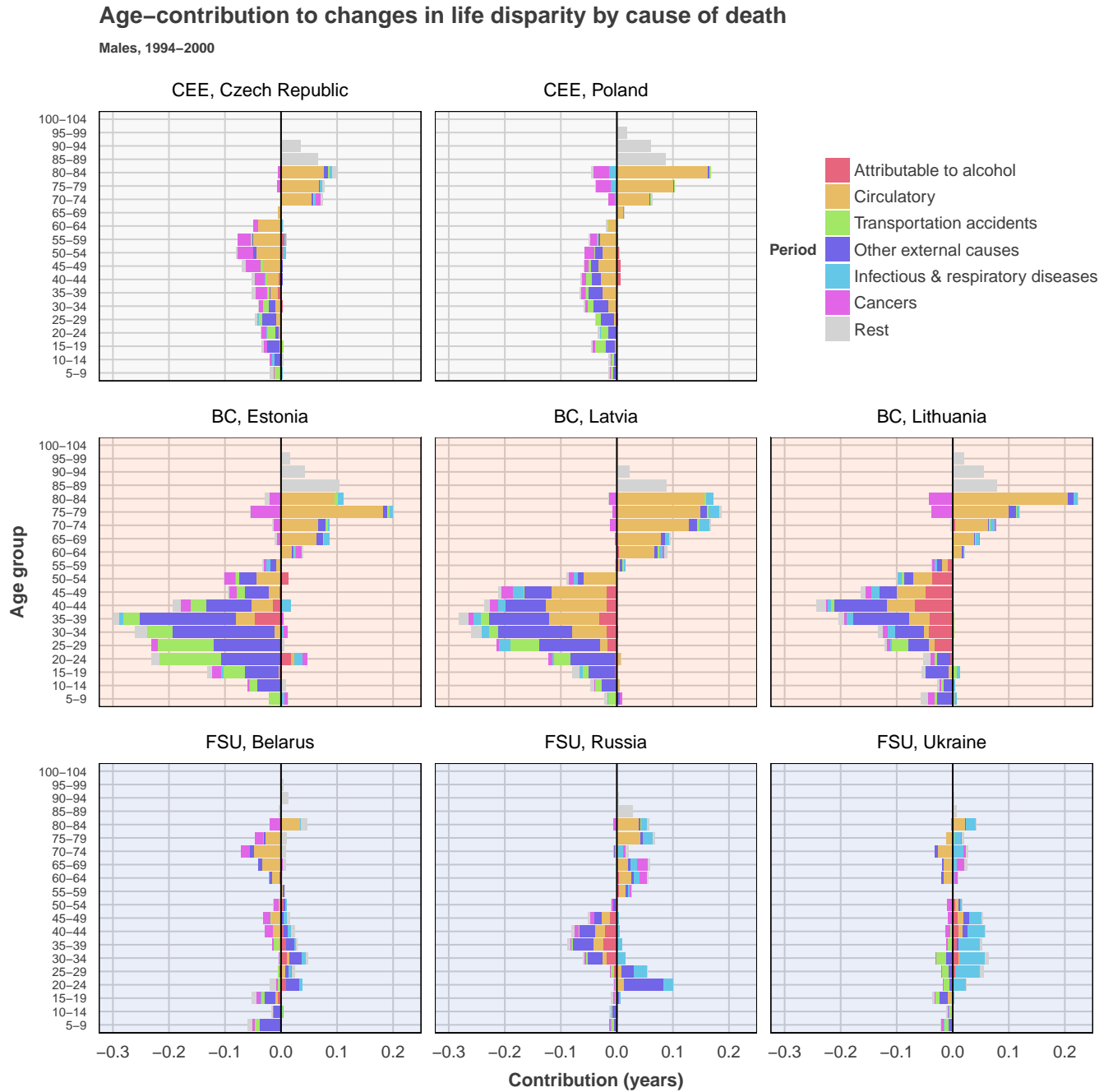
Source: own calculations based on [Human Mortality Database \(2016\)](#) data. Note: data for Slovenia begins in 1983. The black dots are related to changes experienced in Russia. The percentages correspond to the total changes occurred during each period.

Figure 4: Males' age-specific contributions to the change in lifespan disparity e^{\dagger} by periods.



Source: own calculations based on [Human Mortality Database \(2016\)](#) data. Note: data for Slovenia begins in 1983.

Figure 5: Cause specific contributions to the change in male lifespan disparity e^\dagger , 1994-2000



Source: own calculations based on [Human Cause-of-Death Database \(2016\)](#) data.

Figure 6: Cause specific contributions to the change in male lifespan disparity e^\dagger , 2000-2010



Source: own calculations based on [Human Cause-of-Death Database \(2016\)](#) data. Note: data for Poland ends in 2009.