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Life expectancy and lifespan inequality: a perfect linear correlation? Analysis of the relationship with a particular emphasis on the case of countries going through the life expectancy stagnation period

Abstract

In recent years in demography there has been a growing discussion about the relationship between life expectancy and lifespan inequality. It appears that in the long run this relationship tends to be strongly linear – countries with the longest life expectancy are also the most equal. This article takes a closer look at countries that went through long periods of life expectancy stagnation and shows that during those times they also experienced a reduction in inequality, mainly due to a large decrease in infant mortality. However, if only adult mortality is taken into account inequality was stagnating or even rising in many cases. Particularly interesting is the fact that a similar pattern of the relationship between life expectancy and lifespan inequality was observed both in Eastern or Western Europe.

Keywords: life expectancy, lifespan inequality, infant mortality, life expectancy stagnation

Introduction

In recent years, in the field of demography, a growing interest in more detailed analyses of mortality, going beyond mere calculation of death rates or life expectancy, has been noticed. One of the topics that has been brought up in several studies is the measurement of lifespan inequality (Vaupel, Zhang & Van Raalte, 2011; Colchero, Rau, Jones, Barthold, Conde, Lenart, Nemeth, Scheuerlein, Schoeley, Torres, Zarulli, Altmann, Brockman, Bronikowski, Fedigan, Pusey, Stoinski, Strier, Baudisch, Alberts & Vaupel, 2016; Nemeth, 2017; Wróblewska, 2017).

The question that quickly arose was about the relationship between lifespan inequality and life expectancy. It was observed that countries (or regions) with the highest life expectancy are also characterised by the lowest inequality. Conversely, the countries with the lowest life expectancy tended to be the most unequal. Moreover, when proper indicators were used to measure inequality it was noticed that this relationship was very linear and the correlation was extremely high (Vaupel et al., 2011). The conclusion was most strongly formulated by Colchero et al. (2016): *For humans the linear relationship holds for both males and females, for populations in the 21st century and historically, for vastly different levels of life expectancy and vastly different societies*.

Such a conclusion would mean that a rise in life expectancy is virtually always accompanied by a reduction in lifespan inequality and vice versa. This study will aim to show that this is not exactly the case. It can be demonstrated that in many cases the reduction in lifespan inequality happened during periods where little to no improvement in life expectancy was observed.

It should be noticed that all the studies that most strongly assert an almost perfect linear relationship rely on data for several countries across all available time periods (Vaupel et al., 2011; Colchero et al., 2016; Nemeth, 2017). The analysis on such an aggregated level leads to omission of important deviations from the general relationship which happens at the level of individual countries and throughout shorter periods of time.

The focus of the study will be placed on the countries which experienced periods of life expectancy stagnation in the second half of 20th century. These include Central European countries of the former Eastern Bloc – Poland, the Czech Republic, Slovakia, Hungary and East Germany, which during the 1970s and 1980s experienced almost complete stagnation of life expectancy levels for males. For comparison, the analysis also included three Western European countries, namely Denmark, the Netherlands and Sweden, for which long periods of little to no growth were also observed. The article focuses only on male mortality as there were far more periods during which male life expectancy stagnated (and they usually lasted longer).

It must be mentioned that in their recent study Aburto and van Raalte (2018) covered a similar topic, as it focused on the relationship of life expectancy and lifespan inequality in twelve Central and Eastern European countries. Although the authors of this article differentiate between Central Europe, Baltic Countries and the Former Soviet Union (Aburto & van Raalte, 2018) and present some separate graphs and data for particular countries, in the end they formulate conclusions for the region as a whole, which is a great oversimplification. In particular, an assessment that life expectancy and lifespan inequality varied independently (Aburto & van Raalte, 2018) is not really true for Central European Countries which experienced stagnation of life expectancy but not a strong decline.

Definitely an argument can be made that they did not focus enough on the difference between Central Europe and the former Soviet Union. It must be underlined that the pattern of mortality change in Central European countries, which were part of the Eastern Bloc, was vastly different than that of the countries of the former Soviet Union and as a rule they should not be grouped together in such an analysis. In fact, the changes in mortality in Central European countries were closer to Western countries going through the period of stagnation (like Denmark or the Netherlands) than to that of the countries of the former Soviet Union, which experienced a long lasting periods of an outright life expectancy decline.

Data

The calculations for the article were based on lifetables from Human Mortality Database (HMD, 2019). The data for four currently existing Central European countries as well as for East Germany was used. For Hungary, the Czech Republic and Slovakia the data were available from 1950, for East Germany from 1956 and for Poland since 1958. Such a timeframe allowed for a comparison between the stagnation period (roughly 1970–1990) in those countries and periods before and after when life expectancy was mostly growing. The life tables for the Netherlands and Denmark were available for a much longer period but only those from 1950 were used.

The longest time series in Human Mortality Database is available for Sweden (lifetables since 1760). Therefore, the data for Sweden were used to present a quick overview of a historical (before 1950) relationship between life expectancy and lifespan inequality.

All the lifetables used for the calculations in this article were split by single year of age and closed at age category 110+.

Measures of lifespan inequality

Lifespan equality can be measured in several ways. The most traditional way is a comparison of life expectancy between various social categories, most typically based on the completed education level. These analyses are certainly of great value and often lead to very interesting results (OECD, 2017; Hummer & Hernandez, 2013). However, their results are often questioned due to misreporting of education in death certificates. In many countries there are attempts to solve this issue through the so-called *linkage approach*, which aims to combine the data on deaths with the last census (OECD, 2017).

For the purpose of this article the focus will be placed on methods that aim to capture the general variance of life duration in the entire populations of selected countries. In recent years, some indicators have been proposed for measuring lifespan equality, most of them based on lifetables, as they automatically take out the effect that the age structure of a population may have on calculations.

The most common indicators used for measuring lifespan inequality include: coefficient of variation, $e^{\dagger}$ (*e dagger*) – an average number of years lost due to death, the Gini coefficient (which has quite a similar interpretation to the one used in measuring economic inequalities) and Keyfitz's entropy, which is simply $e^{\dagger}$ divided by life expectancy at birth (Shkolnikov & Andreev, 2010).

It has been proved that the indicators are highly correlated with each other and can be used interchangeably (Van Raalte & Casswell, 2013). This holds particularly true for European countries after 1950 when no significant mortality crises were observed (wars, epidemics, hungers). Most inequality indicators are relative to life expectancy but notably $e^{\dagger}$ is not. Therefore, in periods of a severe rise in mortality, which were quite frequent in Europe till World War II, $e^{\dagger}$ tended to show a significant reduction in mortality in contrast to other three indicators mentioned above. As this analysis takes into account the period since 1950, the use of any of the inequality indicators would lead to roughly the same conclusions.

As a result, it was decided that the coefficient of variation will be used as a measure of lifespan inequality. It is calculated using the following formula, which is a standard statistical method, slightly modified to be applicable for lifetable data:

$$CV = \frac{\sqrt{\sum \left(x + a_x - e_0\right)^2 d_x}}{e_0} \tag{1}$$

Where:

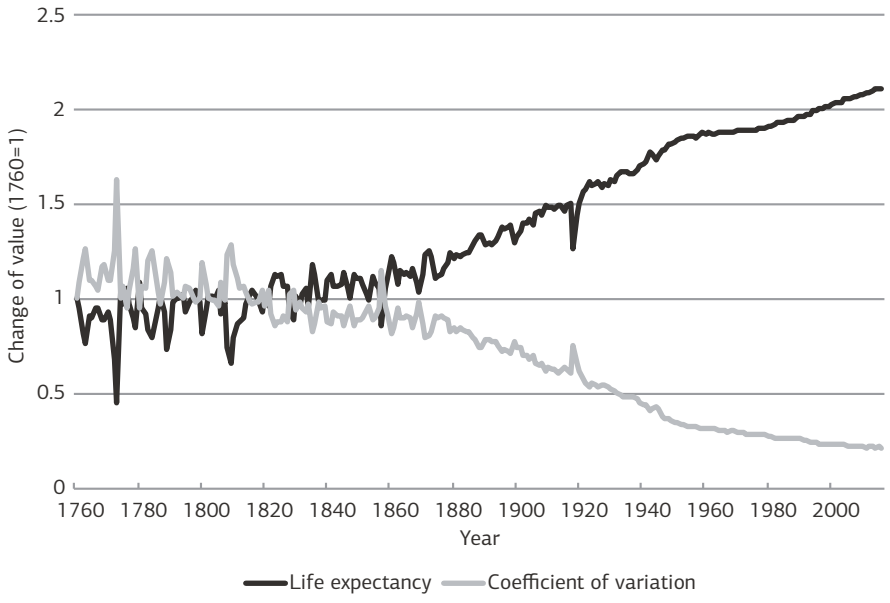
x – age;
a_x – number of years lived in an age interval (assumed to be 0.5 for most ages);
e_0 – life expectancy at birth;
d_x – percentage of deaths in a given age interval (typically in lifetables this is called the 'number of deaths' and multiplied by a certain constant, usually 100,000).

Life expectancy and lifespan equality

Overview

As it has already been mentioned, when any of the inequality indicators is calculated for various countries it can be quickly spotted that it takes lower values (meaning more equality) for countries with higher life expectancy (Nemeth, 2017; Vaupel et al., 2011).

Figure 1. Life expectancy and coefficient of variation for males in Sweden, 1760–2016



Source: own computations based on HMD data.

The strong relationship becomes even more apparent when time series (particularly very long ones) for individual countries are analysed. During the periods of rising life expectancy, the reduction in lifespan inequality is also observed. The speeds of

both processes also clearly 'mirror' each other – the faster rise in life expectancy, the faster reduction of inequality. In earlier time periods, the relationship was strongly visible during sudden 'mortality shocks' (wars, epidemics, hungers), during which a sudden decline of life expectancy was accompanied by a sharp rise in inequality (relative to the average lifespan; Figure 1).

As a side note, the above graph also shows that while life expectancy in Sweden is still growing at a fast and steady pace, the reduction in inequality has decelerated significantly in recent decades. This seems to be the pattern for all the countries with the highest life expectancy (Nemeth, 2017), so it appears that for them a simple linear relationship does not hold anymore.

Lifespan inequality during life expectancy stagnation periods

In the 20th century, the most clear relationship between the two was observed in the countries which experienced a constant growth in life expectancy, only interrupted by severe but short lasting mortality crises (in most cases, Spanish Flu of 1918 and both World Wars). However, in the second half of the century, several European countries experienced long periods of stagnation (or even a decline) in life expectancy, particularly for males. In Western countries they are usually attributed to the quickly rising smoking prevalence (Lindahl-Jacobsen, Oeppen, Rizzi, Möller, Zarulli, Christensen & Vaupel, 2016) but other factors could have also contributed. This stagnation was particularly severe in Eastern European countries of the former Soviet Bloc, however, in some Western countries it was also quite strong. In Eastern Europe stagnation is often linked to the lack of modern therapies and policies tackling deadly diseases which were far more common in the West in that period (Mesle, 2004).

a) Western European countries

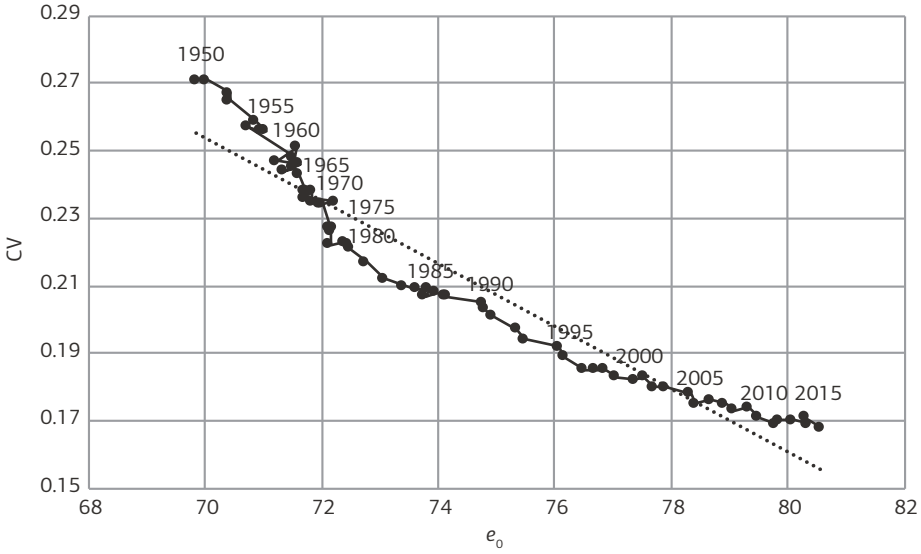
Another look at the aforementioned Swedish data, but for a much shorter period (since 1950) clearly shows that from 1960 till 1980 very little improvement in life expectancy of males was observed (Figure 2).

Nevertheless, during that period there was a significant reduction in inequality. Moreover, this decline was similar in scale to the one that took place in the following two decades (1980–2000) during which life expectancy rose significantly.

An analogous pattern can be observed for the male population in Denmark (where from 1955 till 1980 male life expectancy rose only by 0.8) and the Netherlands (no rise in male life expectancy between 1952 and 1972; Figures 3 and 4). In all three of those countries inequality significantly fell during the stagnation period and

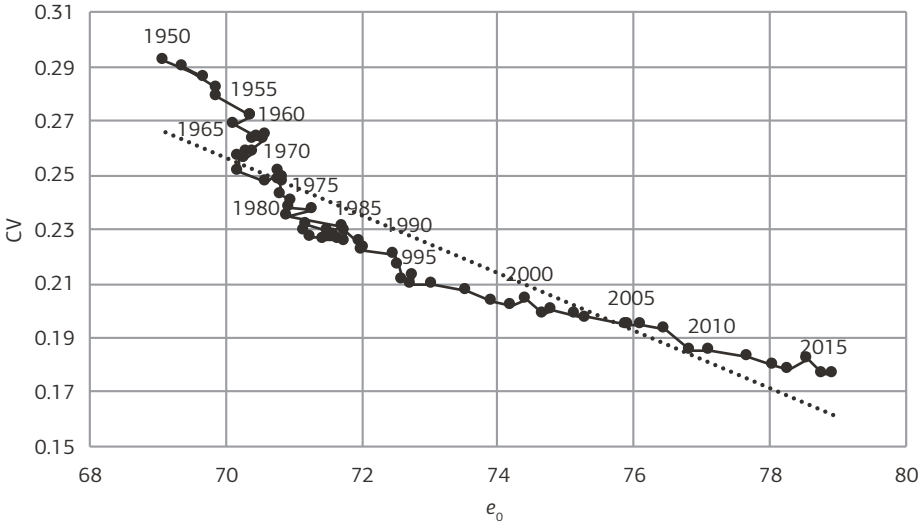
then the relationship became quite linear again, until the most recent period when inequality has been reduced at a slower pace.

Figure 2. Life expectancy and the coefficient of variation for males in Sweden, 1950–2016



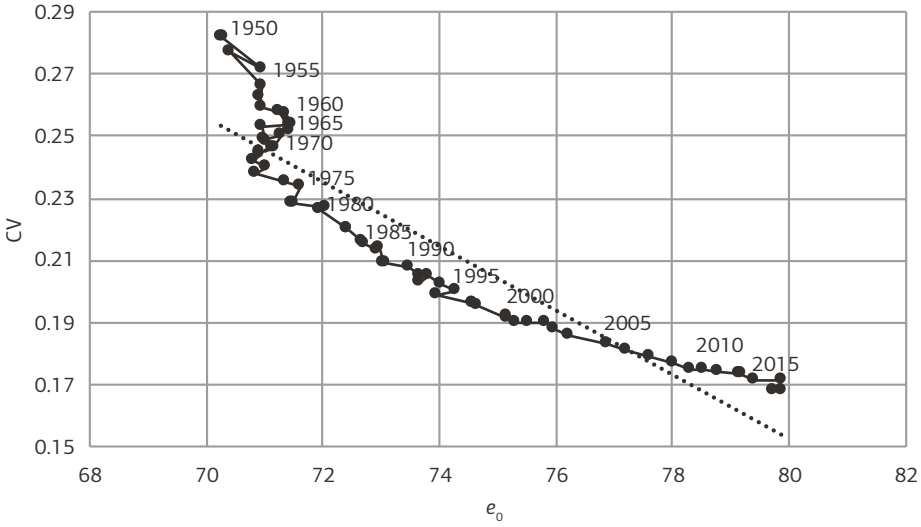
Source: own computations based on HMD data.

Figure 3. Life expectancy and the coefficient of variation for males in Denmark, 1950–2016



Source: own computations based on HMD data.

Figure 4. Life expectancy and the coefficient of variation for males in the Netherlands, 1950–2016



Source: own computations based on HMD data.

b) Central European countries

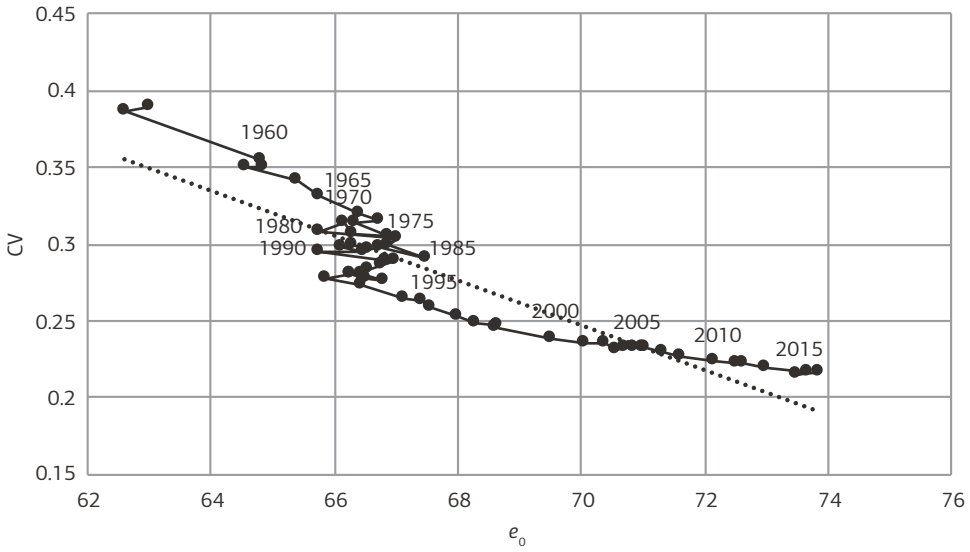
Among the countries of the former Eastern Bloc, at least two subgroups can be distinguished when it comes to developments in life expectancy throughout the post-war period. The first group includes former republics of the Soviet Union which from the 1970s till early 2000s experienced a clear decline in life expectancy. The other group is composed of current Visegrad Group countries as well as former East Germany, which experienced roughly 20 years of stagnating life expectancy throughout the 1970s and 1980s, after which they entered a period of rather stable and fast growth, which has lasted till the present day (McKee & Shkolnikov, 2001).

In this article we focus exclusively on the latter group, as the aim is to analyse patterns in countries which went through a life expectancy stagnation period and no outright decline. The countries of former Soviet Union also appear to contradict the theory about a perfect linear relationship but the pattern of change seems very different from the one in Central Europe. In their case, it seems to be true that the *life expectancy and life disparity varied independently of each other, largely because mortality trends ran in opposite directions over different ages,* as stated in Van Raalte and Abruto's (2018) article.

In Central European countries a very clear pattern appears of a significant reduction in inequality throughout the stagnation period, after the end of which the relationship becomes linear again. In fact, this pattern seems to be quite similar to what happened in Western European countries, mentioned in the previous paragraph, during the periods of stagnation.

When the data for Poland (available from 1958) are analysed, the period of male life expectancy stagnation can be delimited between 1970 (e_0 – 66.17) and 1990 (e_0 – 66.25). Across that interval some minor ups and downs in the value of the coefficient were observed but its value remained roughly at the same level. Similarly to the countries mentioned before, a significant reduction in lifespan inequality was observed in those years. After 1990 there was a growth in life expectancy and a reduction in inequality and the relationship became quite linear (Figure 5).

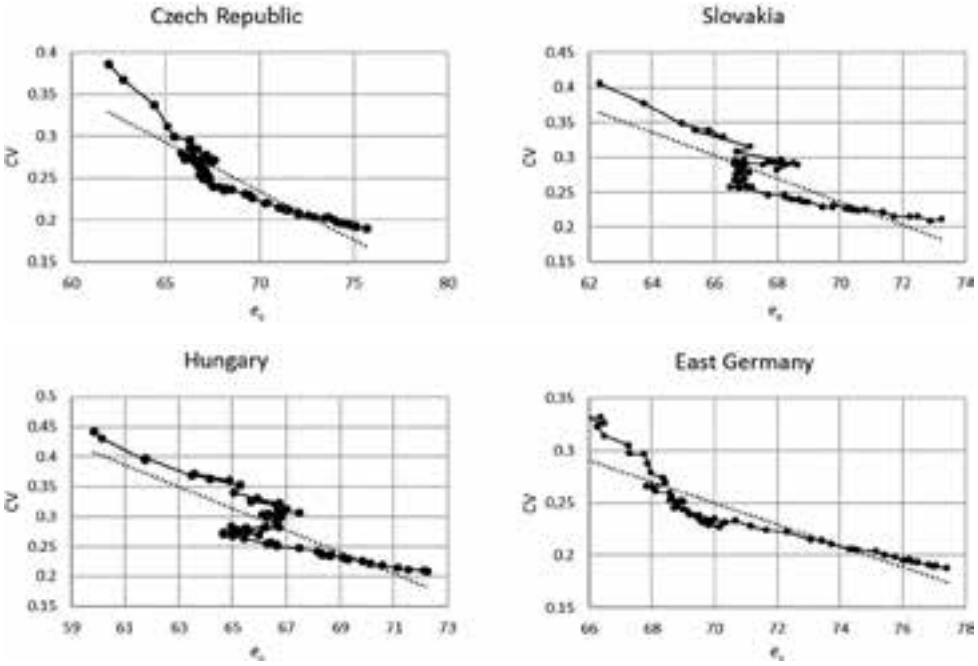
Figure 5. Life expectancy and the coefficient of variation for males in Poland, 1958–2016



Source: own computations based on HMD data.

The situation was very similar in the other countries of the region which also experienced a reduction in lifespan inequality during the period of stagnation. In the case of Hungary, a reduction in inequality happened even though there was a drop in life expectancy (Figure 6).

Figure 6. Life expectancy and the coefficient of variation for males in Central European countries, 1950–2016



Source: own computations based on HMD data.

Lifespan inequality measured with age bound indicators

The presented results raise the questions whether life expectancy stagnation periods are typically characterised by a reduction in lifespan inequality or simply the measurement is flawed. An argument can be definitely made for the latter.

The value of all the equality indicators depends strongly on mortality rates for small children, particularly infants. That mortality has been decreasing in every country included in Human Mortality Database for decades and obviously has been a factor leading to more equality of lifespans. However, it can be shown that in many cases, while overall equality was growing (due to early life mortality reduction), the equality among those who survived till later age was declining.

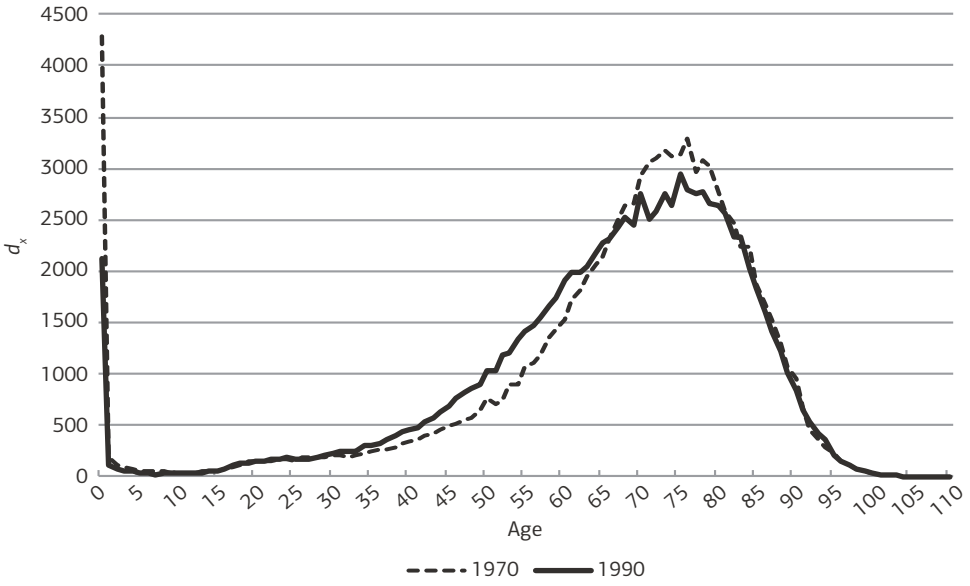
The solution to this issue is to calculate inequality indicators with a lower age limit set to exclude infant and small child mortality. Certainly, the value of the lower limit can be discussed. If the objective is only to eliminate infant and small child mortality, it can be set at the age of 5. If the intent is to focus solely on mortality

dominated by disease and not accident – related death, it can be put as high as 30, when mortality rates typically start to follow the Gompertz curve (Missov, Lenart, Nemeth, Canudas-Romo & Vaupel, 2015). It should be noticed that those indicators (in the case of countries which this paper focuses on), as long as they exclude deaths at the youngest age, are strongly correlated and lead to the same conclusions, which are often vastly different from those drawn from the indicators without age restriction.

a) Central European countries

If the structure of lifetable deaths (d_x) is compared for Polish males in the year 1970 (beginning of the stagnation period) and in 1990 (its ending), it is clear that the only reason for the observed reduction in inequality is a sharp reduction in infant deaths (Figure 7). At the same time there was a clear rise in mortality of males aged 30 to 60, which was a typical phenomenon for Eastern European countries in that period (Mesle, 2004; McKee & Shkolnikov, 2001). It obviously led to a greater disparity in the age of death among adult populations.

Figure 7. Lifetable deaths (d_x) for Poland, 1970 and 1990



Source: HMD.

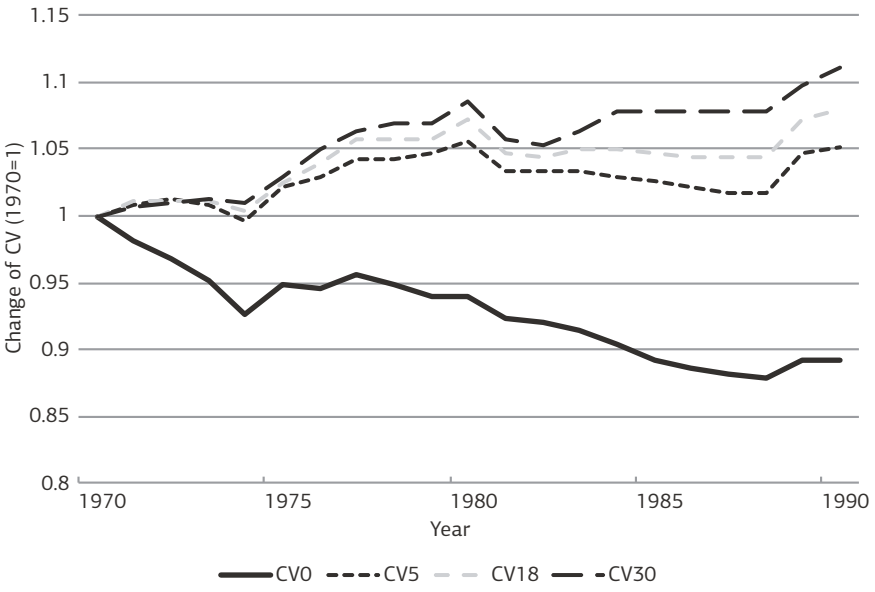
When the data for Poland is analysed, it can be observed that the coefficient of variation (of male lifespan) was decreasing throughout the stagnation period in the

1970s and 1980s. On the other hand, all the age-restricted indicators show that there was a growth in inequality during this time, although it is most pronounced when only mortality over 30 is taken into account (Figure 8).

It is, therefore, clear that throughout the stagnation period two separate processes occured. On the one hand, the reduction in infant and small child mortality continued bringing the inequality down. On the other hand, there was a sharp rise in the excess mortality of males aged 30 to 60, increasing the disparity. Apparently the first process had a bigger impact on the indicator as it went down. However, in the light of what was presented it cannot be said that during the 1970s and 1980s lifespan inequality was really reduced.

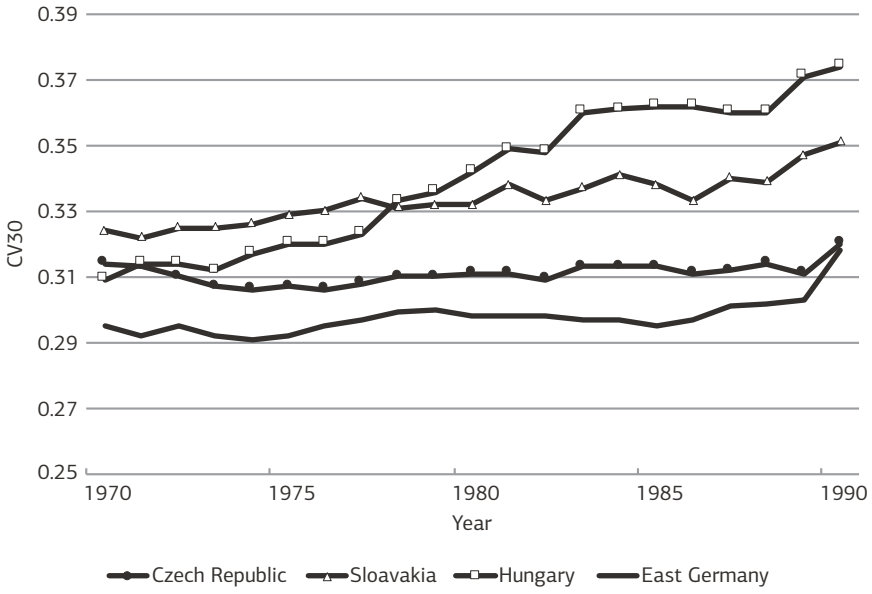
A similar situation occurred in other Central European countries, although the male mortality crisis was less severe in the Czech Republic and East Germany, where lifespan inequality calculated for males above 30 years of age remained roughly constant throughout the period. On the other hand, a particularly strong rise in inequality was observed in Hungary (Figure 9). An important conclusion is that in none of those countries the reduction in lifespan inequality among those who reached adulthood was observed.

Figure 8. Change in the coefficient of variation of male lifespan in Poland counted from the age 0, 5, 18 and 30 from 1970 till 1990 (1970=1)



Source: own computations based on HMD data.

Figure 9. Coefficient of variation counted from the age of 30 for Central European countries, 1970–1990



Source: own computations based on HMD data.

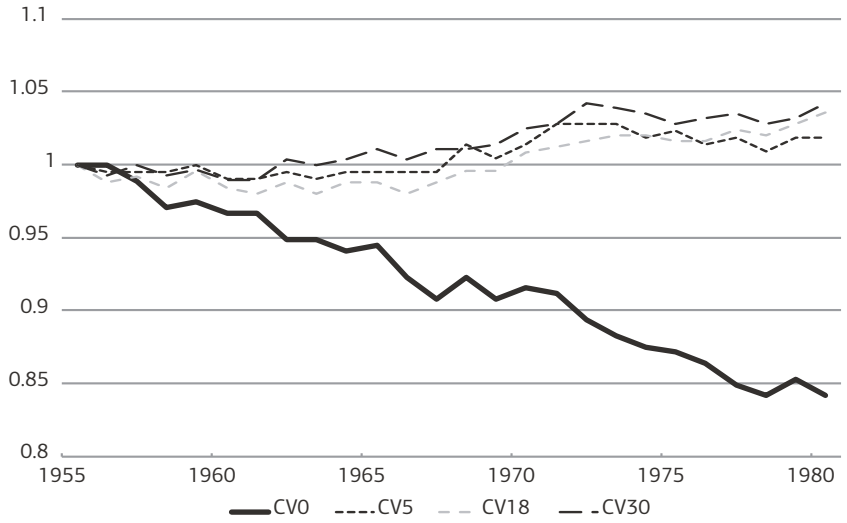
b) Western European countries

Very similar results are also observed for countries outside of the former Eastern Bloc which experienced life expectancy stagnation. In Denmark from 1955 till 1980 overall lifespan inequality expressed by the coefficient of variation was significantly reduced. However, as in the case of Central European countries, when the coefficients of variation with a lower age limit are taken into account, a small rise in inequality is observed (Figure 10).

Although the stagnation of male life expectancy happened in Denmark earlier and at a higher level than in Poland, the changes in lifespan inequality were very similar. There was a slight rise in inequality for those who survived infancy combined with an ongoing reduction in infant and small child mortality. The latter had more impact on the indicator calculated without the lower age limit.

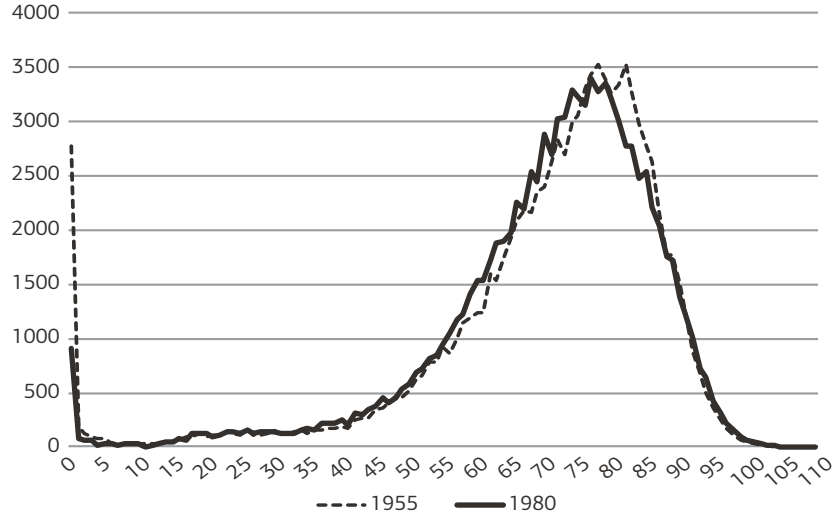
When lifetable deaths at the beginning (1955) and end of the stagnation period (1980) are compared, the change is similar to the one that was observed for Poland. There was a growing (although to a much lesser extent and at later ages) mortality for males in the middle age and a significant drop in infant mortality (Figure 11).

Figure 10. Change in the coefficient of variation of male lifespan in Denmark counted from age 0 and 30 from 1955 till 1980 (1955=1)



Source: own computations based on HMD data.

Figure 11. Lifetable deaths (d_x) for Denmark, 1955 and 1990

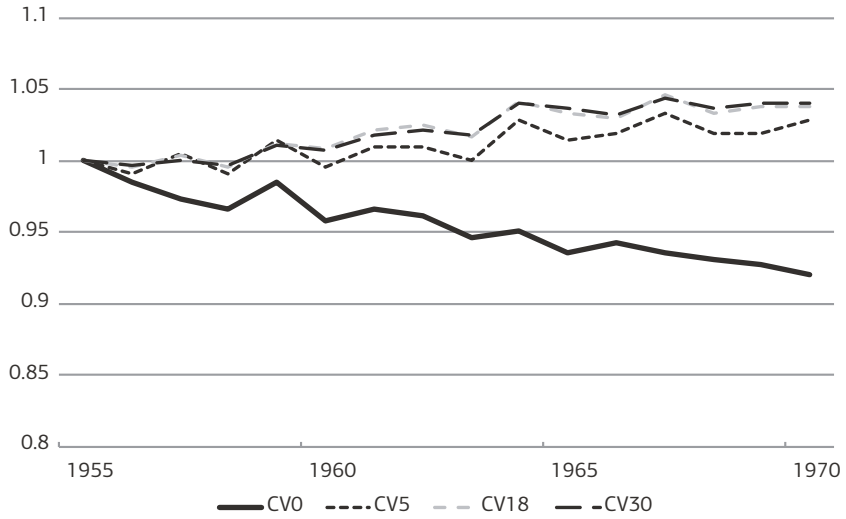


Source: HMD.

Very similar results were also observed for males in the Netherlands (Figure 12) and Sweden (Figure 13), where stagnation periods were shorter and less profound and lasted roughly from 1950 till 1975 and 1960 till 1980, respectively. Overall lifespan

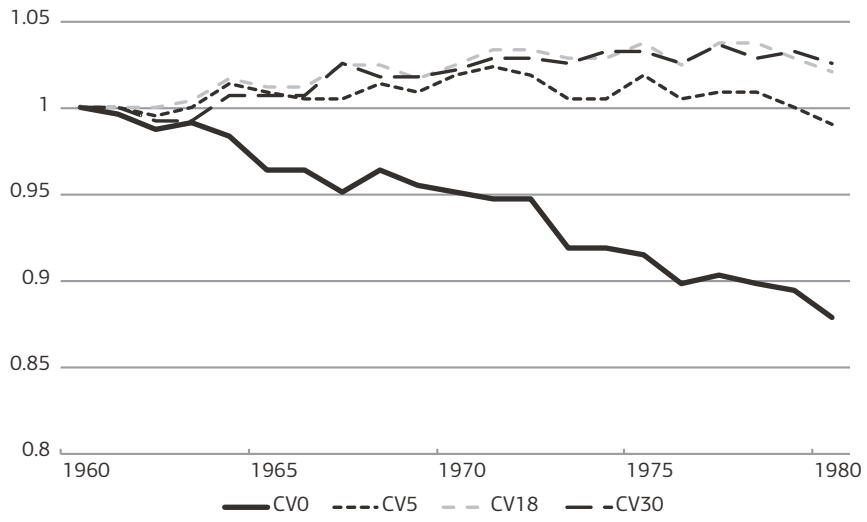
inequality declined, while the one counted only for those above age 5 and higher slightly rose. During this period a sharp reduction in infant mortality was observed in both countries.

Figure 12. Change in the coefficient of variation of male lifespan in the Netherlands counted from age 0 and 30 from 1955 till 1970 (1955=1)



Source: own computations based on HMD data.

Figure 13. Change in the coefficient of variation of male lifespan in Sweden counted from age 0, 5,18 and 30 from 1960 till 1980 (1960=1)



Source: own computations based on HMD data.

Conclusion

It can be stated that the conclusion about a perfect linear relationship between life expectancy and lifespan inequality, which was most strongly formulated in the paper *The Emergence of Longevous Populations* (Colchero et al., 2016) is an oversimplification. This relationship was very clear and strong in historical times (till the last decades of the 19th century) when there were no major improvements in life expectancy and only major mortality crises brought it down, which also resulted in sharp decreases in (relative) inequality. It also appears that the relationship between the two indicators was strongly linear in the modern period (since the late 19th century) in those countries which experienced a constant growth in life expectancy which was only interrupted by short-term mortality crises (like wars and epidemics).

Nevertheless, as it was demonstrated in this article, the simple linear relationship did not hold up for countries which experienced prolonged periods of life expectancy stagnation during the second half of the 20th century. During these periods, lifespan equality did not remain at a constant level. On the contrary, in all those countries inequality was reduced during the stagnation period.

A closer inspection of data showed that during the stagnation period two opposing phenomena occured. There was no improvement or even a worsening mortality of middle-aged males was visible, while on the other end of the spectrum there was a constant, sharp reduction in infant mortality rates. The latter was so strong in virtually every country included in Human Mortality Database that it led to the improvement in the overall equality even through the lifespan of those who survived past infancy was getting more disparate.

Interestingly, quite a similar pattern of mortality changes was observed in countries experiencing the life expectancy stagnation no matter if they were located in the former Eastern Bloc or Western Europe.

The study also confirmed the importance of using age – bound indicators of inequality, which often provide a more precise picture of mortality changes.

Probably worthy continuation of these analyses would be an attempt to measure the impact of mortality in various age groups on overall lifespan inequality. It appears that a reduction of deaths in accidents typical to teenagers and twenty-years-olds may also have some impact on overall inequality.

Another question is the impact of the reduction in the number of particular causes of death. Decomposition techniques can be used here as they have already been applied in various studies (Aburto & Beltran-Sanchez, 2019; Aburto, Wensink,

van Raalte & Lindahl-Jacobsen, 2018; Aburto & van Raalte, 2018) but not within the specific context of countries experiencing life expectancy stagnation.

References

Aburto, J.M., & Beltrán-Sánchez, H. (2019). Upsurge of homicides and its impact on life expectancy and life Span inequality in Mexico, 2005–2015. *American Journal of Public Health*, 109(3), 483–489.

Aburto, J.M., Wensink, M., van Raalte, A., & Lindahl-Jacobsen, R. (2018). Potential gains in life expectancy by reducing inequality of lifespans in Denmark: An international comparison and cause-of-death analysis. *BMC Public Health*, 18(1), 831.

Aburto, J.M., & van Raalte, A. (2018). Lifespan dispersion in times of life expectancy fluctuation: The case of Central and Eastern Europe. *Demography*, 55, 2071–2096.

Colchero, F., Rau, R., Jones, O.R., Barthold, J.A., Conde, D.A., Lenart, A., Nemeth, L., Scheuerlein, A., Schoeley, J., Torres, C., Zarulli, V., Altmann, J., Brockman, D.K., Bronikowski, A.M., Fedigan, L.M., Pusey, A.E., Stoinski, T.S., Strier, K.B., Baudisch, A., Alberts, S.C., & Vaupel, J.W. (2016). The emergence of longevous populations. *Proceedings of the National Academy of Sciences of the United States of America*, 113(48).

HMD (2019). *Human Mortality Database*. Berkeley, USA: University of California, Germany: Max Planck Institute for Demographic Research.

Hummer, R.A., & Hernandez, E.M. (2013). The effect of educational attainment on adult mortality in the United States. *Population Bulletin*, 68(1), 1–16.

Lindahl-Jacobsen, R., Oeppen, J.E., Rizzi, S., Möller, S., Zarulli, V., Christensen, K., & Vaupel, J.W. (2016). Why did Danish women life expectancy stagnate? The influence of interwar generations' smoking behavior. *European Journey of Epidemiology*, 31(12).

McKee, M., & Shkolnikov, V.M. (2001). Understanding the toll of premature death among men in eastern Europe. *BMJ*, 323(7320), 1051–5.

Mesle, F. (2004). Mortality in Central and Eastern Europe: Long-term trends and recent upturns. *Demographic Research*, S2.3, 45–70.

Missov, T.I., Lenart, A., Nemeth, L., Canudas-Romo, V., & Vaupel, J.W. (2015). The Gompertz force of mortality in terms of the modal age at death. *Demographic Research*, 32(36), 1031–1048.

Németh, L. (2017). Life expectancy versus lifespan inequality: A smudge or a clear relationship? *PloS One*, 12(9).

OECD (2017). *Inequalities in longevity by education in OECD countries*, Paris: OECD Publishing.

Shkolnikov, M., & Andreev, E. (2010). *Spreadsheet for calculation of life-table dispersion measures*, MPIDR Technical Report.

Van Raalte, A.A., & Caswell, H. (2013). Perturbation analysis of indices of lifespan variability. *Demography*, 50, 1615.

Vaupel, J.W., Zhang, Z., & van Raalte, A. (2011). A life expectancy and disparity: An international comparison of life table data. *BMJ Open*, 1.

Wróblewska, W. (2017). Pomiar dyspersji wieku w momencie zgonu. Przyczynek do analizy kompresji umieralności w Polsce. *Studia Demograficzne*, 1(171).