Lifespan dispersion in stagnant and decreasing periods of life expectancy in Eastern Europe

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Abstract

Mortality has had atypical patterns in Eastern European countries since the 1960s. Periods of rapid increase in life expectancy followed by stagnation and decreases have been documented. Analyzing life expectancy and variability at age contributes to deeper understanding the impact of changing mortality trends on populations' health. We analyze how lifespan variation has changed since the 1960's for 12 countries from this region and which ages and causes of death have contributed the most to the observed variability of age at death. We drew in high quality mortality sources and cautiously harmonized causes of death for several countries along with a thoughtful classification and demographic techniques. We use $e^{\dagger}$ as a dispersion indicator, which is defined as the average remaining life expectancy when death occurs. Eastern European countries experience higher lifespan variation and great fluctuation in the predictability of life compared to other populations. Life expectancy (e_0) and lifespan disparity ($e^{\dagger}$) moved independently from one another, particularly during periods of life expectancy decrease. Fluctuations in mortality were, to a large extent, directly or partially attributable to changes in alcohol consumption.

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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 shattered in the second half of the past century, as Eastern European countries experienced an unprecedented period of stagnation and, in some countries, decreases in life expectancy at birth after 1960 (Human Mortality Database 2016). For example, Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia and Ukraine presented a substantial period of stagnation in male life expectancy from the 1960s to the mid 1980s, with life expectancy levels between 65 and 70 years. During this period, Russia exhibited the lowest level in male life expectancy in the region, males were living on average 63.7 years in 1960 and 62.72 in 1985 (Human Mortality Database 2016). Similar trends were experienced by females but with higher levels in life expectancy, they were living on average 72.31 years in 1960 and 73.23 in 1985. After 1985, all of these countries experienced a brief period of improvements in life expectancy, which coincided with Gorbachev's anti-alcohol campaign. For instance, Russian males rose life expectancy by two additional years from 1985 to 1987. However, after 1987 these countries experienced divergence in life expectancy trends. Slovenia and the Czech Republic rose continuously life expectancy and by 2014 Czech males had an average length of life of 75.7 years and Slovenian of 77.95 (Human Mortality Database 2016). The rest of the countries, particularly those from the former Soviet Union, experienced a pronounced period of deterioration and some countries, such as Russia and Latvia experienced losses of around 7.5 years in male life expectancy between 1987 and 1994, which led to levels not seen since the 1950s (Shkolnikov et al. 2001). Opposing this trend, from 1994 there was an unexpected period of improvements in countries like Russia, Latvia and Estonia (Meslé et al. 2000). However, while all of the countries experienced improvements since that year, life expectancy in Russia stopped increasing in 1998 and presented a downturn up to the mid 2000s, when life expectancy started rising up to the present (Human Mortality Database 2016). Although in the new century most of the countries in this region improved life expectancy, large differences between them remain. For instance, by 2010 the gap between life expectancy in Slovenia and Russia for males was more than 13 years (Human Mortality Database 2016).

National trends in life expectancy are important and have been extensively studied in Eastern Europe (Meslé 2004, Cockerham 1997, Chenet et al. 1996). Nonetheless, they conceal heterogeneity and variation at age at death. Studying lifespan variability alongside life expectancy is an important subject since individuals may take decisions, such as changing lifestyle behaviors, based on their uncertainty about when they will die (van Raalte et al. 2014). Therefore, if lifespan variation is increasing alongside life expectancy decreases means that not only are people dying younger but they are also facing more uncertainty about the eventual timing of death. Previous research has shown that lifespan variability is largely explained by mortality at infancy and early-adult ages between populations (Wilmoth and Horiuchi 1999, Shkolnikov et al. 2003; 2011, Vaupel et al. 2011). The fact that Eastern Europe experience high levels of premature adult mortality (Rehm et al. 2007) underscores the need of understanding mortality trajectories under these atypical patterns, which could be associated to higher levels of lifespan variability.

Until now, studies have mostly focused on lifespan variation in the context of mortality improvements with increases in life expectancy (Vaupel et al. 2011, Wilmoth and Horiuchi 1999), and recently also in socioeconomic and educational differences (van Raalte et al. 2014; 2011, Shkolnikov et al. 2003). These studies have shown a negative relationship between life expectancy and lifespan variability. That is, countries with higher life expectancy experienced lower levels of uncertainty about their age at death (Vaupel et al. 2011). We complement such studies by focusing in the Eastern European case, which shows atypical periods of mortality upheavals with different patterns in life expectancy. Furthermore, Eastern Europe is particularly interesting because its age pattern of mortality change was very different from that observed in western countries (Meslé 2004). Since mortality mainly experienced changes over working ages, it is a priori unclear what the net effect could be on variability. We analyze how lifespan variation has changed since the 1960's for 12 countries from this region and which ages and causes of death have contributed the most to the observed variability of age at death. We use high quality mortality data from the Human Mortality Database (2016) and Human Cause-of-Death Database (2016), along with demographic techniques to disentangle the impact of specific-ages and causes of death that drive changes in lifespan variability.

Data & Methods

Data

We used death counts, 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 are Belarus, Bulgaria, Czech Republic, Hungary, Poland, Russia, Slovakia, Ukraine, Slovenia, Estonia, Latvia and Lithuania. Data for Slovenia is available since 1983. These data contain information on life table's measures (e.g. deaths distribution, survival function, life expectancy) by single age, sex and country. For each population, we investigated life expectancy and life disparity since birth. We decided not to analyze variability at death conditioned on survival to any older age, as previous studies have done (e.g. van Raalte et al. (2014)), because of the high proportion of deaths concentrated in younger ages (see Appendix's figure 8). Furthermore, our decision is also founded by the upsurge in young age mortality in the 1990s (see Appendix's figure 8) and the low levels of life expectancy that Eastern European countries experienced in the last century (Meslé 2004).

Cause of death classification

Injurious alcohol consumption has long been identified as a major determinant of premature mortality in Eastern European countries (Leon et al. 1997, McKee and Shkolnikov 2001, Rehm et al. 2007, Grigoriev and Andreev 2015). We aim to identify the effect of mortality related to alcohol consumption on lifespan disparity from 1994 to 2010 since improvements in mortality trends have been witnessed in Eastern Europe during this period.

We group causes of death in four categories using the tenth revision of the International Classification of Diseases (ICD-10) (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) Amenable to alcohol consumption, such as Ischemic Heart Diseases (IHD), stroke and transportation accidents; 3) Other conditions susceptible to alcohol consumption (Other external causes and other circulatory conditions); 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 a strong link with alcohol consumption. This group of causes are wholly attributable to alcohol consumption (e.g. attributable fraction of 100%) (Rehm et al. 2010), with the exception of liver cirrhosis. We include liver cirrhosis in this first category because almost every study targeting alcohol related mortality included it as a condition affected by alcohol consumption (Rehm et al. 2003; 2010). In addition, the alcohol-attributable fraction for the region regarding this study is around 73% (Rehm et al. 2003). The second category, amenable to alcohol consumption, is related to those conditions that are not totally 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 they are likely to contribute to mortality changes in Eastern European countries (Grigoriev and Andreev 2015).

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 and circulatory disease with IHD and transport injuries. Although more causes of death can be linked to alcohol consumption, we do not include them in our study because their contributions are likely to be very small to mortality changes in the set of countries that we study (Grigoriev and Andreev 2015).

We rely in information produced by Human Cause-of-Death Database (2016), which provides comparable cause-specific information by year for eight of the countries in the study (Belarus, Czech Republic, Poland, Russia, Ukraine, Slovenia, Estonia, Latvia and Lithuania). These data was corrected by miss-certification, age-specific variations by means of a universal and standardized methodology. We truncate the cause-of-death analysis at age 85 because of classification quality 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 countries in Eastern Europe have recently showed wide country-specific variations, particularly between former USSR and Central European countries (Meslé 2004).

[Table 1 about here]

Dispersion measure

Several dispersion measures have been proposed to analyze lifespan variability (van Raalte and Caswell 2013). In this article, we use $e^\dagger$ 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 (Vaupel 1986). For example, when death is very variable, some people will die 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

$$e_x^\dagger = \frac{1}{\ell_x} \int_x^\omega \ell(a)\mu(a)e(a)da \tag{1}$$

where $\ell(a)$, $\mu(a)$,ω and $e(a)$ are the survival function, the force of mortality, the open-aged interval (110+ in our case), and remaining life expectancy, respectively.

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). These properties allow us to quantify the impact of mortality at different ages, and from different causes, and separate those that decrease lifespan variability from those that increase it by using demographic methods (Zhang and Vaupel 2009, Shkolnikov et al. 2011).

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).

Demographic methods

We first examine changes in age-specific mortality by calculating rates of mortality improvements (Rau et al. 2013) with smoothed mortality surfaces (Camarda 2012) following the next formula:

$$\rho(x, t+1) = -\ln \frac{m(x, t+1)}{m(x, t)} \tag{2}$$

where $m(x, t)$ represents the age-specific mortality rates of age x at time t.

The life disparity measure $e^\dagger$ 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. We perform such decomposition by single period-year, single-age and causes of death based on a continuous change model (Horiuchi et al. 2008) that has the advantage of assuming that covariates change gradually along the time dimension.

Results

Age-specific mortality rates of improvements

Figure 1 shows the age-specific rates of mortality improvements for males in 12 Eastern European countries (results for females are shown in Appendix figure 10). The respective values are expressed in percent. Little changes or no improvements (-0.5% to 0.5%) are depicted in white. Improvements in mortality are shown in blue and mortality deterioration in red. Darker tones mean major changes in mortality rates.

Almost every country experienced a continuous 20-year period of mortality deterioration, from the mid-1960s to the mid-1980s. Mortality rates exhibited increases mainly concentrated in the ages between 20 and 80 years. After 1985, 8 countries experienced sizable improvements in mortality (Russia, Ukraine, Latvia, Lithuania, Poland, Belarus, Czech Republic and Estonia) for a period of 5-10 years. Opposing this trend, in the 1990s every country, except Slovenia, presented an intense worsening in mortality rates, particularly in the countries part of the former Soviet Union. Nevertheless, since the last decade of the past century and the beginning of the 2000s Slovakia, Slovenia, Hungary, Latvia, Poland, Belarus, Estonia and Czech Republic have reduced age-specific mortality rates in almost every age. The biggest improvements are related to the most recent years. However, Russia, Ukraine and Poland's recent data point towards a downturn in population's health in middle and adult ages.

Results for women are similar than men in Russia, Ukraine, Latvia, Lithuania, Belarus and Bulgaria but with fluctuation lower in magnitude (see Appendix figure 10). Importantly, some countries such as Slovakia, Slovenia, Poland, Czech Republic and Estonia experienced a continuous trend of mortality improvements in almost the entire period.

[Figure 1 about here]

Trends in life expectancy and lifespan disparity

Previous research suggests that lifespan disparity should be analyzed alongside life expectancy (Shkolnikov et al. 2011), this allows to capture both the average years a person is expected to live and the uncertainty surrounding individuals' lifespans. Figure 2 shows male's life expectancy at birth (e_0) and lifespan disparity ($e^\dagger$) trends for Eastern European countries from 1960 to the most recent year available (Appendix figure 9 shows females' results). From 1960 to 1984 life expectancy stagnated for most of the countries, some of them even experienced decreases (e.g. Russia, Latvia, Estonia, Ukraine). This period was followed by a notable increase in life expectancy in the mid-1980s. However, in 1987 life expectancy among these countries started to diverge. Slovenia and the Czech Republic exhibited a continuous increase from that point onwards. Hungary, Poland, Bulgaria stagnated for a short period and then continued an upward trend until 2014. The rest of the countries (Russia, Latvia, Estonia, Ukraine, Belarus and Lithuania) experienced a marked decrease in life expectancy from 1988, with the lowest value in 1994. From that point on, almost every country improved life expectancy, with the exception of Russia and Ukraine. These last countries exhibited a decrease in life expectancy after 1998, and since 2006 they have continuously experienced improvements in the average length of life. The trends for both male and females are similar (figure with females' results are shown in Appendix figure 9). Yet, the magnitude of the changes is shorter for women and the level of life expectancy is significantly higher than men.

The right panel shows the average life expectancy losses attributable to death ($e^{\dagger}$) for males in the 12 countries. Results show similar patterns of stagnation between 1960 and 1980 in $e^{\dagger}$. Russia and Lithuania exhibit the highest levels in this period, between 17 and 19 years lost due to death; while the Czech Republic presents the lowest level throughout the same years, between 13 and 14. Importantly, the Czech Republic was not the record life expectancy holder between these years. Around the mid-1980s all the countries experienced compression of mortality, which led to decreases in lifespan disparity, with the exception of Hungary. This period coincides with the life expectancy improvements showed in the same years. After 1991, Lithuania, Russia, Latvia and Estonia significantly increased lifespan disparity with the top peak in 1994-1995, but not with the same levels observed in life expectancy. For example, Russian life expectancy reached levels of life expectancy comparable to that observed in the 1950s, while lifespan disparity shows levels comparable to the 1970's level. In addition, in 1994, when Russia reached the lowest life expectancy level, lifespan disparity is close to the levels observed in Latvia, Estonia and Lithuania, which had higher life expectancy in the same year. Countries such as Hungary, Poland, Bulgaria, Slovakia, Slovenia, Czech Republic continuously decreased variation at age at death since 1994. The rest of the countries also experienced improvements since that year up to 2010-2014, but with higher variability between periods. Such improvements, however, are not as steeper as the life expectancy increases in these countries. Females show similar trends but with lower levels of lifespan disparity over the whole period by country (see Appendix figure 9).

[Figure 2 about here]

Absolute and relative changes in life expectancy and lifespan disparity

Previous studies have shown a negative correlation between life expectancy and lifespan disparity when measured with $e^{\dagger}$ (Shkolnikov et al. 2011). Trends in e_0 and $e^{\dagger}$ suggest that in periods of stagnation and mortality upheavals similar levels of life expectancy do not correspond to similar levels in lifespan disparity. Therefore, we focus on changes and their magnitude to improve in analyzing the dynamics between life expectancy and lifespan variability, as has been previously proposed (Smits and Monden 2009, Fernandez and Beltrán-Sánchez 2015).

Figure 3 shows absolute and relative yearly changes (first differences) in life expectancy (e_0) and lifespan disparity ($e^{\dagger}$) by sex and period. If a negative relationship exists between e_0 and $e^{\dagger}$, we expect changes to concentrate in the top left and bottom right quadrants. Opposing the empirically observed pattern in western countries (Wilmoth and Horiuchi 1999, Shkolnikov et al. 2011), if points fall in the top right and bottom left quadrants, the relationship is positive. We focus on the latter changes and quantify the proportion of them compare to the total changes (percentages in the figure). The period 1960-1987 is related to stagnation and improvements in life expectancy; 1988 to 1995 with periods of mortality deterioration; and 1996 onwards is characterized by divergence between countries in life expectancy trends, and recently with life expectancy improvements. Grey dots correspond to a negative association between life expectancy and lifespan 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 $e^\dagger$).

Absolute values are informative and important since they reflect the changes on life expectancy and lifespan disparity, and their effect is 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 life expectancy's axis than lifespan disparity's. Therefore, it is also important to analyze changes in both measures in relative terms, this allows us to quantify the intensity of such changes.

During 1960-1987, almost 33% of changes correspond to decreases in e_0 and decreases in $e^\dagger$, in both males and females. These changes were mostly lower than one year of change. Conversely, 20.1% and 26.5% of positive changes in e_0 are related to higher lifespan variability in males and females, respectively. The rest of the changes correspond to the opposite direction between these measures. This means that, by adding both quadrants, the measures in this period were moving in the same direction more than half of the time. In 1988-1995, when most of the changes correspond to significant decreases in e_0, 13.1% of changes in male life expectancy are related to decreases in e_0 and in $e^\dagger$. Importantly, the magnitude of such changes in life expectancy do not reflect the same magnitude in changes in lifespan disparity. For example, Russia lost 3 years of male life expectancy (around 5%) between 1992 and 1993, while lifespan disparity shows a negligible increase (less than 2.5%). From 1994 to 1995 this country increased life expectancy by almost one year, while $e^\dagger$ shows a positive increase comparable to the one observed between 1992 and 1993. Finally, from 1996 onwards, when most of these countries experienced life expectancy improvements, around 8.5% is related to decreases in e_0 and $e^\dagger$ at the same time, while 25.7% and 21.4% of the total positive changes correspond to increases in lifespan disparity in males and females, respectively.

Under the negative association between e_0 and $e^\dagger$ framework, we would expect that an increase in e_0 should correspond to a decrease in $e^\dagger$. However, these results suggest that both measures change independently from one another. In addition, relative changes in lifespan disparity were mostly stronger than those shown in life expectancy, suggesting that variation in age at death is more sensitive to mortality fluctuations than the level of mortality in these countries. We further analyze age-specific patterns in lifespan disparity to investigate the trade off between ages in which morality changes contribute positively (expansion) to lifespan variability from those that compress it (Zhang and Vaupel 2009).

[Figure 3 about here]

Age-specific decomposition

Figure 4 and 5 show age-specific contributions to the change in lifespan disparity $e^\dagger$ for ages 0-4 and above age 4, respectively, by period (results for females are shown in Appendix figure 11). Bars on the left (decreases in variation) come about from mortality decrease at young ages, and increases at old ages, separated by a threshold age. Inversely, if mortality is increasing at all ages the components would flip from bottom right (increases in variation) to top left (decreases in variation). The periods are labeled as follows according to life expectancy trends in figure 2: stagnation from 1960 to 1980 (grey), improvements from 1980 to 1987 (blue), 1987-1994 is related to a period of deterioration (red), 1994-2000 is labeled as divergence between countries (green), and convergence corresponds to the period 2000-2010 (magenta). If the colors are all lined up on one side it suggests that mortality changed in different directions for the different ages.

[Figure 4 about here]

Results show that over all the period 1960-2010 (figure 4), sizable improvements in mortality were made in ages below five in both females and males, which decreased $e^\dagger$. Particularly between 1960-1980 (grey), when some countries like Bulgaria, Belarus, Hungary, Lithuania, Poland and Russia reduced $e^\dagger$ by one year. However, some countries, such as Latvia, Lithuania and Bulgaria, increased lifespan variability in periods of life expectancy deterioration (red) in these ages.

Figure 5 shows age-specific contributions to the change in male lifespan disparity ($e^\dagger$) above age 4 by period (results for females are shown in Appendix figure 11). Over periods of stagnation (grey), changes in lifespan disparity were driven by increases in mortality at all ages, which expand age at death variability in young and young-adult ages; and compress variation at older ages in all countries (except in Slovenia because of data availability). It is worth noting that these changes offset each other since old-age's compression is comparable to the net effect made by young and young-adult ages in Russia, Slovakia, Ukraine, and Poland. In fact, in Bulgaria and Belarus, the compression experienced in older ages is greater than the expansion made by the younger ages caused by mortality deterioration.

A similar pattern is observed during periods of life expectancy deterioration (red). Most of lifespan variability increases were explained by expansion of mortality at young and middle ages, with small compression at older ages in this period. However, some countries like Slovenia, Slovakia, Poland and Czech Republic show improvements in mortality between ages 5 and 30 that resulted in declines on $e^\dagger$.

Opposing these trends, in periods of improvements (blue), almost all of the countries followed a western pattern with lifespan variability decreases mostly caused by improvements in young and young-adult ages mortality, and small negative effects at older ages after the threshold age. However, some countries like Slovakia, Poland and Hungary showed atypical patterns with reductions on $e^\dagger$ in ages between 5 and 30 associated with increases in mortality in these ages. From 1994 (green and magenta), all countries showed lifespan variability compression at young and young-adult ages and expansion at older ages after the threshold age. Importantly, during these periods, mortality fluctuations at relatively young ages (20-50) had the largest impact on lifespan variability changes. However, the contributions at older ages in countries like Hungary, Slovenia, Latvia, Poland, Czech Republic and Estonia are sizable, compared with the rest of the countries. Russia, Ukraine and Belarus are special cases since in the period 1994-2000 they experienced lifespan variability compression at young ages.

[Figure 5 about here]

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

Figures 6 and 7 show how alcohol-related mortality contributed to the changing lifespan variation ($e^{\dagger}$) at different ages over the periods 1994-2000 and 2000-2010 for males (results for women are shown in Appendix figures 12 and 13). Figures show decomposition results for Russia, Ukraine, Latvia, Lithuania, Poland, Belarus, Czech Republic and Estonia. This subset of countries was chosen because time series have been carefully reconstructed for the Human Cause-of-Death Database (2016) and are more comparable over time and across countries. Bars on the right (positive) correspond to ages at which mortality change increased lifespan disparity; bars on the left (negative) are related to changes in mortality that decreased lifespan variability. Red colors are related to causes attributable to alcohol consumption; blue tones correspond to deaths from causes amenable to alcohol consumption. The darkest blue refers to Ischemic Heart Diseases (IHD), the lightest to transportation accidents, and the mid-blue to stroke mortality. Orange and green colors relate to other external causes and the rest of circulatory diseases, respectively. The rest of causes and mortality above age 84 is depicted in grey.

The period 1994-2000 was characterized by a divergence trend between countries in life expectancy, some countries improved continuously, Czech Republic for example; while others countries experienced both periods of deterioration and improvements, such as Russia. Results show that in Russia, Ukraine and Belarus lifespan variation stagnated between 1994 and 2000 because the magnitude of compression in variability canceled the expansion in lifespan variation. During this period, mortality deterioration in Russia at ages 20-29, and in Ukraine and Belarus between 20 and 49 increased $e^{\dagger}$. Most of this deterioration was caused by external causes in Russia and Belarus, while in Ukraine was due to non-alcohol related mortality. On the contrary, Latvia, Lithuania and Estonia experienced sizable improvements in alcohol-related mortality in early-adult ages, which decreased variability. Similarly, mortality decline in older ages, above the threshold age, increased variability in these countries. Importantly, most of such improvements were on conditions amenable to alcohol consumption, particularly from IHD and stroke; and in Lithuania a strong component in reducing mortality from causes attributable to alcohol consumption in ages between 20 and 60 was translated into sizable decreases in lifespan disparity. Results for females (Appendix figure 12) show similar patterns on cause-specific contributions to the change in lifespan variability between 1994-2000.

In the first decade of the 21st century all the countries in Eastern Europe improved survival and decreased lifespan variation. Most of the mortality compression below the threshold age was due to improvements in early-adult ages, with exception of Lithuania where a reversal in mortality trends in ages between 30 and 45 occurred relative to 1994-2000. Conditions wholly attributable to alcohol consumption played a negligible role in lifespan variability compression over the period. However, transportation accidents and other external causes significantly contributed to the reduction in lifespan disparity below the threshold age. Their effect was stronger in Russia, Latvia, Lithuania, Belarus and Estonia. Above the threshold age, almost all the countries experienced declines in mortality, with the exception of Lithuania, Latvia, Estonia and Belarus, where mortality from non-related to alcohol and circulatory (other than IHD) deteriorated. The larger contributions to changes in lifespan variation due to conditions amenable to alcohol consumption above the threshold age were found in Russia, Latvia, Poland, Czech Republic and Estonia; particularly from declines in mortality caused by IHD, stroke and other circulatory diseases. Results for females are alike (Appendix figure 13), a strong component of external causes in early-adult ages and improvements in IHD, stroke and other circulatory diseases at older ages drove lifespan disparity changes from 2000 to 2010.

[Figures 6 & 7 about here]

Limitations

The limitations of our study should be mentioned. Firstly, different measures of inequality differ from each other in formal properties and in the degree of their fluctuation to variability (van Raalte and Caswell 2013). Edwards and Tuljapurkar (2005) use the standard deviation of age at death for ages 10 and above (S_{10}), we decided to use $e^{\dagger}$ unconditional to survival at any age because it allows us to capture the contributions of improvements at young ages in the set of countries in our study. Other authors have chosen measures of relative inequality, such as the Gini coefficient, Theil index of inequality or the average interindividual difference (Shkolnikov et al. 2003, Smits and Monden 2009, Moser et al. 2005). To rule out significantly differences from our results with these kind of measures, we performed a sensitivity analysis replicating all the results shown in this study with the Gini coefficient following Shkolnikov et al. (2003) (see Appendix section B.1). We did not find major differences with the results discussed in this article. Finally, we do not expect major dissimilarities in variation trends if Keyfitz's entropy (Keyfitz and Caswell 2005) were used because it is defined as $e^{\dagger}$ weighted by life expectancy at birth (Vaupel and Canudas-Romo 2003).

Secondly, estimating alcohol-attributable mortality is not an easy task. For instance, we were not able to precisely estimate the proportion of deaths that were caused because of alcohol consumption as previous studies have done (Kraus et al. 2015, Martikainen et al. 2014). Additionally, potential protective effects of alcohol in cause-specific mortality rates were out of the scope of the study; however, some authors have been able to quantify the positive effects of alcohol in some conditions, such as diabetes (Rehm et al. 2010). Rehm et al. (2010) estimate that 10% of deaths caused by alcohol consumption would be avoided if people were to moderate its consumption. Alternatively, we took a more cautious approach that shows changing effects that are at least partly attributable to changing alcohol patterns without over or under-interpreting its absolute impact. We focus only in those causes of death that would not have occurred without alcohol consumption available in the Human Cause-of-Death Database (2016) following Rehm et al. (2010). 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". However, interpretations of results of these conditions do not mean that they were caused by alcohol consumption, rather mean that a strong component from accidents or IHD could point to alcohol-related mortality. Finally, it is not possible to attribute mortality at any period to alcohol, since some conditions, such as IHD, do not kill instantly (e.g. poisoning by exposure to alcohol) and it is necessary to account current and past consumption patterns of individuals. We do not have follow-up longitudinal studies to disentangle differential alcohol consumption and its effect on specific causes of death for these countries. In addition, 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 occasionally drinking, 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). Moreover, these data would exclude homemade alcohol, which is sizable and associated with increasing mortality in Eastern Europe (Popova et al. 2007, McKee et al. 2005); and 'alcohol tourism' (e.g. the case of Finland and Estonia) (Mäkelä and Österberg 2009, Rabinovich et al. 2009).

Discussion

The results derived from this study allow us to analyze and compare long time series in lifespan variability for 12 countries from Eastern Europe. They shed light into the determinants of variation at age at death across time and countries. In addition, we use high quality comparably reconstructed cause of death data to analyze the role of alcohol-related mortality on changing lifespan variation based on a reflective classification. This is the first comparative study of Eastern Europe making use of the Human Cause-of-Death Database (2016). Over the study period, life expectancy (e_0) and lifespan disparity ($e^\dagger$) moved independently from one another, particularly during periods of life expectancy decrease. Fluctuations in mortality were, to a large extent, directly or partially attributable to changes in alcohol consumption.

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

Eastern Europe experienced atypical mortality trends since 1960 compared to other European regions and with the pattern observed in the record life expectancy (Oeppen and Vaupel 2002). These countries experienced a fairly large period of stagnation (1960-1990) with a mean life expectancy around 66 years. In the subsequent years after Gorbachev's anti-alcohol campaign was finished and the Soviet Union broke up, some of these countries exhibited an unprecedented decrease in life expectancy. Russia and Latvia's male life expectancy declined from 64 in 1991 to 57 and 58 in 1994, respectively. To put this in perspective, Russia and Latvia were having the same level of life expectancy as Slovakia used to have in 1959 and contradicting the best practice upward tendency (Oeppen and Vaupel 2002). Opposing this trend, in the first ten years of the new century life expectancy has showed significant improvements in all the Eastern European countries, yet high levels of inequality between and inside the countries remain, as other authors have found (Leon 2011).

Our results reveal that, although life expectancy experienced major variations in most countries in Eastern Europe, changes in lifespan variability ($e^{\dagger}$) do not correspond in intensity with those observed in life expectancy trends. Since the 1970s, most studies have shown that temporal increases in life expectancy correspond to decreases in lifespan disparity (Wilmoth and Horiuchi 1999). However, a high proportion of changes in life expectancy coincided with changes in lifespan variability in the same direction in this region. Nearly half of the total changes in life expectancy during 1960-1987 correspond to changes in the same way on $e^{\dagger}$ and more than one fifth afterwards. Moreover, a high proportion of such changes in lifespan variability were positive, even in periods where life expectancy increased. Increasing lifespan variability underscores the rise in within-group heterogeneity and the uncertainty that people face regarding their age at death. From a public health perspective, these results are important because they disclose inequalities underlying populations' health that could not be identified by looking only to life expectancy. Similar outcomes have been found previously for some countries and they are seen as outliers.- not following the classic western trend (Wilmoth and Horiuchi 1999, Zhang and Vaupel 2009). For instance, Shkolnikov et al. (2003) found that, during a period of emergence of some public health problems, lifespan disparity above age 14 increased between the mid-1980s and mid-1990s in the US. Similarly, van Raalte et al. (2014) found life expectancy increases along with expansion in variability at age at death in the Finnish manual classes, while Sasson (2016) found similar results in the low educated groups in the United States between 1990-2010. 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 such trend and of the independence of the two measures during large periods of time with atypical mortality schedules .

Age-specific contributions to changes in $e^{\dagger}$

We further analyzed lifespan variability dynamics by specific ages to disentangle changes driven by an early-age component and an old-age component, as noted by Zhang and Vaupel (2009). Unlike the common pattern observed in previous studies, our results show that changes in $e^{\dagger}$ were mainly by an offsetting effect caused by higher lifespan disparity in younger ages in periods of stagnation (1960-1980) and during the mortality crises between 1987-1994, with lower variability in ages above 55 in the same periods. This interplay between young and old is the outlying pattern from what was observed in most western European countries, where changes in lifespan variability were mainly driven by mortality reductions in younger ages, while older-age mortality fluctuations' impact was very small (Wilmoth and Horiuchi 1999). For instance, in Finland differences in mortality reduction at young ages between social groups were more important than the old-age component since the 1970s (van Raalte et al. 2014). Whereas in countries like Russia, Ukraine, Bulgaria and Belarus the old-age component played an important role on lifespan variability changes, particularly in periods of life expectancy stagnation and deterioration. The effect was such in these countries that it completely counterbalanced the effect of the younger ages above age 10. A similar effect was previously documented in Russia, showing that lifespan variability's increases were mainly driven by mortality changes between ages 20 and 55 from 1960 to 1980, relative to the values observed in 1959 (Shkolnikov et al. 2003, van Raalte and Caswell 2013). Although the premature mortality component played an important role on increasing uncertainty about when people would die, it is worth noting that below age 10 almost every country experienced progress in averting deaths, as shown by mortality rates of improvements. Such progress was translated into sizable decreases in lifespan variability below age 5 mainly. 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 Czech Republic, Hungary and Poland (Chenet et al. 1996).

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

Alcohol related mortality has played an important role in lifespan variability and life expectancy trends since the 1980s in Eastern European countries (Rehm et al. 2007, Shkolnikov et al. 2003; 2001). Our study improves in this subject by further decomposing age-specific contributions by causes of death related to alcohol consumption after 1994 for eight countries (Belarus, Czech Republic, Estonia, Latvia, Lithuania, Poland, Russia and Ukraine). Fluctuations in lifespan variability were in large part attributable to changes in alcohol consumption in all the countries included in the study. For Russia, this results are consistent with Shkolnikov et al. (2003)'s findings between 1979 and 1989. The authors found that early-adult mortality compression during this period was attributed to a decrease in alcohol-related mortality as consequence of Gorbachev's anti-alcohol campaign.

Alcohol-related mortality contributed to variability compression in Russia, Latvia, Lithuania and Estonia in young-adult ages after 1994; while in the rest of the countries, Ukraine, Poland, Belarus and Czech Republic the effect of alcohol related mortality on lifespan variability changes was much smaller. This can be related to the different developments on alcohol consumption patterns in the region. For example, Russia and Belarus showed quite different trends on mortality and alcohol consumption levels in the 1990s and early 2000s (Grigoriev and Andreev 2015). Importantly, most of lifespan variability changes in young-adult ages was explained by transportation accidents and other external causes in most of the countries. These results are consistent with the reduction on age-standardized rates of these conditions in Russia and Belarus and the lower alcohol consumption (Grigoriev and Andreev 2015, Shkolnikov et al. 2013). Preventing external deaths at young ages has been previously highlighted as a immediate factor to reduce lifespan variability differences;

for instance, Firebaugh et al. (2014) stated that resources allocation to reducing homicides in the black population in the U.S. are likely to provide a narrowing effect on racial disparity in lifespan variation than the same level of funds spent in more common causes of death. It is also interesting to note the role of causes amenable to alcohol consumption in old-ages; particularly IHD and stroke mortality improvements largely explain mortality expansion on these ages in Latvia, Lithuania, Czech Republic and Estonia. Unexpectedly, 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 on lifespan disparity. Out of the eight countries in the study, only Lithuania, Russia and Latvia showed large mortality improvements in these conditions that caused compression of mortality at young ages. This finding is consistent with mortality rates sharp declines from cirrhosis of liver and alcohol poisoning mainly after 1994 through the early 2000s in Lithuania, relative to those observed in Belarus (Grigoriev et al. 2015).

Analyzing life expectancy and variability at age contributes to deeper understanding the impact of changing mortality trends on populations' health. That Eastern European countries experience higher lifespan variation and great fluctuation in the predictability of life compared to other populations highlights the deprivation that these countries continuously face. The results from this study underscore the impact of declining mortality at very young ages on the reduction of lifespan disparity, and call attention to the still central role of fluctuating alcohol patterns on the uncertainty of age at death that these populations confront. We were able to capture such effects by going beyond correlation metrics and further analyzed first difference changes and carefully disentangle the impact of specific ages and causes of death on lifespan variability fluctuations. We drew in high quality mortality sources and cautiously harmonized causes of death for several countries along with a thoughtful classification. As Eastern European countries experience larger inequalities in mortality, partly due to socioeconomic inequalities in accessibility, utilization and quality of health care services (Kunst 2009), our findings suggest that policies to reduce lifespan variability should focus on mortality amenable to alcohol consumption across the entire lifespan and continued efforts to reduce health inequalities and self-hazardous behavior. Given such socioeconomic differences, we suggest that future research focus on sub-population levels in these countries and unravel lifespan variability differences by social and educational groups (van Raalte et al. 2014, Sasson 2016), complemented by alcohol-consumption differences.

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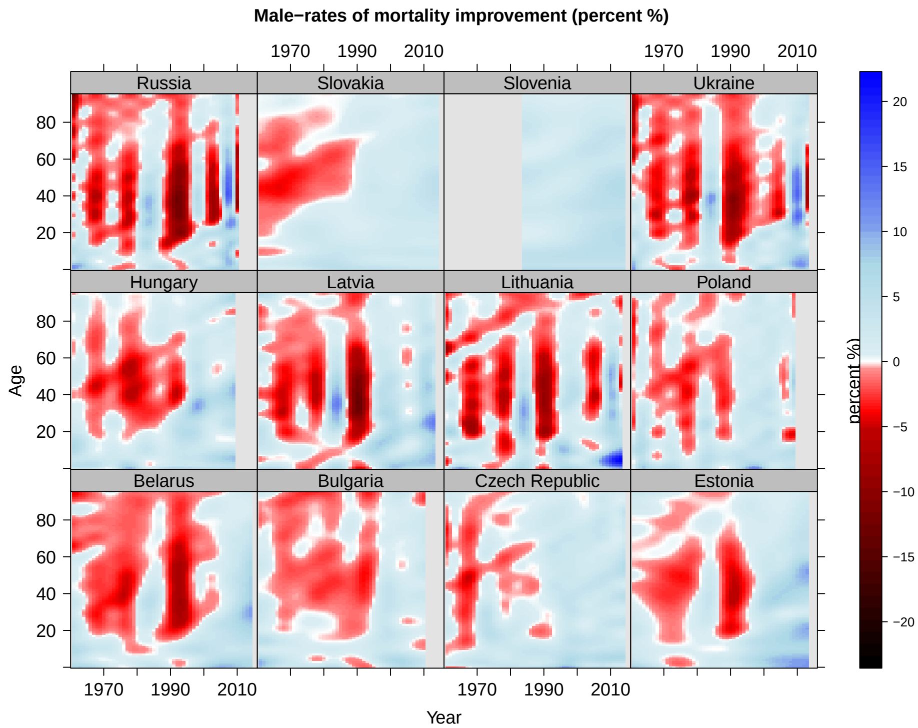
Figures and tables

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

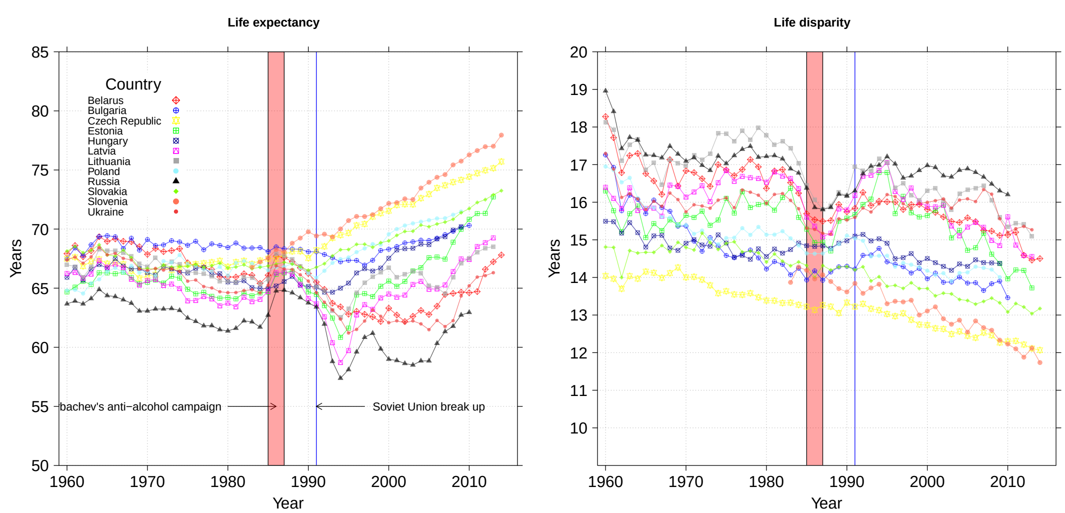
Category	ICD-10 codes
1) Alcohol attributable conditions	
Mental and behavioral disorders due to use of alcohol, alcohol liver disease and cirrhosis of the liver, poisoning by exposure to alcohol	F10, K70 & K74, X45
2) Amenable to alcohol consumption	
Ischemic Heart Diseases, stroke and transport accidents	I20-25, I60-I67 & G45, 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) and **other circulatory conditions** (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)	(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) and (I00-I09; I10; I11-I15; I26-I28; I34-I38; I46; I50; I30-I33, I40-I45, I47-I49; I51; I69; I70-I78; I80-I99)
4) Residual causes	
Rest of conditions and mortality above age 85	

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. Russia, Hungary, Bulgaria and Poland after 2010. Slovenia before 1983.

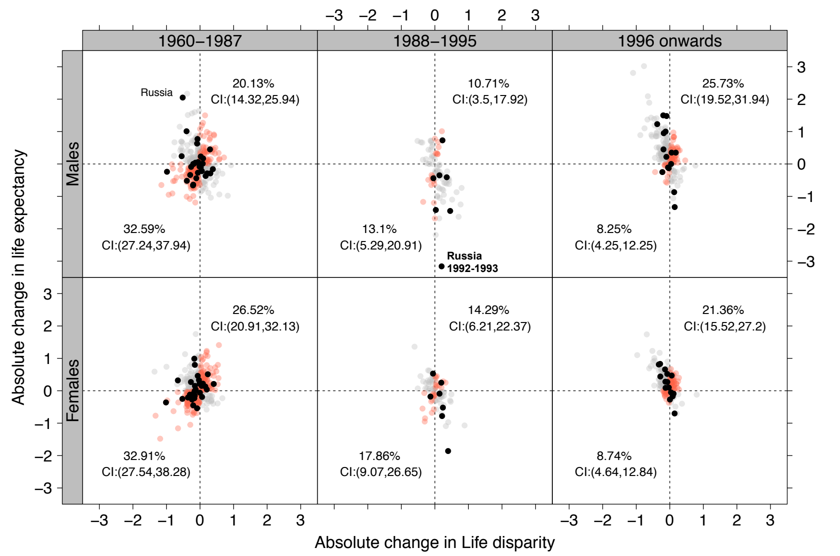
Figure 2: Trends in males life expectancy (e_0) and lifespan disparity ($e^\dagger$) for 12 Eastern European countries, 1960-2014



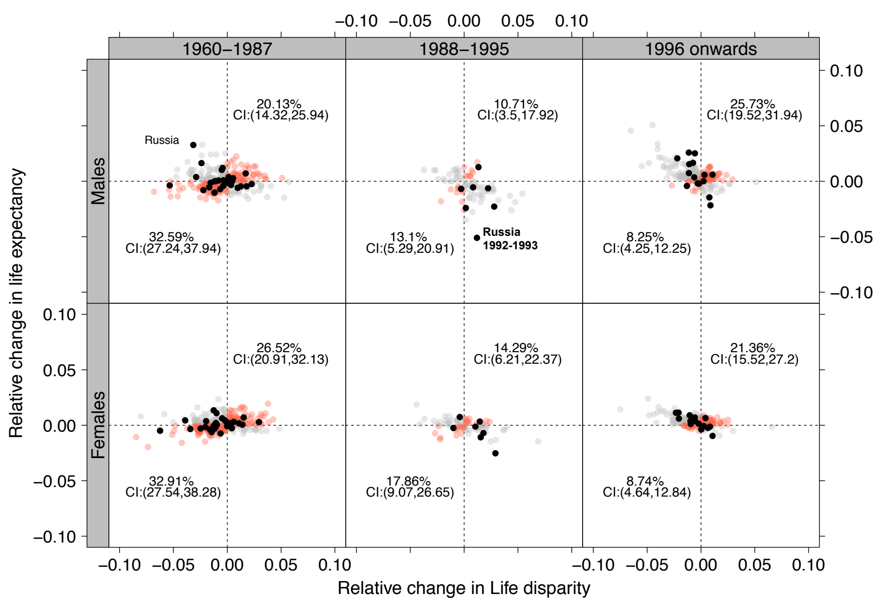
Source: own calculations based on Human Mortality Database (2016) data.

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

(a) Absolute changes

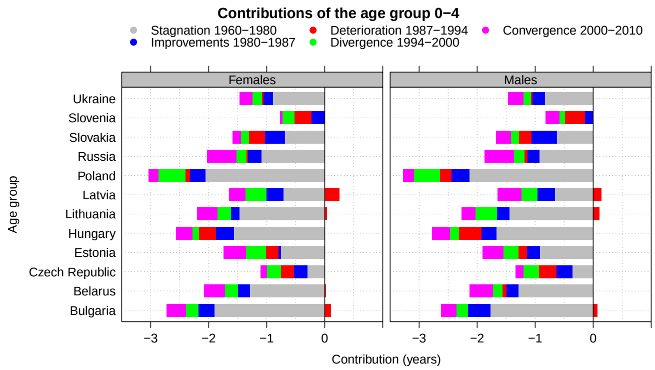


(b) Relative changes



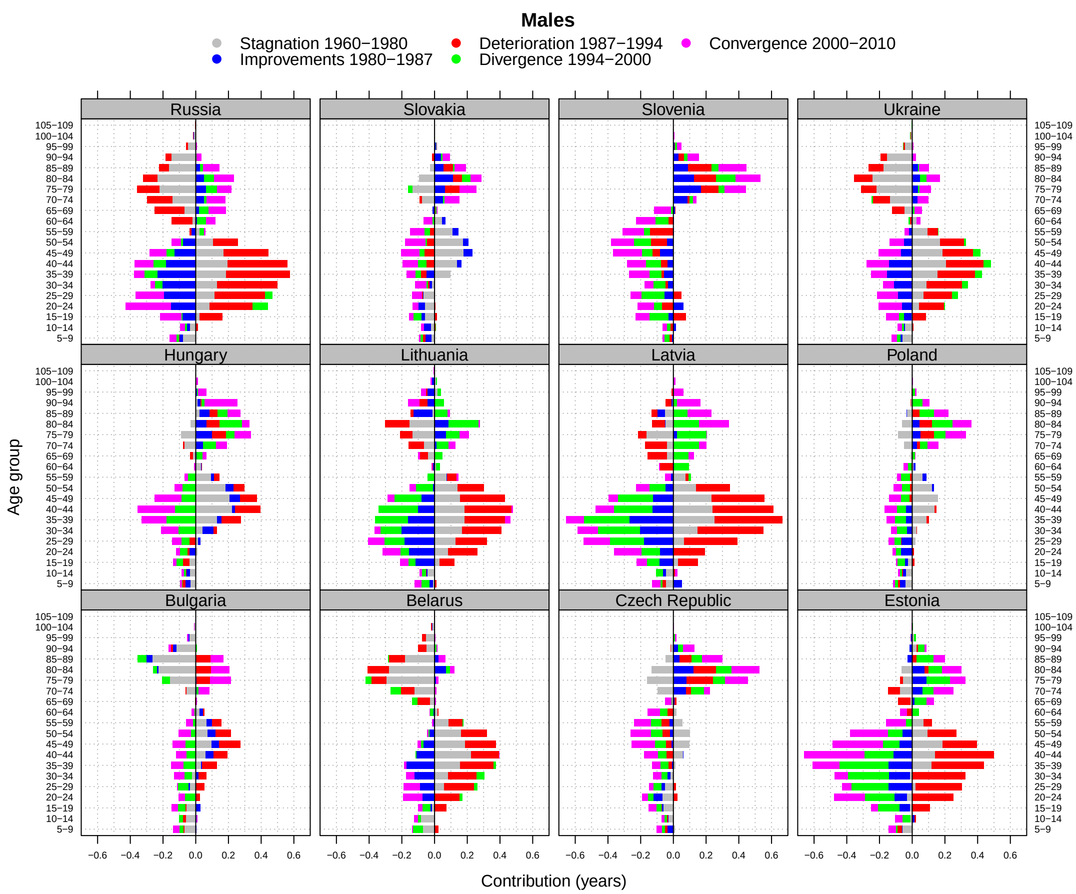
Source: own calculations based on Human Mortality Database (2016) data. Note: data for Slovenia begins in 1983. The black dots are related to changes experienced in Russia. The percentages correspond to the total changes occurred during each period.

Figure 4: Infancy (age-group 0-4) contributions to the change in lifespan disparity $e^{\dagger}$.



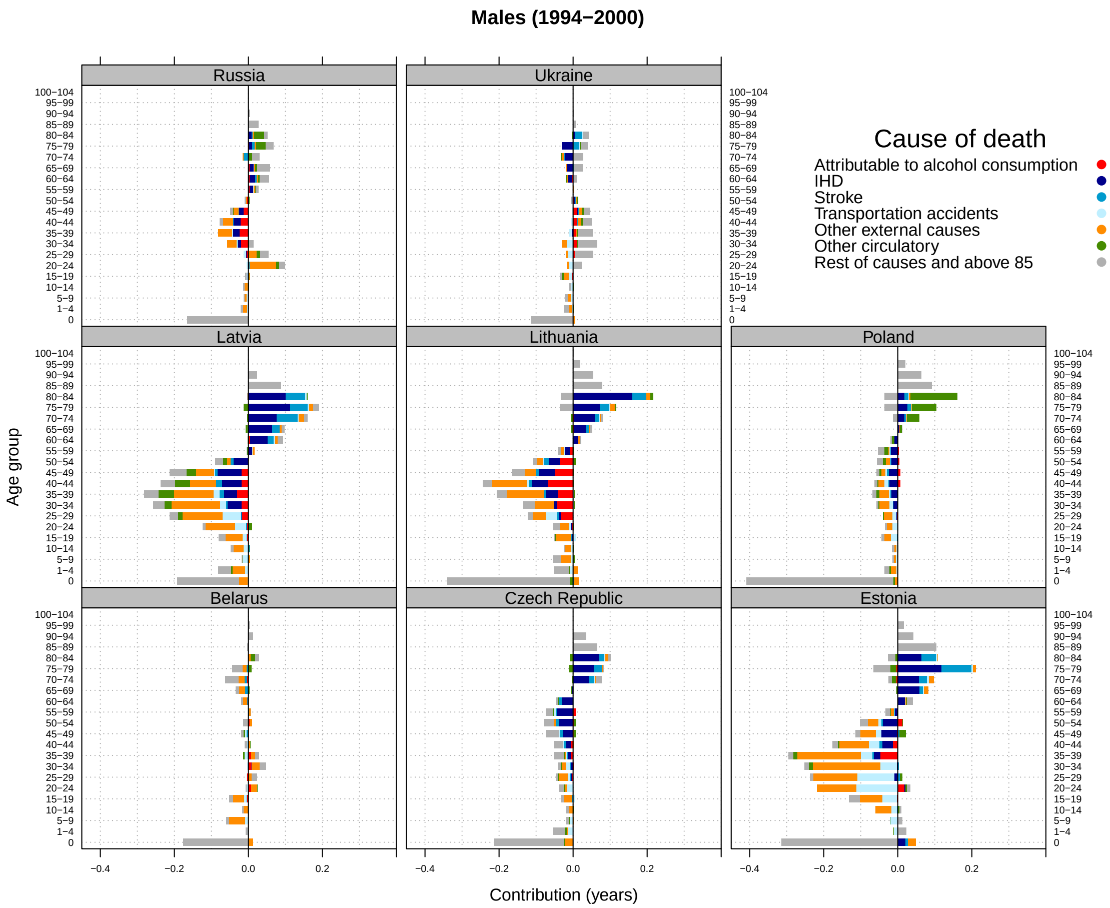
Source: own calculations based on Human Mortality Database (2016) data. Note: data for Slovenia begins in 1983.

Figure 5: Males' age-specific contributions to the change in lifespan disparity $e^{\dagger}$ by periods.



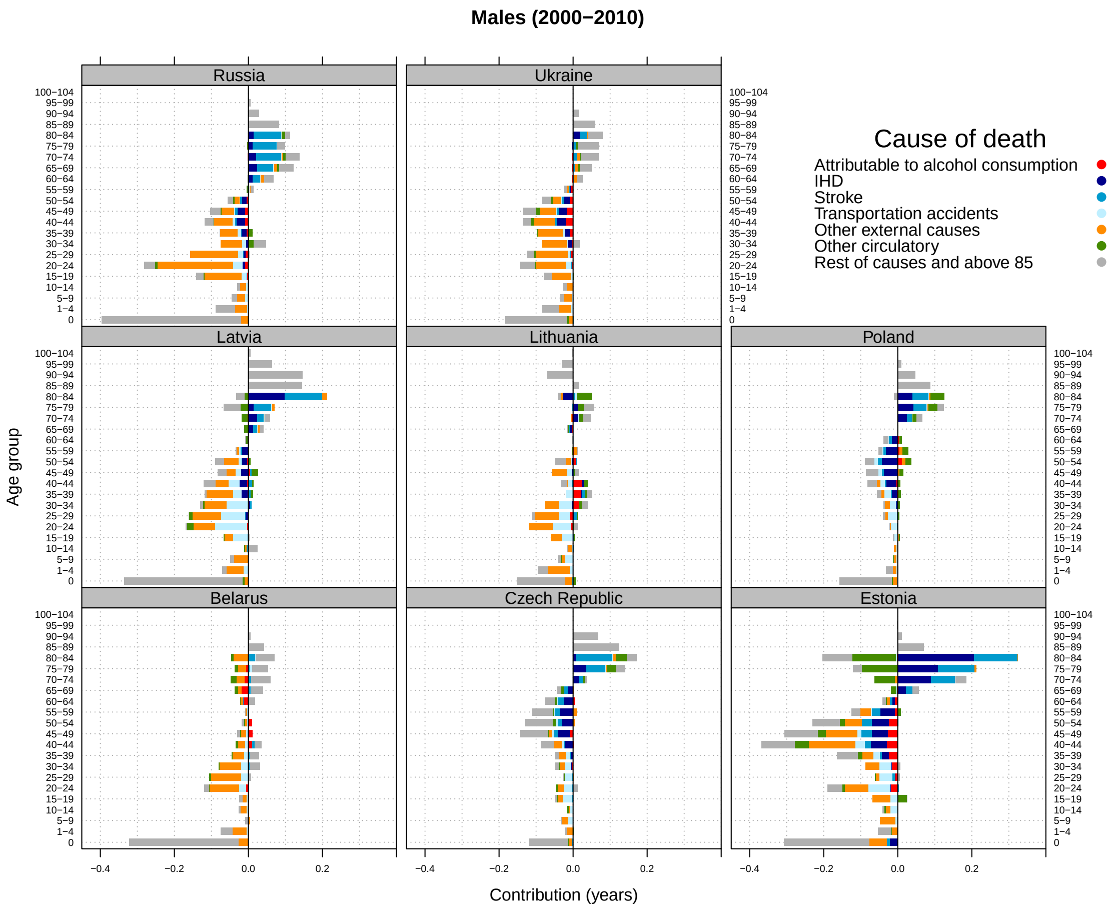
Source: own calculations based on Human Mortality Database (2016) data. Note: data for Slovenia begins in 1983.

Figure 6: Cause specific contributions to the change in male lifespan disparity $e^\dagger$, 1994-2000



Source: own calculations based on Human Mortality Database (2016) data.

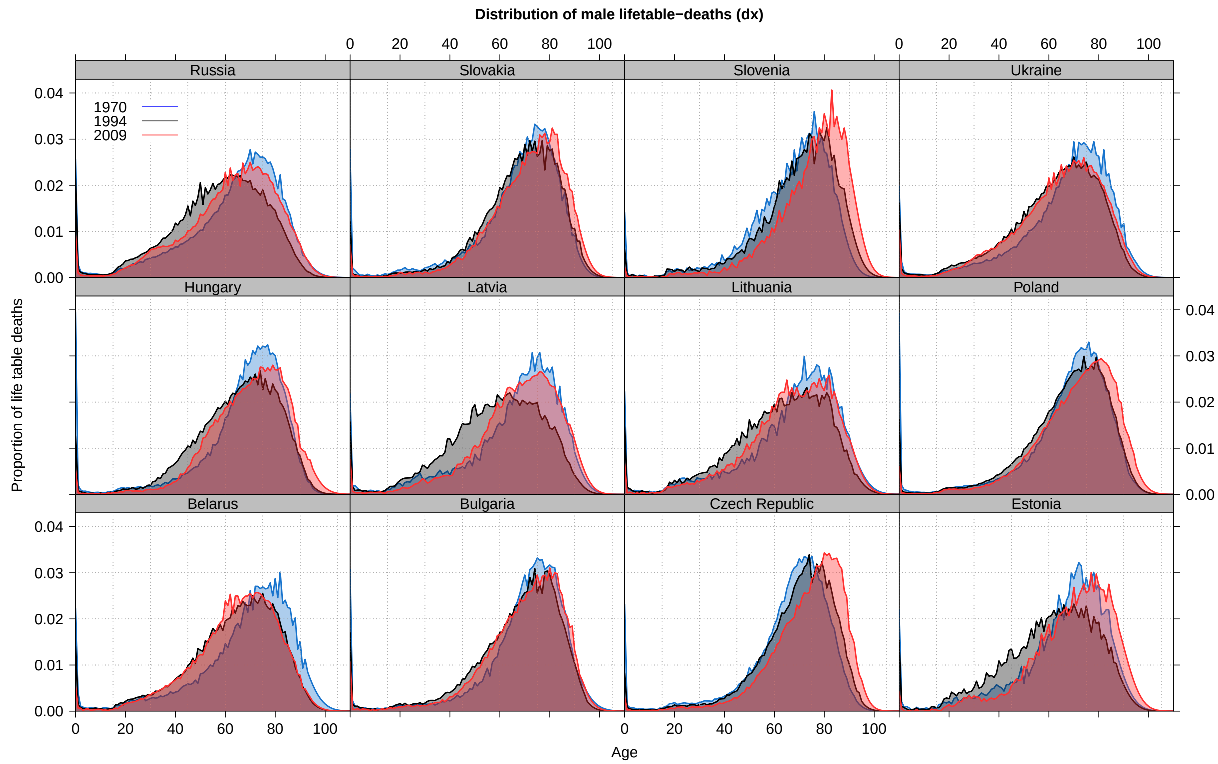
Figure 7: Cause specific contributions to the change in male lifespan disparity $e^{\dagger}$, 2000-2010



Source: own calculations based on Human Mortality Database (2016) data. Note: data for Poland ends in 2009.

A Supplemental material: Mortality

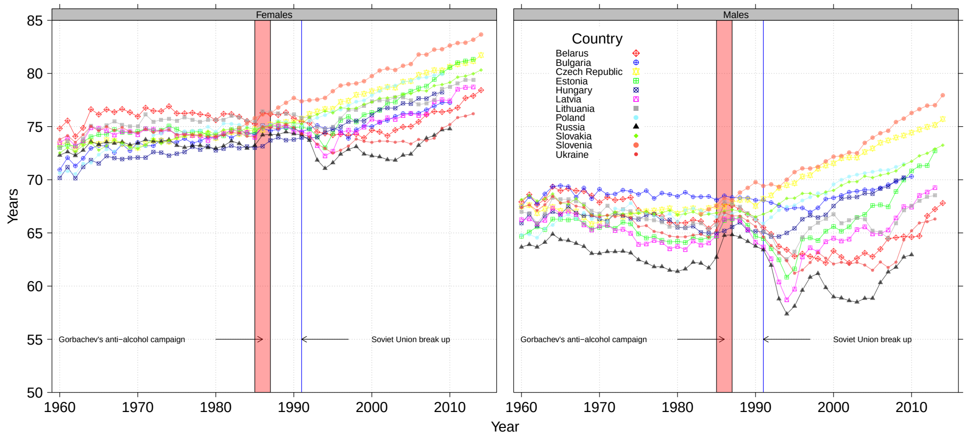
Figure 8: Distribution of deaths for males 1970,1994 and 2009



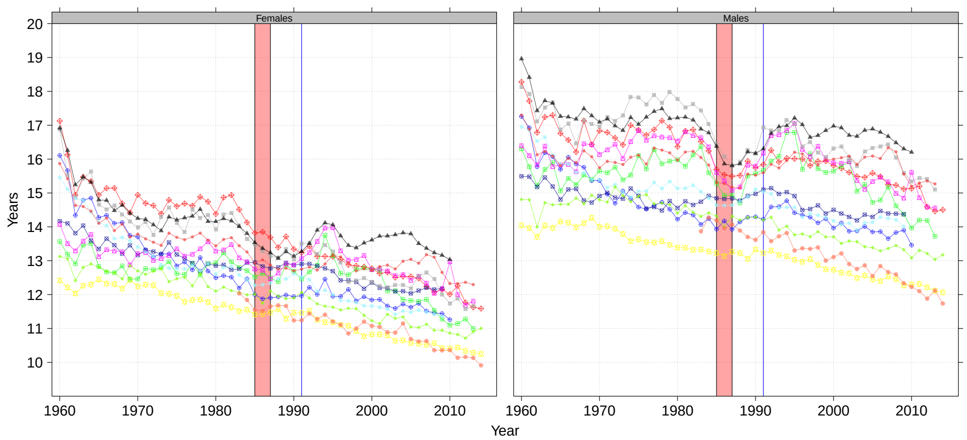
Source: own calculations based on Human Mortality Database (2016) data. Note: the blue distribution for Slovenia corresponds to 1983.

Figure 9: Trends in e_0 and $e^{\dagger}$ for 12 Eastern European countries by sex, 1960-2014

(a) e_0

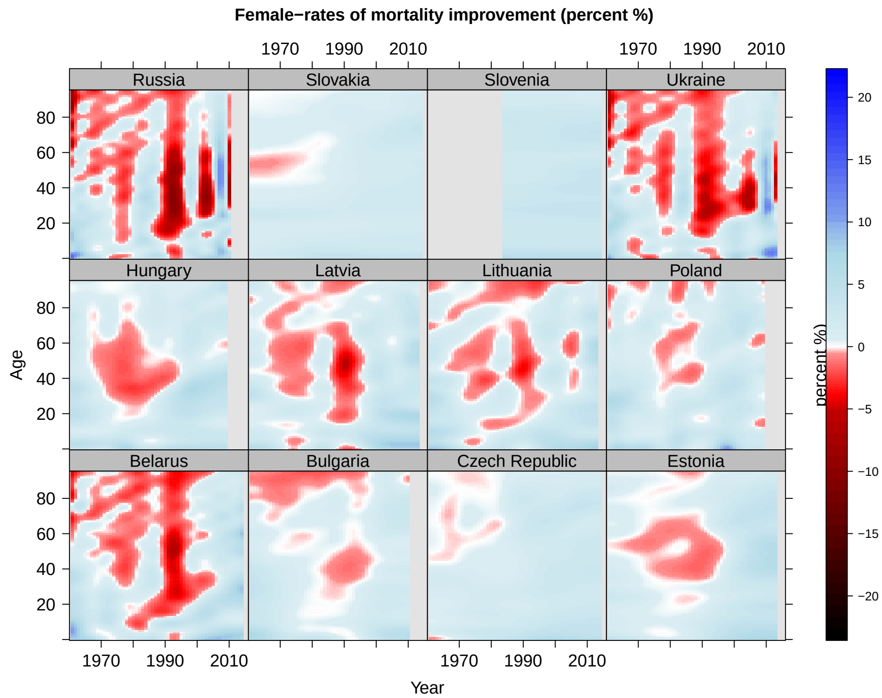


(b) $e^{\dagger}$



Source: own calculations based on Human Mortality Database (2016) data.

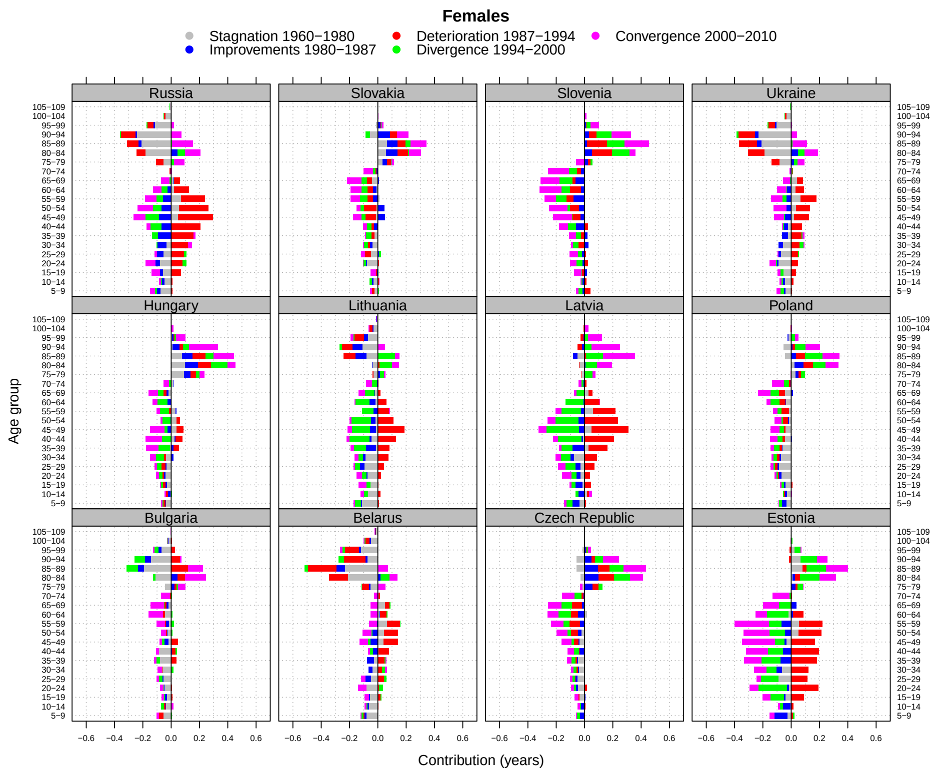
Figure 10: Female mortality surface showing rates of mortality improvements.



Source: own calculations based on Human Mortality Database (2016) data. Note: The regular light -grey areas indicate no data available. Russia, Hungary, Bulgaria and Poland after 2010. Slovenia before 1983.

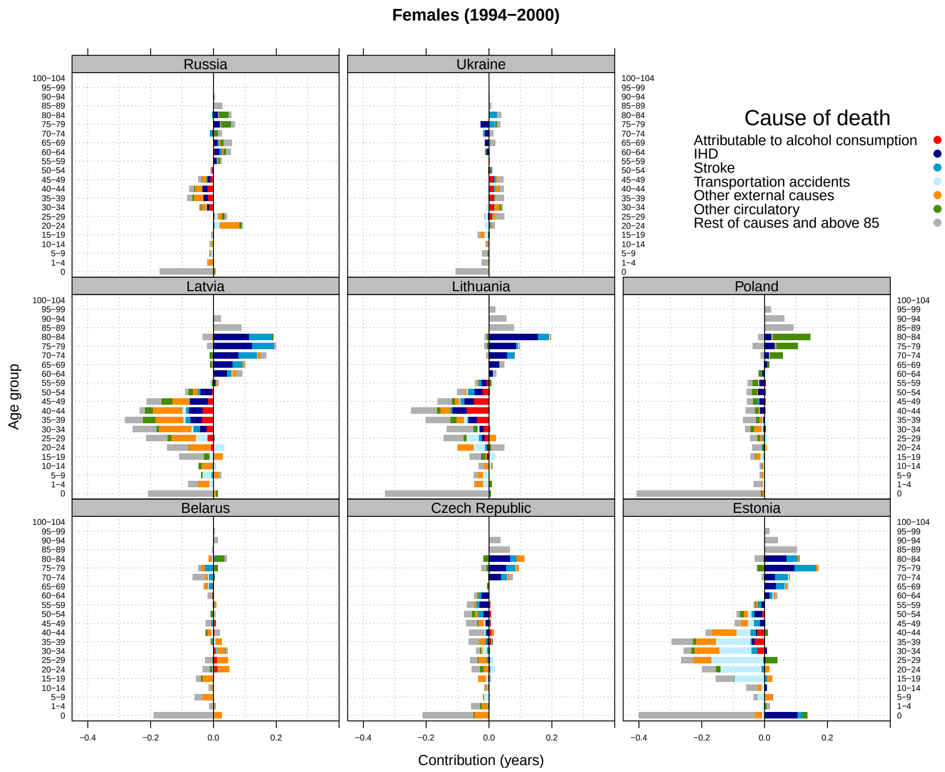
B Supplemental material: Decomposition Results

Figure 11: Females' contributions to the change in lifespan disparity $e^{\dagger}$ by periods.



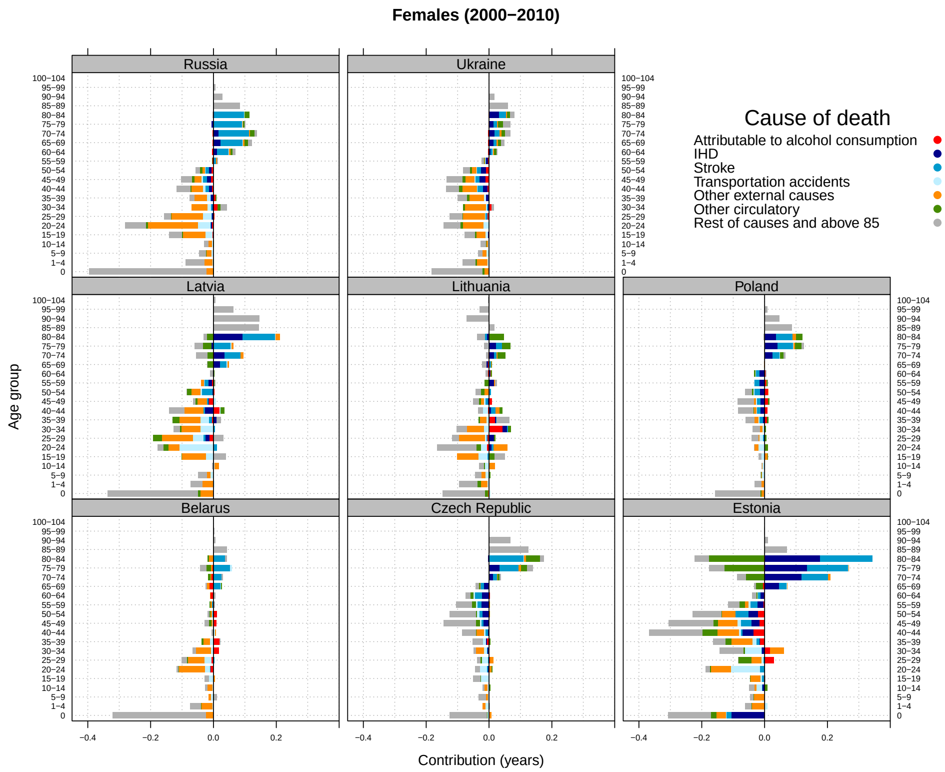
Source: own calculations based on Human Mortality Database (2016) data. Note: data for Slovenia begins in 1983.

Figure 12: Cause specific contributions to the change in female lifespan disparity $e^{\dagger}$, 1994-2000



Source: own calculations based on Human Mortality Database (2016) data.

Figure 13: Cause specific contributions to the change in female lifespan disparity $e^{\dagger}$, 2000-2010



Source: own calculations based on Human Mortality Database (2016) data. Note: data for Poland ends in 2009.

B.1 Sensitivity analysis with Gini coefficient based on Human Mortality Database (2016)

Figure 14: Trends in life expectancy and Gini coefficient by sex for Eastern European countries

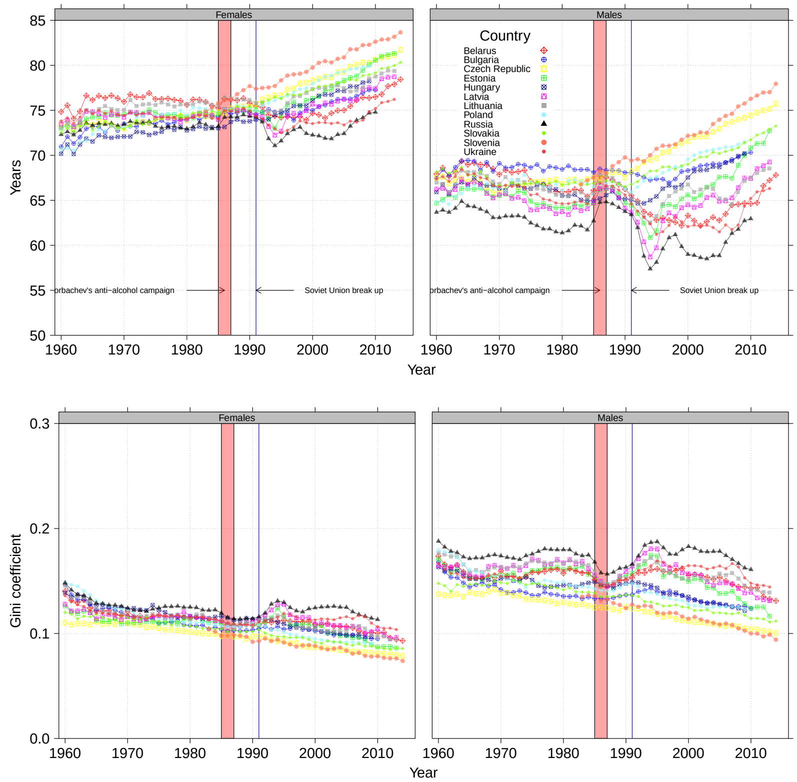


Figure 15: Absolute changes in life expectancy and Gini coefficient by sex for Eastern European countries

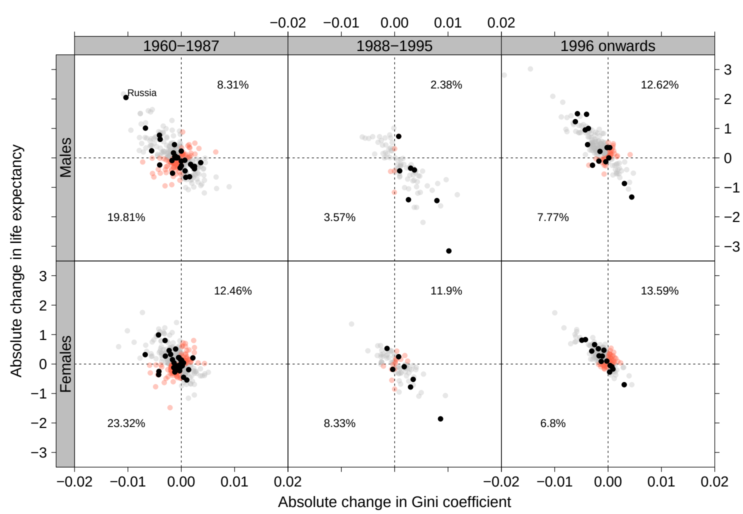


Figure 16: Relative changes in life expectancy and Gini coefficient by sex for Eastern European countries

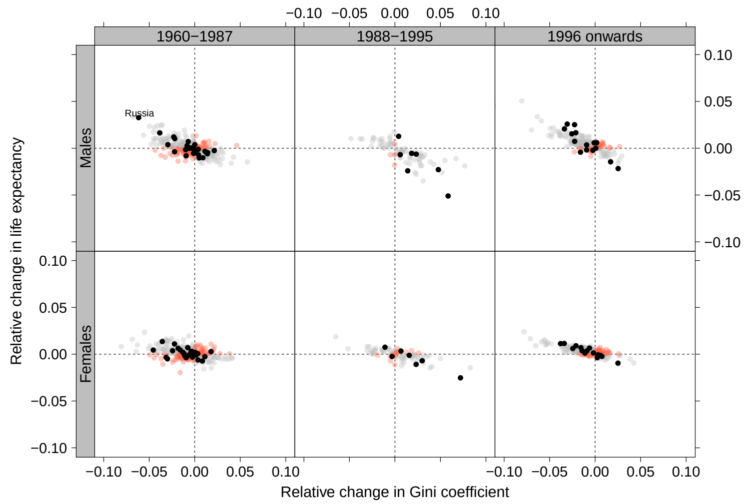


Figure 17: Contributions to changes in Gini coefficient by period

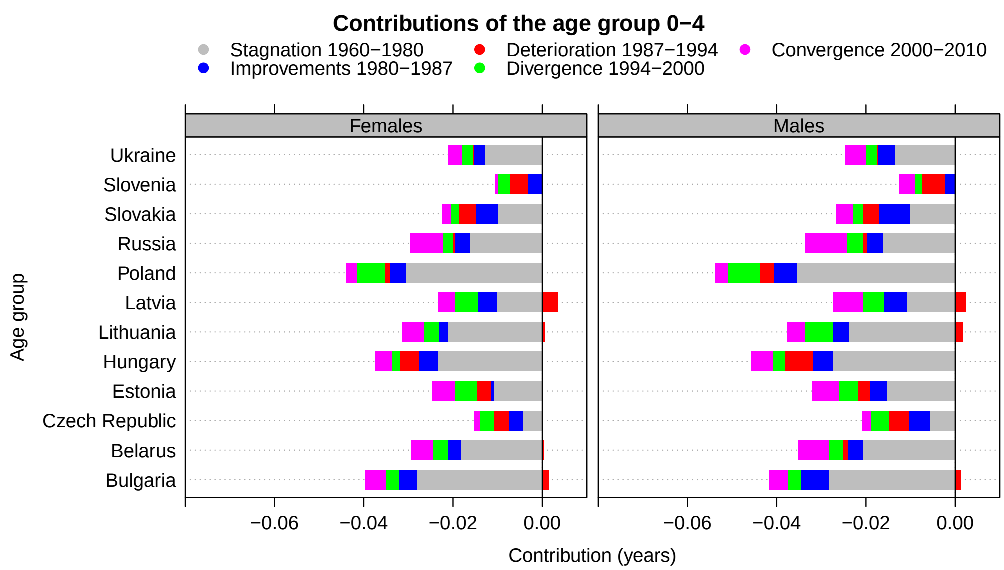


Figure 18: Contributions to changes in Gini coefficient by period, Males.

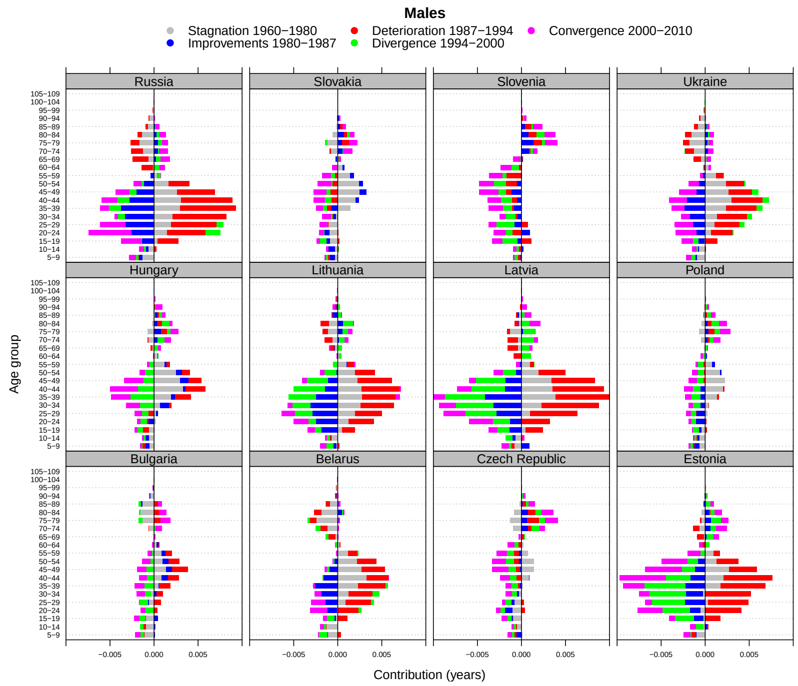


Figure 19: Contributions to changes in Gini coefficient by period, Females.