Life expectancy and disparity

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2011-000128
Article Type:	Research
Date Submitted by the Author:	23-Mar-2011
Complete List of Authors:	Vaupel, James; Max Planck Institute for Demographic Research, Survival and Longevity Zhang, Zhen; Max Planck Institute for Demographic Research, Survival and Longevity van Raalte, Alyson; Max Planck Institute for Demographic Research, Survival and Longevity; Erasmus University Medical Centre, Public Health
Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, BASIC SCIENCES

Life expectancy and disparity

James W Vaupel, Zhen Zhang, Alyson A van Raalte

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
James W Vaupel, Founding Director

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
Zhen Zhang, Research Scientist

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany and Department of Public Health, Erasmus MC, University Medical Centre Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands
Alyson A van Raalte, PhD student

Correspondence to: James W Vaupel jwv@demogr.mpg.de

Keywords: Premature death, lifespan variation, health progress, international comparisons of life expectancy, historical trends in mortality

Word Count - 2280 words

ABSTRACT

- **objectives –** To determine the contribution of progress in averting premature deaths to the increase in life expectancy and the decline in lifespan variation.
- **design** - International comparison of national lifetable data from the Human Mortality Database
- **setting** – 40 developed countries and regions, 1840 to 2009
- **population** – Men and women of all ages
- **main outcome measure –** We use two summary measures of mortality: life expectancy and life disparity. Life disparity is a measure of how much lifespans differ among individuals. We define a death as premature if postponing it to a later age would decrease life disparity.
- **results** - In 89 of the 170 years from 1840 to 2009, the country with the highest male life expectancy had the lowest male life disparity. This was true in 86 years for female life expectancy and disparity. In all years, the top several life expectancy leaders were also the top life disparity leaders. Although only 38% of deaths were premature, fully 84% of the increase in life expectancy resulted from averting premature deaths. The reduction in life disparity resulted from reductions in early-life disparity, i.e., disparity caused by premature deaths; late-life disparity levels remained roughly constant.
- **conclusions –** The countries that have been the most successful in averting premature deaths have consistently been the life expectancy leaders. Greater longevity and greater equality of individuals' lifespans are not incompatible goals. Countries can achieve both by reducing premature deaths.

Article focus

- We examined the relationship between high life expectancy and low life disparity.
- We determined the relative importance of premature vs. late deaths in increasing life expectancy and reducing life disparity.
- We examined whether policies to increase life expectancy were compatible with those to reduce lifespan variation.

Key messages

- Most of the gains in life expectancy have come from reducing disparities in how long people live, by averting premature mortality.
- Progress in reducing death rates for people who live longer than average has had little effect on life disparity levels, and its contribution to life expectancy gains has been modest.
- The countries that have been most successful at reducing premature mortality enjoy the highest life expectancies and the greatest equality in individuals' lifespans.

Strengths and limitations

- We are the first to examine this issue using a large, comparable database of 40 developed countries from 1840 to 2009 containing 6940 lifetables.
- Our analysis was limited to countries with high enough quality data to be included in the database. Although this database contains high mortality lifetables from historic populations, it is unknown whether the patterns we observed would also be seen in contemporary emerging and developing countries.

Introduction

The rise in life expectancy, from under 40 years in all areas of the world two centuries ago to over 80 years today in many developed countries, has fundamentally improved the human condition.[1 2] Equally significant and closely linked to the increase in life expectancy has been the reduction of differences among individuals in the age at death.[3-6] Even in the most egalitarian societies before the mid-19th century the fate of most newborns was to die young but a fortunate minority survived to old age. Death rates today in health leaders such as Japan, Spain and Sweden imply that three-quarters of babies will survive to celebrate their 75th birthdays.[2]

The negative correlation between high life expectancy and low lifespan variation has been investigated for several countries, including the United States,[4 6 7] England and Wales[7], Sweden[6] and Japan[6]. The correlation is strong but there are discrepancies. Some countries, notably the United States, have substantially greater lifespan dispersion than might be predicted from their high levels of life expectancy.[3-5]

Progress in reducing premature deaths reduces variation in lifespans, whereas progress in reducing deaths at older ages increases variation in lifespans. A recently-developed demographic formula permits ready determination of the ages at which deaths are premature.[8] We use this new formula and apply it to a large dataset on developed countries to gain a deeper understanding of the relationship between high life expectancy and low lifespan variation. We find that the countries that have been the most successful in reducing premature deaths, and consequently in reducing lifespan variation, have consistently been the life expectancy leaders.

Methods

Our calculations are based on all period lifetables of the Human Mortality Database (*HMD*), from 1840 to the most recent year available in the data set.[2] This is a freely available database with reliable, comparable data covering 40 countries and areas. (Table 1 in the Supplementary Appendix lists the countries or regions and years used in the analysis.)

We measure dispersion in age-at-death by the life disparity measure, $e^{\dagger}$ (technical description in the Supplementary Appendix).[8 9] Life disparity is defined as the average remaining life expectancy at the ages when death strikes; it is a measure of life years lost due to death. The more egalitarian the lifespan distribution is, the lower the life disparity. In the Swedish female life table for 2008 life expectancy reached 83 years; for those women who survived to age 83, remaining life expectancy was 7.5 additional years. Hence a death shortly after birth would contribute 83 years whereas a death at age 83 would contribute 7.5 years. The average of such values over the Swedish female population, weighted by the number of deaths at each age, gives a life disparity of 9. In 1840 life expectancy for Swedish women was only 46 and life disparity was 24. Over time, as deaths became concentrated at later ages, the average gap was reduced between the age at which a person died and the remaining lifespans of people who survived beyond this age.

Saving lives (i.e., averting deaths) at any age increases life expectancy. Lifespan disparity, on the other hand, narrows or widens depending on the balance between saving lives at 'early' ages, which compresses the distribution of lifespans, and saving lives at 'late' ages, which expands this distribution. Separating the two is a unique threshold age, $a^{\dagger}$. Henceforth, we refer to deaths occurring before the threshold age as 'premature deaths', while those occurring after this age are 'late deaths'. This definition implies that deaths at surprisingly old ages can be premature deaths. In 2008 deaths up to age 82 were premature deaths for Swedish females (Table 1).

The life disparity measure has the property that it can be additively decomposed at any age such that the components before and after this age sum to the total life disparity.[8] When it is decomposed at the threshold age, the components are defined as 'early-life disparity' and 'late-life disparity'.

While it is known that high life expectancy is associated with low lifespan variation, we wanted to establish whether life expectancy leaders had the most egalitarian lifespan distributions. For each sex, year, and for up to 40 countries depending on the year, we determined the male and female record high life expectancy and record low life disparity. We calculated how many fewer years of life expectancy and additional years of life disparity each country experienced compared with the record-holding country in that year.

We next investigated the relative importance of premature vs. late deaths in determining the relationship between high life expectancy and low life disparity. To do so, we calculated first the number of premature and late deaths as a proportion of all deaths, measured by 10-year averages across all countries and years. We then compared this to the respective contributions of averting premature and late deaths to increases in life expectancy, using a 20-year moving average to smooth mortality trends over exceptional years of war, pandemics or famine.

Finally, we ranked countries according to their life expectancy and life disparity for the latest year for which we had data.

Results

Populations with high life expectancy enjoy low life disparity. In 89 out of 170 years, holders of record life expectancy for males also enjoyed the lowest life disparity (fig 1). For females this happened 86 times (appendix fig 1 on bmj.com). These countries increased life expectancy not because of a general decrease in life disparity at all ages, but because of a decrease in early-life disparity. Figure 2 shows that the reduction in life disparity—from around 25 years in 1840 to between 9 and 12 years at present—is overwhelmingly due to reductions in early-life disparity. Although mortality at old ages has come down considerably (which might cause one to expect increases in late-life disparity), the shifting of the threshold age to higher ages has caused late-life disparity to stay roughly constant at around or just under five years.

For females since 1840, premature deaths have accounted for only 38 percent of all deaths, but fully 84 percent of the increase in life expectancy resulted from decreases in premature deaths (appendix fig 2 on bmj.com). During this time the threshold age rose considerably, rising from 47 for Swedish women in 1840 to 85 for Japanese women in 2009. Historically (and today in less developed countries) infants, children and younger adults suffered most premature deaths. In today's more developed countries, premature deaths have shifted primarily to older adults in their sixties and seventies. The rise in the threshold age is highly correlated with the rise in life expectancy.

Table 1 displays the latest period life expectancy, threshold age and life disparity calculated for each country. In Russia life expectancy is extraordinarily low and life disparity is very high. In the United States, life expectancy is much longer than in Russia but short compared with countries of similar income per capita. Life disparity in the U.S. is worse than in many Eastern European countries for both males and females. In contrast Japanese females are remarkably successful. They hold the record for life expectancy, 86.4 years in the lifetable for 2009. Half of deaths occurred after age 88 and the most common age of death was 93: deaths up to age 85 were premature in the sense that averting such deaths would decrease life disparity.

Discussion

These findings make clear that the correlation between high life expectancy and low lifespan variation is due to progress in reducing early-life disparity. The countries that have the highest life expectancy today are those who have been most successful at postponing the premature deaths that contribute to early-life disparity.

In addition to life disparity, several other measures of lifespan dispersion have been proposed.[3 4 6 10] We analyzed the extent to which our findings depend on our use of life disparity as our measure of lifespan variation. We calculated Pearson correlation coefficients between pairs of the more commonly used measures of lifespan variation, based on all male and female period life tables available from the Human Mortality Database (appendix table 1 on bmj.com). As shown in Table 2 of the Supplementary Material, these measures are highly correlated with each other. In particular, the correlation of life disparity with the other measures never falls below 0.966 for females and 0.940 for males. Hence life disparity can be viewed as a surrogate for the other measures. Although the various measures are highly correlated, they differ somewhat in their sensitivity to deaths at different ages in the lifespan distribution.[4 11] The use of an alternate measure of lifespan variation would result in some changes in the ranking of countries with similar life disparity levels, but the high correlation between measures implies that such changes would be minor.

Some researchers have examined whether lifespan variation above the modal age at death has changed with increased survivorship. These studies also tend to find a gradual decline in later life mortality variation.[10 12-14] More generally, whether expansion or compression of the lifespan distribution is observed over time can depend on the age range examined.[15-17] While being a life expectancy leader is associated with low life disparity when the entire lifetime is examined, this relationship might not hold for selected age ranges.

Reducing early life disparities helps people plan their less-uncertain lifetimes. A higher likelihood of surviving to old age makes savings more worthwhile, raises the value of individual and public investments in education and training, and increases the prevalence of long-term relationships. Hence, healthy longevity is a prime driver of a country's wealth and well-being.[18] While some degree of income inequality might create incentives to work harder, premature deaths bring little benefit and impose major costs.[19]

Moreover, equity in the capability to maintain good health is central to any larger concept of societal justice.[20] The tenet that everyone should be entitled to a long, healthy lifespan has gained support as mortality at younger ages has declined. Currently, rates of change for adult mortality vary more across countries than those for infants and children.[21] In Williams' concept of *fair innings*,[22] individuals dying early are "cheated" while those living beyond a "normal" lifespan are "living on borrowed time". Groups and areas with lower socioeconomic status account for a disproportionate share of lifespan variation:[3 4 7] this compounds the inequity of premature death.

If death rates continue to decline, most babies born in advanced nations today may live to enjoy their 100th birthday.[23] As we celebrate this progress in extending lives it is reasonable to question whether we ought to continue aiming for ever longer lives *on average* or to ensure that more individuals avoid premature death. Policymakers face a choice of where to target health care spending. Reducing life disparity would lead to health policies that prioritize early mortality and to social protection schemes designed to shield vulnerable individuals and groups. We are not the first to make this argument. Heath poignantly reasoned that if health care services were serious about reducing health inequality they should direct their attentions to reducing premature mortality—even if this meant reducing expensive medical treatments for the elderly.[24] The accompanying editorial in *BMJ* proclaimed that "premature deaths should be the priority for prevention".[25]

Russia, the U.S. and other laggards can learn much from research on the reasons why various countries (including Japan, France, Italy, Spain, Sweden and Switzerland) have been more successful in reducing premature deaths. The reasons involve health care, social policies, personal behavior (especially cigarette smoking and alcohol abuse), and the safety and salubriousness of the environment.[26-33] Genetic variation plays a modest role in determining variation in how long we live[34 35] and cannot account for the major declines in life disparity and increases in life expectancy or the large differences in life expectancy and disparity among countries.

Smits and Monden[5] recently showed that countries achieving some level of life expectancy earlier than others did so with higher levels of lifespan variation. This led them to conclude that "reducing inequality and gaining increases in life expectancy might be alternative goals that require different policy measures to be achieved". Our results differ because we examine differences between countries in lifespan variation for each year whereas they examine differences over time in lifespan variation within each country. These different set-ups can lead to different conclusions. In a study comparing the United States to England and Wales, reductions in circulatory diseases were causing most of the changes in lifespan variation over time (in each country) whereas differences in external mortality were contributing most of the differences in life disparity between countries at any given time.[7] As can be seen in Figure 3 the relationship between being pioneers in life expectancy and having high life disparity is weak, especially after 1960. We take issue with Smits and Monden's conclusion which our cross-sectional results do not support. Over the past 170 years, the country with the lowest life disparity most often had the highest life expectancy. Even today, the most egalitarian countries are all among the longest living.

The increase in life expectancy is given by the product of two factors—life disparity and the rate of progress in reducing age-specific death rates.[9] The lower life disparity is, the greater is the rate of progress needed to achieve an additional year of life expectancy. Consequently it might be thought that countries with long life expectancy would tend to have high life disparity. The opposite is true (Figure 1). The reason is that the countries with long life expectancy have gained this victory by focusing on reductions in premature deaths—and reductions in premature deaths reduce life disparity. It is not a question of either long life or low disparity: countries can achieve both by averting premature deaths.

We thank A. Baudisch, J. R. Goldstein , E. Loichinger, J. Oeppen, V. M. Shkolnikov, K. W. Wachter and H. Wilkoszewski for helpful comments. We are grateful to M. Murphy and V. Canudas-Romo for reviewing the paper.

Contributors: JWV conceived the research idea and co-wrote the drafts, ZZ managed the data analysis and commented on the drafts, AvR contributed to data analysis and co-wrote the drafts.

Funding: We acknowledge support from the Max Planck Society and the U.S. National Institute on Aging (NIA P01-08761).

Competing interests: "All authors declare that the answer to the questions on your competing interest form are all No and therefore have nothing to declare"

Ethics approval was not required for this study.

References

1. Oeppen J, Vaupel JW. Broken Limits to Life Expectancy. *Science* 2002;296(5570):1029-1031.
2. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org (data downloaded on 18/02/2011)
3. Edwards RD, Tuljapurkar S. Inequality in life spans and a new perspective on mortality convergence across industrialized countries. *Popul Dev Rev* 2005;31:645-74.
4. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-58.
5. Smits J, Monden C. Length of life inequality around the globe. *Soc SciMed* 2009;68:1114-236.
Wilmoth JR, Horiuchi S. Rectangularization Revisited: Variability of Age at Death within Human Populations. *Demography* 1999;36:475-95.
7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* in press.
8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.
9. Vaupel JW, Canudas Romo V. Decomposing Change in Life Expectancy: A Bouquet of Formulas in Honor of Nathan Keyfitz's 90th Birthday. *Demography* 2003;40:201-16.
10. Cheung SL, Robine JM, Tu EJ, Caselli G. Three dimensions of the survival curve: horizontalization, verticalization, and longevity extension. *Demography* 2005;42:243-58.
11. Anand S, Diderichsen F, Evans T, Shkolnikov V, Wirth M. Measuring Disparities in Health: Methods and Indicators. In: T. Evans MW, F. Diderichsen, A. Bhuiya, M. Wirth editor. *Challenging inequities in health: from ethics to action*. New York: Oxford University Press, 2001.
12. Thatcher AR, Cheung SLK, Horiuchi S, Robine J-M. The compression of deaths above the mode. *Demogr Res* 2010;22:505-538.
13. Cheung SL, Robine JM. Increase in common longevity and the compression of mortality: the case of Japan. *Popul Stud (Camb)* 2007;61:85-97.
14. Kannisto V. Mode and Dispersion of the Length of Life. *Population* 2001;13:159-171.
15. Robine J-M. Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France. *Population* 2001;13:173-193.
16. Nusselder WJ, Mackenbach JP. Rectangularization of the survival curve in The Netherlands, 1950-1992. *Gerontologist* 1996;36(6):773-782.
17. Engelman M, Canudas-Romo V, Agree EM. The Implications of Increased Survivorship for Mortality Variation in Aging Populations. *Popul Dev Rev* 2010;36:511-539.
18. Bloom DE, Canning D. The Health and Wealth of Nations. *Science* 2000;287:1207-09.
19. Anand S. The concern for equity in health. *J Epidemiol Community Health* 2002;56:485-87.
20. Sen A. Why health equity? *Health Econ* 2002;11:659-66.
21. Rajaratnam JK, Marcus JR, Levin-Rector A, Chalupka AN, Wang H, Dwyer L, et al. Worldwide mortality in men and women aged 15-59 years from 1970 to 2010: a systematic analysis. *Lancet* 2010;375:1704-17.
22. Williams A. Intergenerational Equity: An Exploration of the Fair Innings Argument. *Health Econ* 1997;6:117-32.
23. Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. *Lancet* 2009;374:1196-1208.
24. Heath I. What do we want to die from? *BMJ* 2010;341:c3883.
25. Godlee F. Premature deaths should be the priority for prevention. *BMJ* 2010;341:c3946.
26. Doll R, Peto R, Boreham J, Sutherland I. Mortality in relation to smoking: 50 years' observations on male British doctors. *BMJ* 2004;328:1519.

27. Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL. Selected major risk factors and global and regional burden of disease. *Lancet* 2002;360:1347-1360.
28. Kauhanen J, Kaplan GA, Goldberg DE, Salonen JT. Beer binging and mortality: results from the kuopio ischaemic heart disease risk factor study, a prospective population based study *BMJ* 1997;315:846.
29. Lundberg O, Yngwe MÅ, Stjärne MK, Elstad JI, Ferrarini T, Kangas O, et al. The role of welfare state principles and generosity in social policy programmes for public health: an international comparative study. *Lancet* 2008;372:1633-1640.
30. Marmot M, Friel S, Bell R, Houweling TAJ, Taylor S. Closing the gap in a generation: health equity through action on the social determinants of health. *Lancet* 2008;372:1661-1669.
31. Peto R, Boreham J, Lopez AD, Thun M, Heath C. Mortality from tobacco in developed countries: indirect estimation from national vital statistics. *Lancet* 1992;339:1268-1278.
32. Rehm J, Mathers C, Popova S, Thavorncharoensap M, Teerawattananon Y, Patra J. Global burden of disease and injury and economic cost attributable to alcohol use and alcohol-use disorders. *Lancet* 2009;373:2223-2233.
33. Whitehead M, Dahlgren G. Concepts and principles for tackling social inequities in health: Levelling up Part 1. *WHO, Copenhagen* 2007:1-45.
34. McGue M, Vaupel JW, Holm NV, Harvald B. Longevity is moderately heritable in a sample of Danish twins born 1870- 1880. *J Gerontol* 1993;48:237-44.
35. Herskind A, McGue M, Holm N, Sørensen T, Harvald B, Vaupel J. The heritability of human longevity: A population-based study of 2872 Danish twin pairs born 1870–1900. *Hum Genet* 1996;97:319-23.

Tables and Figures

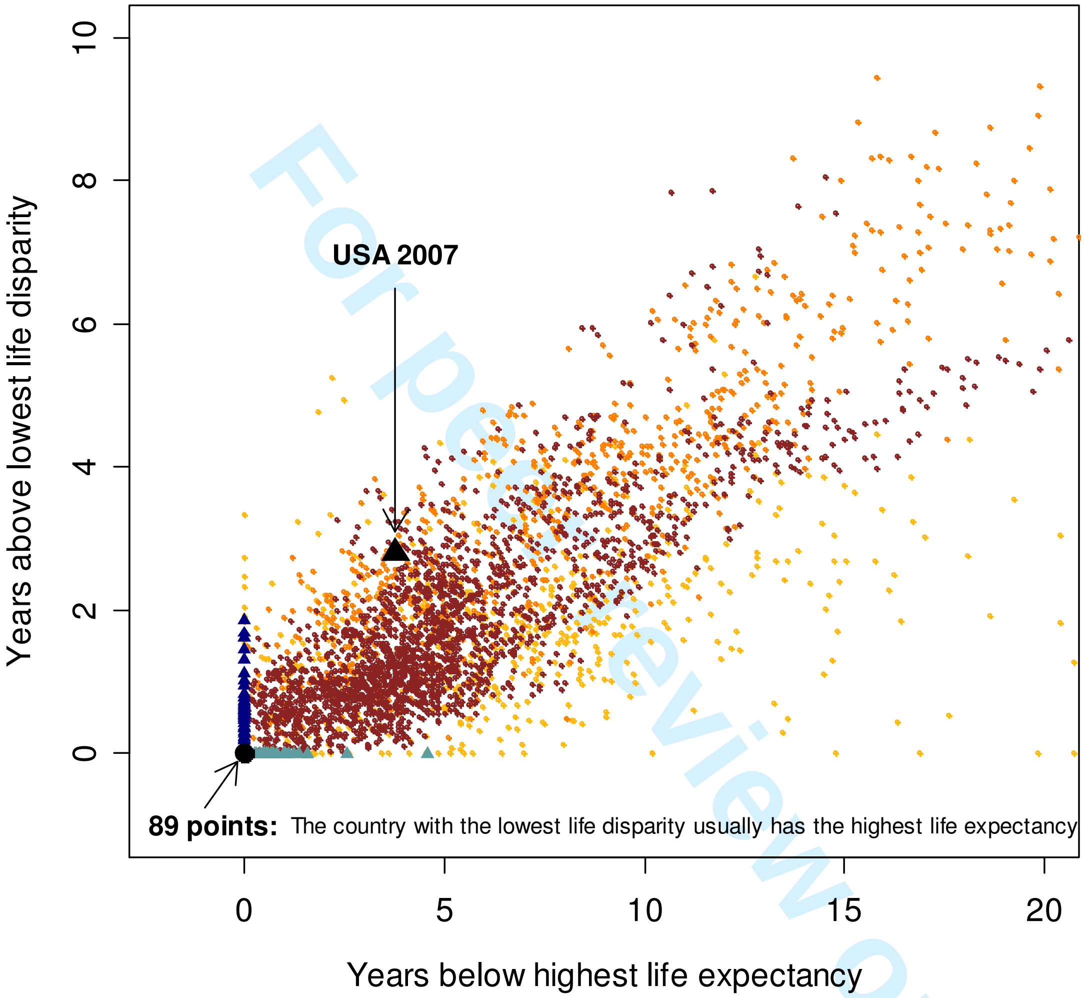

Fig 1: The association between life disparity in a specific year and life expectancy in that year for males in 40 countries and regions, 1840-2009 (Table 1 in the Supplementary Material). The correlation coefficient between them is 0.77 (95% confidence interval 0.76 to 0.78). The black triangle represents the United States in 2007: the U.S. had a male life expectancy 3.78 years lower than the international record in 2007 and a life disparity 2.8 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 89 holders of record life expectancy also enjoyed the lowest life disparity. The equivalent figure for females is presented as Fig 2 in the Supplementary Material.

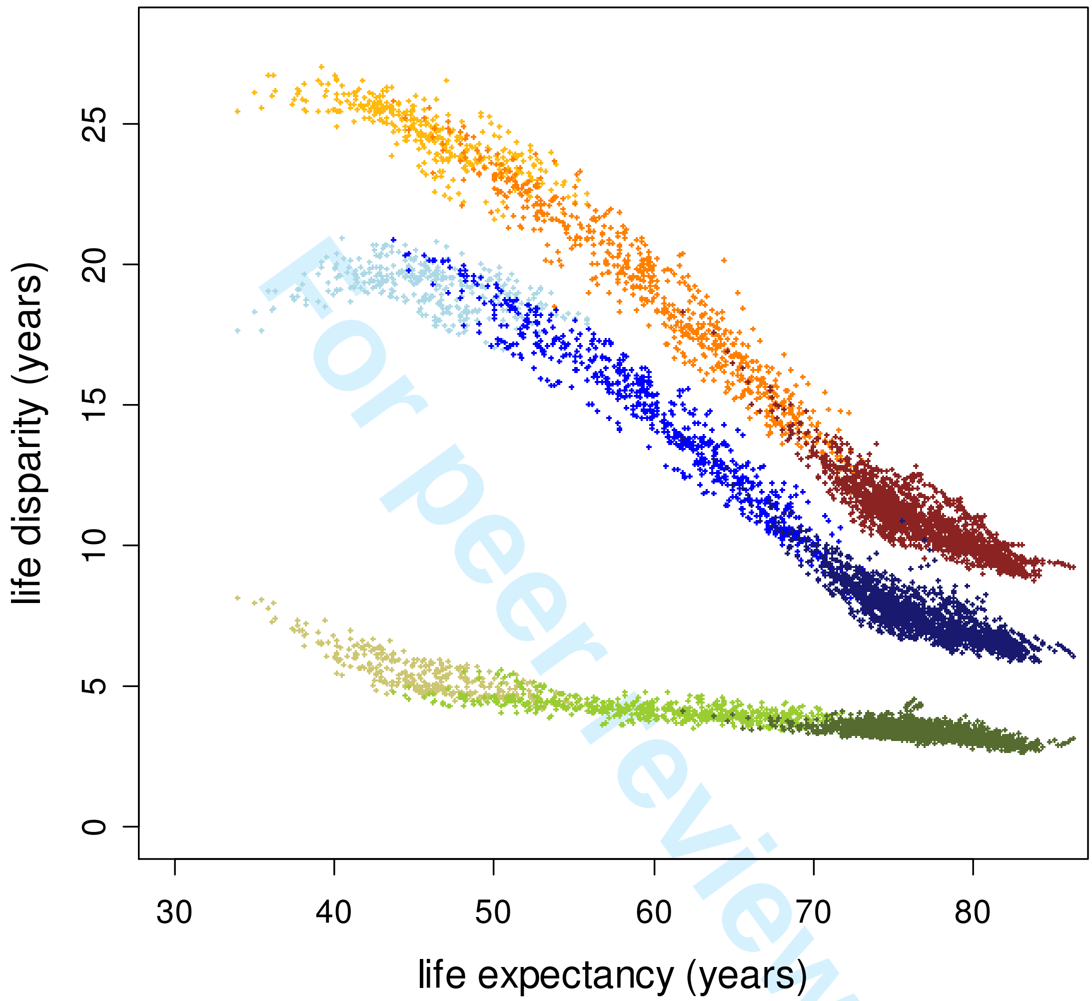

Fig 2: The relationship between total life disparity (red), early life disparity up to the threshold age (blue) and late life disparity after the threshold age (green). The three curves can be fit by linear regression. The adjusted R^2 is .97 with slope -0.438 (95% confidence interval -0.440 to -0.435) for the red curve, 0.96 with slope -0.376 (-0.379, -0.373) for the blue curve, and 0.77 with slope -0.061 (-0.062, -0.060) for the green curve. The darkest hues relate to data from 1950-2009, middle hues 1900-1949 and lightest hues 1840-1899. Total disparity is an additive function of early life disparity and late life disparity. Since 1840 the decrease in total life disparity has resulted from reductions in early life disparity. The correlation coefficient between early life disparity and total life disparity is 0.997 (0.997, 0.997). Late life disparity has remained remarkably constant at about 5 years across a wide range of life expectancies. Hence, according to this measure, there has been neither a marked compression nor expansion of mortality at advanced ages as life expectancy has increased. Data are for females from the 40 countries and regions of the Human Mortality Database (Table 1 in the Supplementary Material).

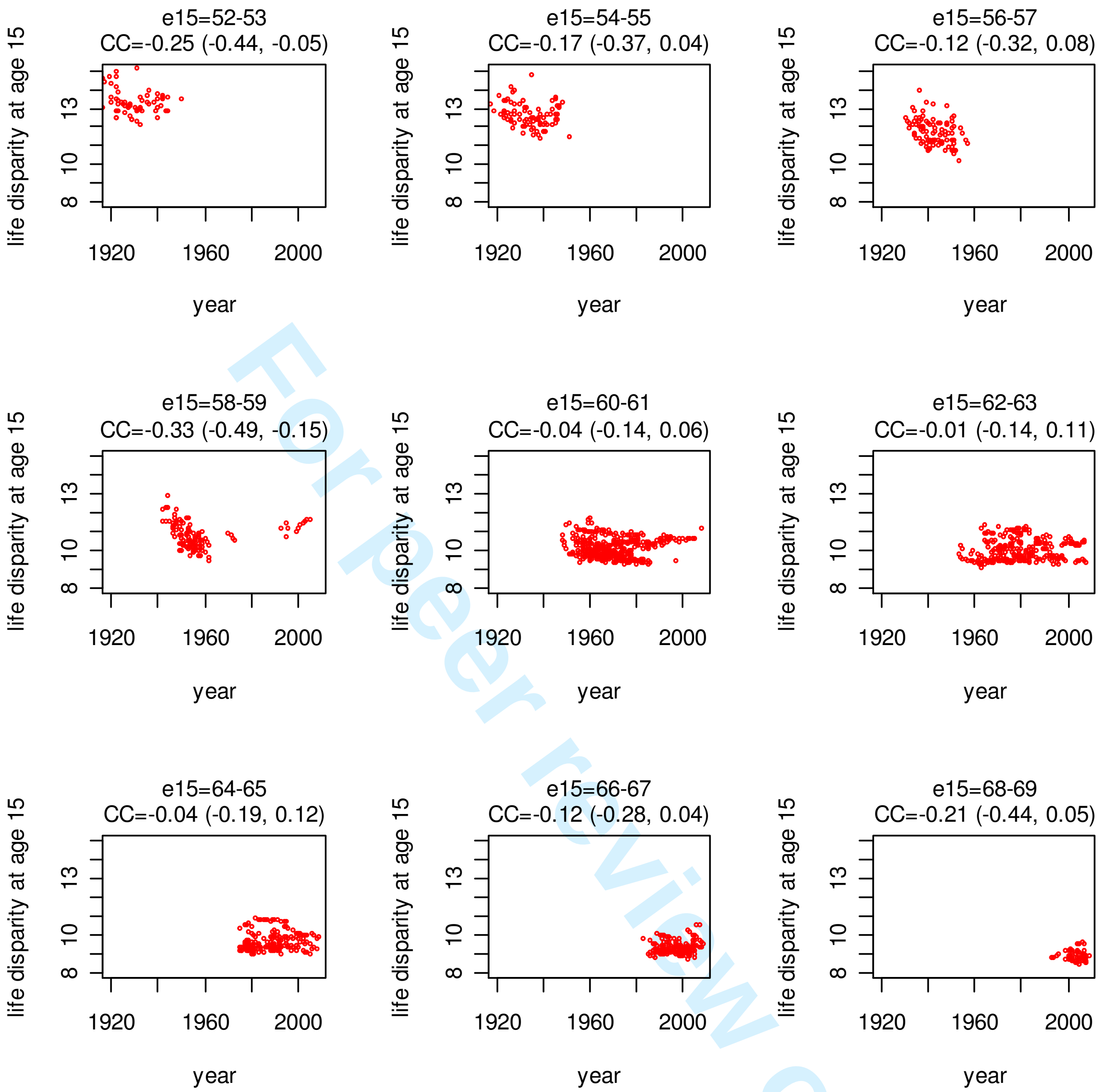

Fig 3: The relationship between remaining life expectancy at age 15 (e_{15}) and life disparity at age 15, according to the year in which e_{15} was first reached. Up until 1960 and for e_{15} from 54 to 59, the pioneers in first attaining a level of remaining life expectancy did so with higher levels of life disparity than the laggards. Since 1960 and at higher remaining life expectancies, the relationship between remaining life expectancy and life disparity at age 15 are not correlated. Ages 15 and over were examined to make the results comparable to those obtained by Smits and Monden.[5] Data are for females from the 40 countries and regions in the Human Mortality Database (Table 1 in the Supplementary Material).

Country or region	Females			Males		
	e_0	$e^\dagger$	$a^\dagger$	e_0	$e^\dagger$	$a^\dagger$
Japan	86.4 *(86.3, 86.4)*	9.2 *(9.1 ,9.2)*	85.3 *(85.3, 85.4)*	79.6 *(79.6, 79.6)*	10.6 *(10.6, 10.6)*	78.0 *(77.9, 78.0)*
France	84.4 *(84.3, 84.4)*	9.3 *(9.3, 9.4)*	83.8 *(83.7, 83.8)*	77.4 *(77.4, 77.5)*	11.4 *(11.3, 11.4)*	76.5 *(76.5, 76.6)*
Switzerland	84.1 *(83.9, 84.2)*	9.0 *(8.9, 9.1)*	83.2 *(83.1, 83.4)*	79.3 *(79.2, 79.5)*	10.2 *(10.1, 10.3)*	78.0 *(77.9, 78.3)*
Italy	84.1 *(84.0, 84.1)*	8.8 *(8.8, 8.9)*	82.9 *(82.8, 82.9)*	78.8 *(78.8, 78.9)*	10.2 *(10.1, 10.2)*	77.3 *(77.2, 77.3)*
Spain	84.1 *(84.0, 84.1)*	8.8 *(8.7, 8.8)*	82.9 *(82.9, 83.0)*	77.6 *(77.5, 77.6)*	11.1 *(11.0, 11.1)*	76.0 *(76.0, 76.1)*
Australia	83.7 *(83.7, 83.8)*	9.3 *(9.2, 9.3)*	82.9 *(82.8, 83.0)*	79.3 *(79.2, 79.4)*	10.6 *(10.5, 10.6)*	78.0 *(77.9, 78.1)*
Finland	83.1 *(83.0, 83.3)*	9.1 *(9.0, 9.2)*	82.4 *(82.2, 82.6)*	76.5 *(76.3, 76.7)*	11.2 *(11.1, 11.3)*	75.3 *(75.1, 75.5)*
Sweden	83.1 *(83.0, 83.2)*	8.9 *(8.8, 8.9)*	82.2 *(82.1, 82.3)*	79.1 *(79.0, 79.2)*	9.8 *(9.7, 9.8)*	77.9 *(77.7, 78.0)*
Austria	83.0 *(82.9, 83.0)*	8.9 *(8.8, 8.9)*	82.1 *(82.0, 82.2)*	77.6 *(77.5, 77.7)*	10.6 *(10.5, 10.7)*	76.6 *(76.4, 76.8)*
Norway	83.0 *(82.8 ,83.1)*	9.1 *(9.0, 9.2)*	81.9 *(81.7, 82.0)*	78.3 *(78.2, 78.5)*	10.0 *(9.9, 10.1)*	77.2 *(77.0, 77.4)*
Iceland	83.0 *(82.5, 83.7)*	8.7 *(8.3, 9.1)*	81.9 *(81.4, 82.6)*	79.7 *(79.0, 80.4)*	9.8 *(9.3, 10.3)*	78.2 *(77.1, 79.2)*
Canada	82.9 *(82.9 ,83.0)*	10.0 *(9.9, 10.0)*	81.9 *(81.8, 82.0)*	78.3 *(78.3, 78.4)*	11.0 *(10.9, 11.0)*	76.9 *(76.8, 77.0)*
Israel	82.9 *(82.7, 83.0)*	9.2 *(9.1, 9.3)*	81.1 *(81.0, 81.3)*	79.0 *(78.8, 79.2)*	10.9 *(10.7, 11.0)*	77.0 *(76.8, 77.2)*
England & Wales	82.5 *(82.4, 82.5)*	9.8 *(9.8, 9.8)*	81.1 *(81.1, 81.2)*	78.3 *(78.3, 78.4)*	10.9 *(10.9, 10.9)*	76.6 *(76.6, 76.7)*
West Germany	82.4 *(82.4, 82.5)*	8.9 *(8.9, 9.0)*	81.7 *(81.7, 81.8)*	77.5 *(77.5, 77.6)*	10.5 *(10.4, 10.5)*	76.1 *(76.0, 76.1)*
East Germany	82.4 *(82.2, 82.5)*	9.1 *(9.0, 9.1)*	81.2 *(81.1, 81.2)*	76.5 *(76.4, 76.6)*	11.0 *(10.9, 11.1)*	74.8 *(74.7, 74.9)*
Portugal	82.4 *(82.4 ,82.5)*	8.9 *(8.8, 8.9)*	81.5 *(81.4, 81.6)*	76.4 *(76.3, 76.5)*	11.0 *(10.9, 11.0)*	75.5 *(75.3, 75.6)*
Belgium	82.3 *(82.2, 82.4)*	9.5 *(9.4, 9.5)*	81.6 *(81.5, 81.7)*	76.9 *(76.8, 77.0)*	10.9 *(10.8, 10.9)*	75.7 *(75.5, 75.8)*
Netherlands	82.3 *(82.3, 82.4)*	9.6 *(9.5, 9.7)*	80.9 *(80.8, 81.0)*	78.3 *(78.2, 78.4)*	9.8 *(9.8,9.9)*	76.7 *(76.6, 76.8)*
Slovenia	82.2 *(82.0, 82.5)*	8.9 *(8.8, 9.1)*	81.0 *(80.7, 81.2)*	75.7 *(75.5, 76.0)*	11.0 *(10.8, 11.2)*	73.9 *(73.5, 74.2)*
Luxembourg	82.1 *(81.6, 82.6)*	9.2 *(8.9, 9.6)*	81.4 *(80.8, 82.0)*	76.6 *(76.1, 77.2)*	10.0 *(9.7, 10.4)*	76.0 *(75.2, 76.7)*
New Zealand non-Maori	82.1 *(81.9, 82.3)*	9.6 *(9.4, 9.7)*	81.2 *(81.0, 81.4)*	77.8 *(77.6, 78.0)*	10.4 *(10.3, 10.6)*	76.6 *(76.3, 76.8)*
Taiwan	82.0 *(81.9,82.1)*	10.1 *(10.0, 10.2)*	80.5 *(80.4, 80.6)*	75.9 *(75.8, 76.0)*	12.6 *(12.5, 12.7)*	73.7 *(73.6, 73.9)*
Ireland	81.9 *(81.7, 82.1)*	9.4 *(9.3, 9.6)*	80.3 *(80.1, 80.6)*	77.3 *(77.1, 77.4)*	10.2 *(10.1, 10.4)*	75.5 *(75.3, 75.8)*
Northern Ireland	81.3 *(81.0,81.6)*	9.9 *(9.7, 10.1)*	80.6 *(80.3, 80.9)*	77.2 *(76.9, 77.5)*	11.0 *(10.8, 11.3)*	76.1 *(75.7, 76.4)*
Denmark	80.9 *(80.8, 81.0)*	9.9 *(9.8, 10.0)*	79.4 *(79.2, 79.6)*	76.5 *(76.3, 76.6)*	10.7 *(10.6, 10.8)*	74.9 *(74.7, 75.1)*
USA	80.8 *(80.7, 80.8)*	11.1 *(11.0, 11.1)*	79.8 *(79.8, 79.8)*	75.6 *(75.6, 75.6)*	12.5 *(12.5, 12.5)*	74.5 *(74.4, 74.5)*
Chile	80.7 *(80.6, 80.8)*	10.7 *(10.6, 10.8)*	78.9 *(78.8, 79.0)*	75.0 *(74.9, 75.1)*	12.7 *(12.5, 12.8)*	72.3 *(72.0, 72.5)*
Scotland	80.4 *(80.3, 80.6)*	10.3 *(10.2, 10.4)*	78.9 *(78.7, 79.1)*	75.9 *(75.7, 76.0)*	11.6 *(11.5, 11.7)*	74.0 *(73.8, 74.2)*
Czech Republic	80.3 *(80.2, 80.4)*	9.3 *(9.2, 9.4)*	78.9 *(78.8, 79.0)*	74.0 *(73.9, 74.1)*	11.2 *(11.2, 11.3)*	71.7 *(71.6, 71.9)*
Estonia	*80.0* *(79.7,80.3)*	*9.9* *(9.6, 10.1)*	*79.0* *(78.8, 79.3)*	*69.7* *(69.4, 70.1)*	*12.9* *(12.7, 13.2)*	*66.3* *(65.8, 66.9)*
Poland	79.9 *(79.8, 80.0)*	10.0 *(9.9, 10.0)*	78.9 *(78.8, 79.0)*	71.5 *(71.4, 71.5)*	12.5 *(12.5, 12.6)*	68.7 *(68.6, 68.8)*
Slovakia	78.8 *(78.7, 79.0)*	9.8 *(9.6, 9.9)*	77.2 *(77.0, 77.3)*	70.8 *(70.6, 71.0)*	12.2 *(12.1, 12.3)*	67.8 *(67.6, 68.0)*

Lithuania	78.6 *(78.4,78.7)*	10.2 *(10.1, 10.4)*	78.0 *(77.8, 78.2)*	67.5 *(67.3, 67.7)*	13.6 *(13.4, 13.7)*	64.0 *(63.6,64.3)*
China[*]	*78.2*	*11.7*	*76.5*	*73.4*	*12.6*	*72.0*
Latvia	78.0 *(77.8,78.3)*	10.5 *(10.4, 10.7)*	77.5 *(77.2, 77.7)*	68.3 *(68.0, 68.5)*	13.2 *(13.0, 13.3)*	64.8 *(64.5, 65.1)*
Hungary	77.7 *(77.5, 77.8)*	10.7 *(10.7, 10.8)*	76.1 *(76.0, 76.2)*	69.2 *(69.0, 69.3)*	12.9 *(12.8, 13.0)*	65.0 *(64.8, 65.1)*
Bulgaria	77.3 *(77.1,77.4)*	10.1 *(10.0, 10.2)*	76.3 *(76.1, 76.4)*	70.0 *(69.9, 70.2)*	12.6 *(12.5, 12.7)*	67.3 *(67.2, 67.5)*
Belarus	76.1 *(76.0, 76.3)*	10.9 *(10.8, 11.0)*	74.7 *(74.6, 74.9)*	64.5 *(64.4, 64.7)*	13.7 *(13.6, 13.7)*	60.4 *(60.2, 60.6)*
Russia	74.2 *(74.1, 74.2)*	11.9 *(11.9, 11.9)*	73.4 *(73.4, 73.5)*	61.8 *(61.7, 61.8)*	15.0 *(15.0, 15.1)*	57.4 *(57.3, 57.4)*
Ukraine	73.8 *(73.7, 73.9)*	11.6 *(11.6, 11.7)*	72.9 *(72.8, 72.9)*	62.3 *(62.2, 62.4)*	14.7 *(14.7, 14.8)*	58.0 *(57.9, 58.0)*
India[*]	*63.8*	*18.2*	*72.8*	*61.8*	*18.2*	*69.7*
South Africa[*]	*52.6*	*20.7*	*60.6*	*50.0*	*19.8*	*56.8*

Data sources: [*] Data for 2006 from World Health Organization (WHO), not used in the analysis but shown here for comparative purposes. All other data are from the Human Mortality Database 2011; see Table 1 in the Supplementary Material for latest year available.

Table 1: Countries and regions of the Human Mortality Database[2] used in our analysis, ranked by female life expectancy for the latest year available. Life expectancy is denoted by e_0, the threshold age separating 'premature' from 'late' deaths by $a^{\dagger}$, and life disparity by $e^{\dagger}$, with 95% confidence intervals given in brackets (see supplementary material). Information for Eastern European countries is shown in red and for the United States in blue. The countries used in our analyses are in regular type face. The countries in italics are shown for comparison; data are less reliable for these countries.

Supplementary Material

Life Disparity

Life disparity, $e^{\dagger}$, is the life expectancy lost due to death, $e^{\dagger} = \int_0^{\omega} e(x,t) f(x,t)dx$, where $e(a,t) = \frac{\int_a^{\omega} l(x,t)dx}{l(a,t)}$ is remaining life expectancy at age a and time t, $l(a,t) = \exp(-\int_0^a \mu(x,t)dx)$ gives the probability of survival to age a and $\mu(a,t)$ denotes the age-specific hazard of death. The life table distribution of deaths is given by $f(a,t) = l(a,t)\mu(a,t)$. Maximum lifespan is denoted by ω.

Conceptually, this measure is similar to Greville's 1948 variant of the Potential Years of Life Lost (PYLL) measure,[S1] which weights the death counts from a given disease at each age by remaining life expectancy in order to assess the importance of major causes of death. In this way the age profile of disease mortality is taken into account, which can lead to different conclusions than assessments that compare diseases strictly on the basis of death counts or on their average effect on lifespan.

When all causes of death are taken into account, life disparity functions in much the same way. Saving lives at ages with both many remaining life years and a high number of death counts has the greatest impact on lifespan variation. This was first observed by Keyfitz,[S2,S3] who derived the formula for the elasticity of life expectancy to a proportional change in mortality (also known as the entropy of the life table, or Keyfitz' *H*), which he observed was related to variation in age-at-death. Life disparity equals the entropy of the life table multiplied by life expectancy.[S4-S6] It is only in recent years that the full potential of life disparity as a measure of lifespan variation has been realized.[S7,S8]

Methods to obtain confidence intervals

To be sure that random fluctuation was not substantially affecting our rankings of life expectancy, life disparity and the threshold age in Table 1, we estimated 95 % confidence intervals around our results. This was done by Monte Carlo simulation, assuming a binomial distribution of death counts. For each age interval the number of observations in each simulation round was based on the observed number of deaths, D_x, divided by the probability of dying, q_x. The simulated death counts, d_x^{sim}, divided by the observed population at risk, N_x, gave us simulated death probabilities q_x^{sim}. From these values we simulated 1000 life tables that we used to generate confidence intervals around our life-table-based estimates. Others have used similar methods to generate confidence intervals around life expectancy and healthy life expectancy for small populations.[S9-S12]

Country or region	Earliest year	Latest year
Australia	1921	2007
Austria	1947	2008
Belgium*	1841	2007
Bulgaria	1970	2009
Belarus	1970	2007
Canada	1921	2007
Switzerland	1876	2007
Chile	1992	2005
Czech	1950	2009
West Germany	1956	2008
East Germany	1956	2008
Denmark	1840	2008
Spain	1908	2006
Estonia	1959	2009
Finland	1878	2009
France	1840	2007
England & Wales	1841	2009
North Ireland	1922	2009
Scotland	1855	2009
Hungry	1950	2006
Ireland	1950	2006
Iceland	1840	2008
Israel	1983	2008
Italy	1872	2007
Japan	1947	2009
Latvia	1970	2009
Luxembourg	1960	2007
Lithuania	1959	2009
Netherlands	1850	2008
Norway	1846	2008
New Zealand non-Maori	1901	2008
Poland	1958	2009
Portugal	1940	2009
Russia	1959	2008
Slovakia	1950	2009
Slovenia	1983	2009
Sweden	1840	2008
Taiwan	1970	2009
Ukraine	1970	2006
USA	1933	2007
Australia	1921	2007

Table S1: Countries and regions of the Human Mortality Database used in our analysis. We used data from the earliest year given in the table through the latest year. *No data was available for 1914-1918.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.993	1.000						
Standard deviation (σ)	0.985	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.972	0.964	0.961	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.966	0.936	0.919	0.916	1.000			
Gini coefficient (*G*)	0.983	0.961	0.946	0.937	0.997	1.000		
Inter-Quartile Range (*IQR*)	0.967	0.944	0.917	0.921	0.966	0.974	1.000	
Inter-individual difference (AID)	0.995	0.998	0.996	0.973	0.937	0.962	0.945	1.000

Table 2(a): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3474 female period life tables available from the Human Mortality Database, 1840-2009.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.986	1.000						
Standard deviation (σ)	0.979	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.940	0.909	0.908	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.958	0.913	0.898	0.879	1.000			
Gini coefficient (*G*)	0.979	0.946	0.933	0.898	0.996	1.000		
Inter-Quartile Range (*IQR*)	0.965	0.937	0.913	0.890	0.948	0.964	1.000	
Inter-individual difference (AID)	0.992	0.997	0.995	0.930	0.917	0.950	0.941	1.000

Table 2(b): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3474 male period life tables available from the Human Mortality Database, 1840-2009.

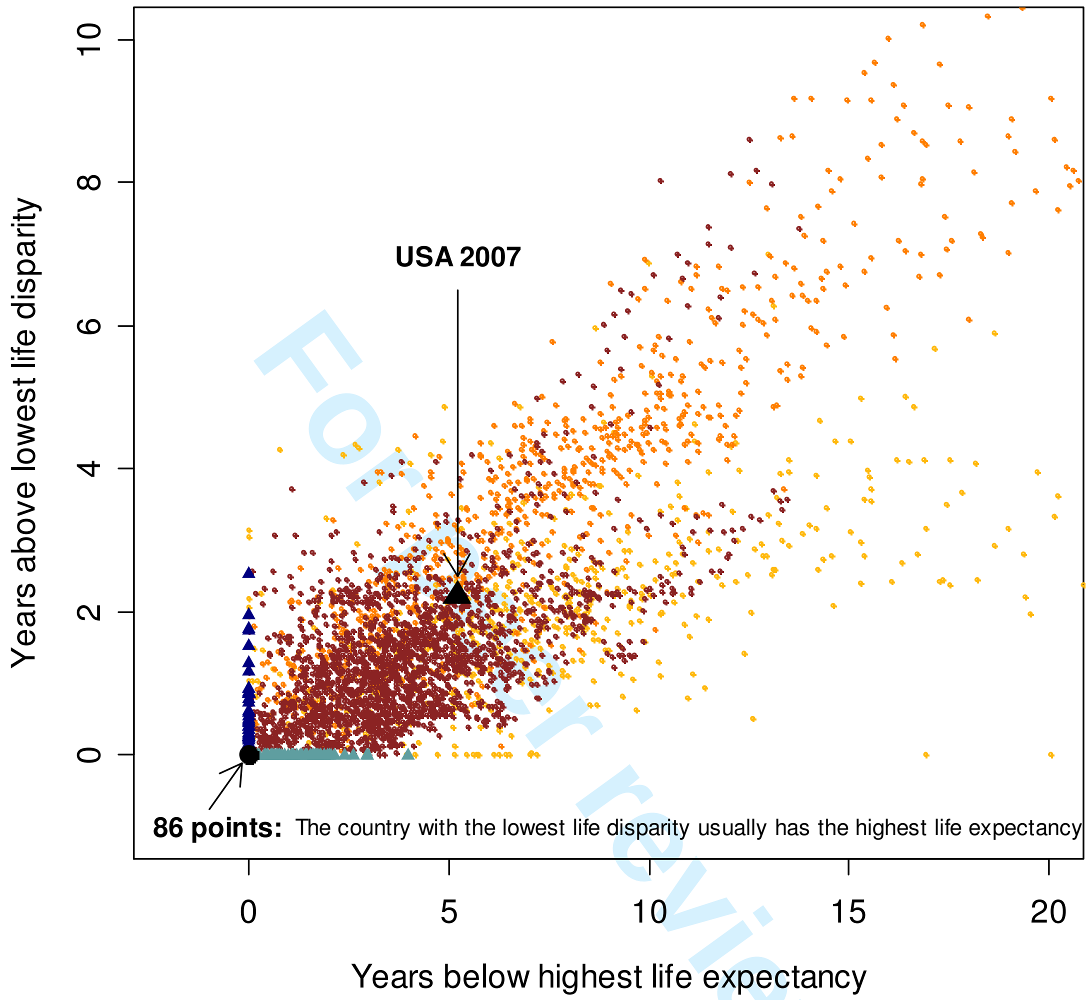

Fig. S1: The association between life disparity in a specific year and life expectancy for females in that year for the 40 countries and regions in the Human Mortality Database, 1840-2009 (Table S1). The correlation coefficient between them is 0.75 (95% confidence interval 0.73 to 0.76). The black triangle represents the United States in 2007: the U.S. had a female life expectancy 5.2 years lower than the international record in 2006 and a life disparity 2.2 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 86 holders of record life expectancy also enjoyed the lowest life disparity.

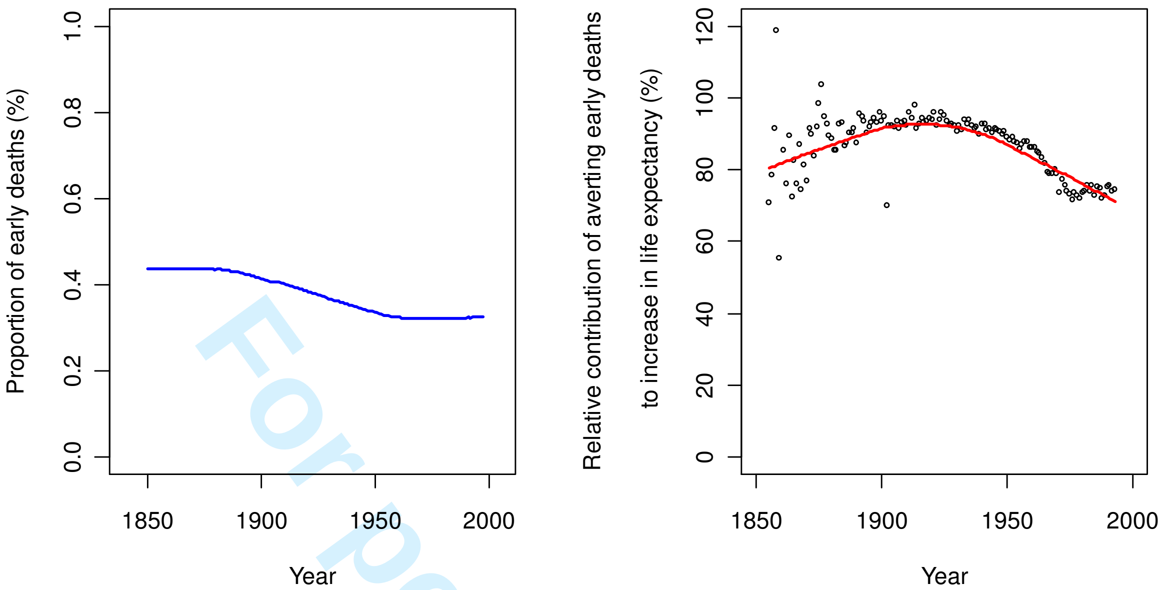

Figure S2: The left panel expresses early deaths as a proportion of all deaths, smoothed by 20-year averages. The right panel displays the 30-year moving average of the relative contribution of averting early deaths to the increase in life expectancy, with the red line marking the trend. The data pertain to females, 1840-2009, all 40 countries and regions of the HMD.

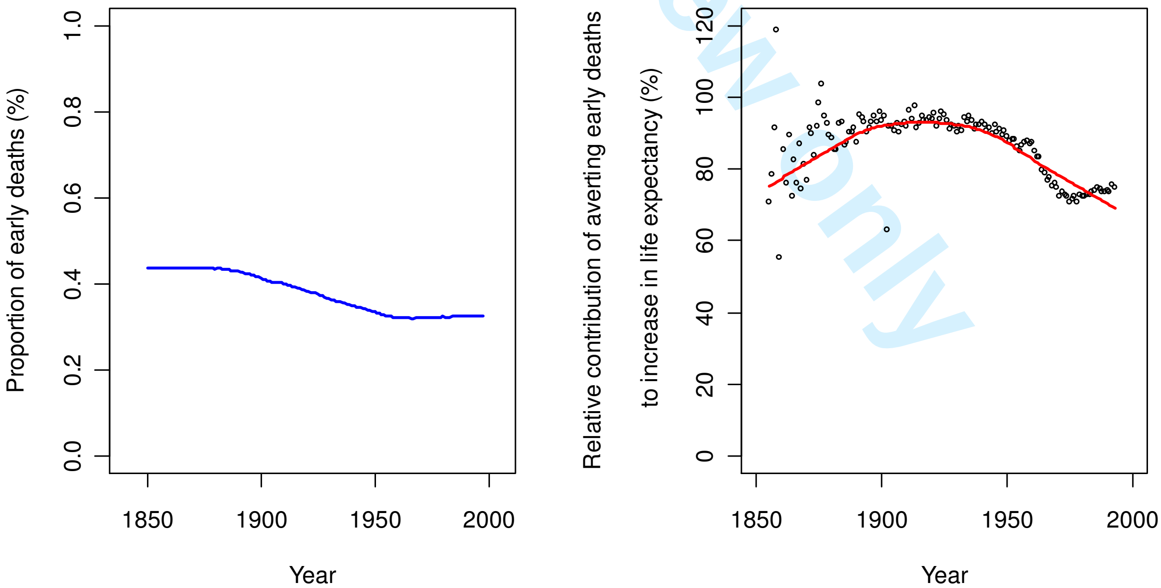

Figure S3: To show that the trends in Figure S2 above are not due to compositional change from new entrants into our dataset, we plotted the two relationships using only the eleven countries for which we had over 100 years of data (see Table S1).

Alternative calculations using the AID measure

Some concern might be raised about whether artefactual correlations are present in our findings since calculation of life disparity involves prior knowledge of life expectancy. We showed the high correlation between life disparity and other measures of lifespan variation in Table 2 of the supplementary material. Some of these other measures do not contain life expectancy in their formulation. To be sure that our results were robust to other measures, we ran our analysis with an alternative measure of lifespan variation, the absolute inter-individual difference (AID). While AID and life disparity are highly correlated, AID tends to be more sensitive to mortality change at younger ages than life disparity.[S7]

The AID is an alternative measure of lifespan variation that is related to the well-known Gini coefficient of inequality. There are many equivalent formulations to the AID, but the Kendall and Stuart definition is the most helpful for understanding the nature of the statistic, which essentially measures the average absolute distance in years between each pair of individuals' age at death (length of life) in the population.[S13] From the life table, it can be calculated as follows:

$$AID = \frac{1}{2}\int_0^\omega \int_0^\omega |x - y| f(x) f(y) dxdy \qquad (1)$$

where $|x - y|$ is the absolute value of the distance in years between age x and age y, and f(x) and f(y) are the probabilities of death at ages x and y respectively.

Using the AID measure, the country with the highest life expectancy also had the lowest AID 74 times for females (Figure S3), and 67 times for males (Figure S4) out of 170 years. Differences in this relationship between the two measures were mostly owing to differences in historical populations, especially during war, famine and epidemic years, when certain countries had qualitatively different age at death distributions from other countries.

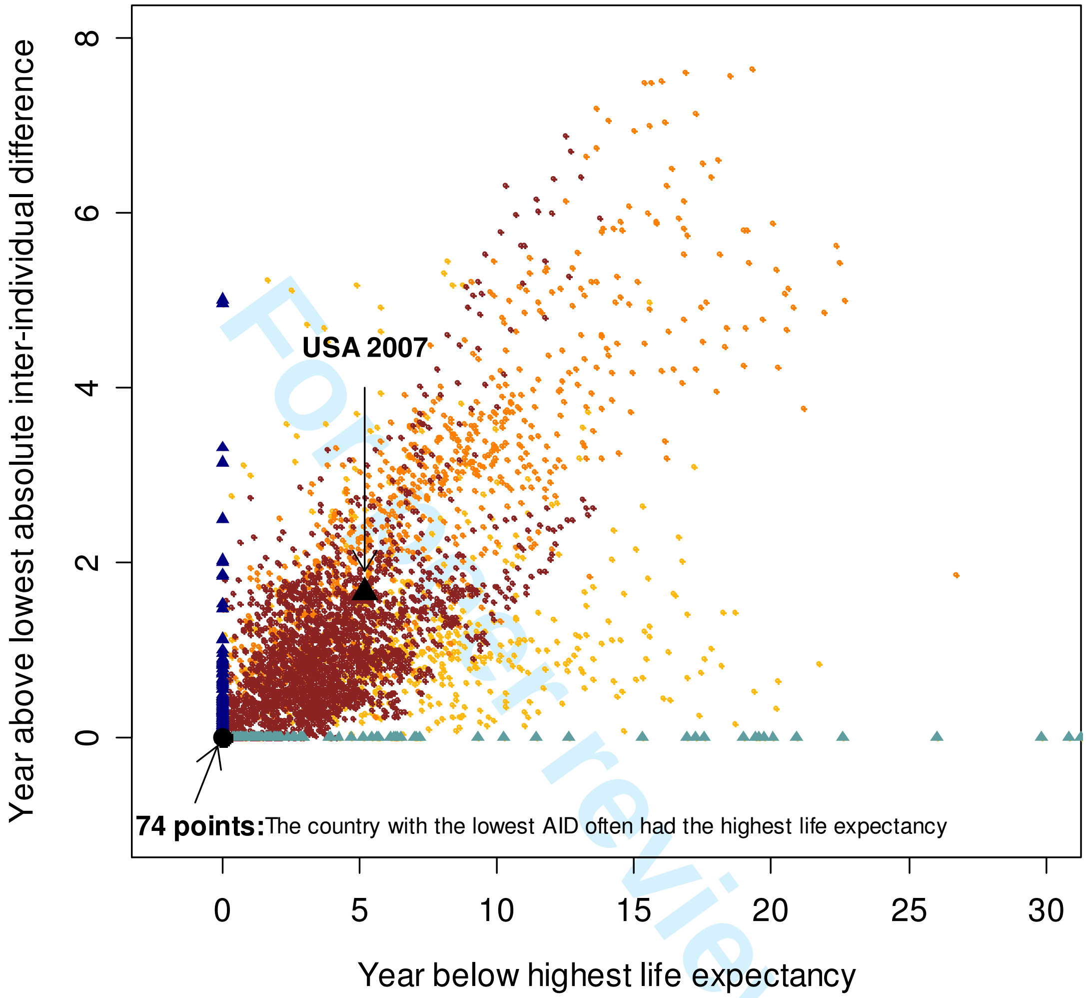

Figure S4: Alternative calculations using the AID measure, females. The correlation coefficient between them is 0.60 (0.58 to 0.62).

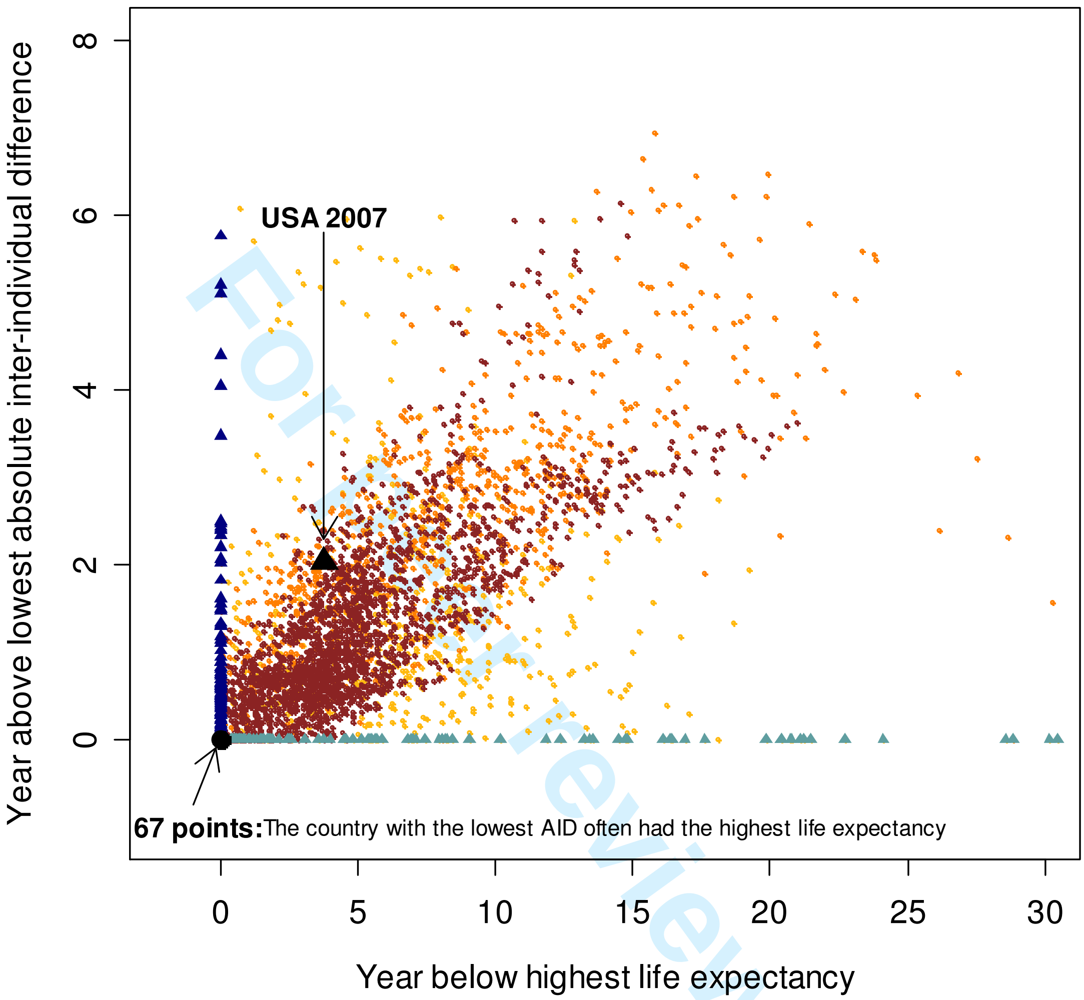

Figure S5: Alternative calculations using the AID measure, males. The correlation coefficient between them is 0.62 (0.60 to 0.64).

Supplementary References:

S1. Greville TNE. Comments on Mary Dempsey's article on decline in Tuberculosis: the death rate fails to tell the entire story. *Am Rev Tuberc* 1948;57:417-19.

S2. Keyfitz N, Golini A. Mortality comparisons: the male-female ratio. *Genus* 1975;31:1-34.

S3. Keyfitz N. Applied mathematical demography. 1st ed. New York: Wiley; 1977.

S4. Mitra S. A Short Note on the Taeuber Paradox. *Demography* 1978;15:621-23.

S5. Goldman N, Lord G. A New Look at Entropy and the Life Table. *Demography* 1986;23:275-82.

S6. Vaupel JW. How Change in Age-Specific Mortality Affects Life Expectancy. *Popul Stud* 1986;40:147-57.

S7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* in press.

S8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.

S9. Veugelers PJ, Kim AL, Guernsey JR. Inequalities in health. Analytic approaches based on life expectancy and suitable for small area comparisons *J Epidemiol Community Health* 2000;54:375-380

S10. Salomon JA, Mathers CD, Murray CJ, Ferguson B. Methods for life expectancy and healthy life expectancy uncertainty analysis. *Global Programme on Evidence for Health Policy Working Paper No. 10, World Health Organization* 2001.

S11. Silcocks PBS, Jenner DA, Reza R. Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities *J Epidemiol Community Health* 2001;55:38-43.

S12. Eayres D, Williams ES. Evaluation of methodologies for small area life expectancy estimation *J Epidemiol Community Health* 2004;58:243-249

S13. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-358.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	Report numbers of outcome events or summary measures
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Response to review for manuscript:

BMJ/2010/815423
BMJ/2011/862375 (resubmission)

Detailed comments from the meeting (original submission):

* We thought this an interesting paper - if it is true.

* However, as written you have not included any statistics which are needed to understand what you have done; looking at the ranking tables of all the countries we have no way of knowing whether the observed differences are random or real. There are no correlations calculated, etc. While there may be some relationship here, there are multiple ways in which it could arise.

* The indexes (life expectancy and disparity) you are considering almost certainly have artefactual correlations as the second involves knowing the first. Hence some of your conclusions may be overstated but without the statistics it is difficult to work out.

* The paper is more suited to a demography journal at present, and needs to be re written with the BMJ's readership in mind. You also need to discuss the implications for public health more clearly.

Comments to review committee meeting:

Thank you for your suggestions. We have taken the following steps to show that our results are not based on random fluctuation and to help readers to understand what we have done.

1) Providing statistics to back up our claim

- We calculated confidence intervals around our estimates of all of the indicators in Table 1: e_0, $e^\dagger$, $a^\dagger$ etc. We described the method to obtain these confidence intervals in the Supplementary material.
- We estimated the correlation coefficient for all relationships represented in figures along with their 95% confidence intervals.

2) Showing that our claim is not based on the artefactual correlations from the measures themselves:

- We ran our analysis with the Absolute Inter-individual Difference, a measure of the average difference in years in age at death between individuals (Description in Supplementary material including Figures S4 and S5). The results were qualitatively similar.

3) Changing the paper to suit BMJ's readership and discussing implications for public health:

- We simplified the language where it was too technical. We strengthened our discussion by suggesting that equalizing lifespans should be given higher priority in public policy debates. As suggested by one of our reviewers (Mike Murphy), we tied this discussion to the recent editorial by Iona Heath in BMJ “What do we want to die from?” and the accompanying BMJ editorial “Premature death should be the priority for prevention”.

Reviewer Comments

Name: Vladimir Canudas-Romo
Position: Associate Professor, University of Copenhagen

I greatly enjoyed reading the “Life expectancy and disparity” manuscript. It is a pleasure to fly over their lucid interpretation of important measures of population health. Looking at their appendix, their derivations and mathematics that involved their results could be thought as difficult or hard to interpret, but the authors have done a superb job carrying the readers along their important contribution to the field: Life expectancy increases have been accompanied by lifespan concentrations.

My next paragraphs express the need to express my frustration as a reader that cannot communicate directly to the authors and debate face to face on their ideas. I would urge the authors to taken them as suggestions that might help bringing the readers closer to their article.

It is debatable which measure should be used to calculate “life disparity”. The authors’ candidate is a measure which they have baptized as e-dagger. They do a good job by comparing their results to other robust measures that account for lifespan distribution and show their high correlations. Part of the demographic and epidemiological transitions are the declines in mortality, starting at young ages and later in time observed also on older ages. However, in the present manuscript little effort is made to really show what is happening currently at older ages in terms of disparity of life (or death). What would be the result if instead of taking e-dagger at age 0 or 15 the authors would have taken it at age 55 or 60 or any age after that? which is actually the starting ages where currently deaths are concentrated. I am sure they will find that instead of compression of lifespan, they would have observed minor expansions. So instead to find in their conclusion a positive covariance between maximum life expectancy and life disparity concentration, they would have found a negative one. Interpretation is open, but I welcome more debate on mortality at older ages where most of the deaths are currently occurring, than to hear the already known explanation of young mortality decline as explaining both increase in life expectancy and decline in lifespan disparity.

I am also surprised to find that in the authors’ measures a death at age 82 can be counted as a premature death. I should emphasize that, this time, it is a delightful surprise, mainly because it adds a new perspective to the debate of the increase in life expectancy. Similar findings are observed when studying the old-age modal age at death, or age where most of the deaths are concentrated. It has been shown that this modal age at death can be taken as an alternative measure of longevity that captures well stages of the demographic and epidemiological transitions that are not seen in the time trend of life expectancy at birth. Therefore, I would urge the authors to try to link more in depth the relations of these different measures to their findings. Particularly to bring more in the interpretation of the increase in life expectancy and decline of life disparity the change from a dominance of young mortality declines to old mortality declines.

Comments to Vladimir Canadus Romo

We thank you for your thoughtful comments, and have made the following changes to the manuscript in response.

1) The age range examined
   - You are right to point out that our examination would not necessarily hold over all age ranges. We mentioned this, citing papers that have shown how an arbitrary starting age (usually at middle age) can lead to different results because of capturing a different distribution. We would not want to start our examination at age 50, since it would cut out some of the most tragic premature deaths of individuals with many years of remaining life expectancy, which we feel are important to quantify. By decomposing our measure at the threshold age, we aimed to get a separate picture of premature mortality compression vs. late life mortality compression.
2) Comparing our findings to studies examining the mode:
   - We added a paragraph which compared our late life disparity findings to compression of mortality above the mode.
   - We explained how late life compression has remained stable despite increases in longevity because of the shifting threshold age—a similar dynamic which is observed when examining compression above the mode.

Name:M Murphy
Position:Professor of Demography

This is an interesting paper that sets out the changing contribution of mortality at different ages to the overall increase in relation to the disparity in ages at death. The paper summarises the literature well, and it introduces a range of indicators of variability in ages at death, many of which may be unfamiliar to readers. It concentrates on an indicator that defines a cut-off age for 'premature' deaths. The paper serves to act as a counterweight to some of the more pessimistic views about possible mortality decline by adopting a long-term perspective. The paper also highlights the benefits of considering 'young' and 'old' ages as relative and dependent on the morality regime, rather than using a fixed indicator such as proportion of deaths above a fixed age limit such as 65 or 80.

The findings are robust in that the authors show that similar results are found with alternative indicators. Although not directly relevant to clinical decision-making, this work reinforces the conclusion of a recent BMJ editorial "Premature deaths should be the priority for prevention" (BMJ 2010; 341:c3946 doi: 10.1136/bmj.c3946 22 July 2010).

There are a few points in the interpretation that the authors could consider. For example the statement that "progress in reducing death rates at older ages increases variation in lifespans" could be contrasted with Figure 2 which appears to show that life disparity generally falls with decreasing mortality. The reasons why the conclusions of this paper differ from those of Smits and Monden could also be discussed. The data base used includes different groups of countries at different time periods. The extent to which this may affect the results in the left panel of Figure S2 could be considered, and also if such compositional changes can account for a possible steep decline in the trend around 1850 in the right hand panel (although the data are noisy in this period).

Comments to Mike Murphy

We thank you for your thoughtful comments, and have made the following changes to the manuscript in response.

(1) Linking progress in reducing death rates which increases lifespan variation with Fig 2
- We added the following sentence to explain the mechanism behind this apparent contradiction: "Although mortality at old ages has come down considerably (which might cause one to expect increases in late-life disparity), the shifting of the threshold age to higher ages has caused late-life disparity to stay roughly constant at around or just under five years".

(2) Explaining why our conclusions differ from Smits and Monden

- We explained how examining within country differences over time (their study) can lead to different conclusions than cross-sectional differences between countries (our study). We cited the paper by Shkolnikov et al. which found that circulatory diseases were causing most of the changes in life disparity over time (in each country) while differences in external mortality were causing much of the difference in life disparity between countries at any given time.

(3) Compositional change

- We did as you suggested and separately examined countries with a long time series from the other entire group of countries (Fig S3) which showed similar patterns to Fig S2.

Life expectancy and disparity

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2011-000128.R1
Article Type:	Research
Date Submitted by the Author:	17-May-2011
Complete List of Authors:	Vaupel, James; Max Planck Institute for Demographic Research, Survival and Longevity Zhang, Zhen; Max Planck Institute for Demographic Research, Survival and Longevity van Raalte, Alyson; Max Planck Institute for Demographic Research, Survival and Longevity; Erasmus University Medical Centre, Public Health
Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, BASIC SCIENCES

Life expectancy and disparity

James W Vaupel, Zhen Zhang, Alyson A van Raalte

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
James W Vaupel, Founding Director

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
Zhen Zhang, Research Scientist

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany and Department of Public Health, Erasmus MC, University Medical Centre Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands
Alyson A van Raalte, PhD student

Correspondence to: James W Vaupel jwv@demogr.mpg.de

Keywords: Premature death, lifespan variation, health progress, international comparisons of life expectancy, historical trends in mortality

Word Count - 2280 words

ABSTRACT

- **objectives** – To determine the contribution of progress in averting premature deaths to the increase in life expectancy and the decline in lifespan variation.
- **design** - International comparison of national lifetable data from the Human Mortality Database
- **setting** – 40 developed countries and regions, 1840 to 2009
- **population** – Men and women of all ages
- **main outcome measure** – We use two summary measures of mortality: life expectancy and life disparity. Life disparity is a measure of how much lifespans differ among individuals. We define a death as premature if postponing it to a later age would decrease life disparity.
- **results** - In 89 of the 170 years from 1840 to 2009, the country with the highest male life expectancy had the lowest male life disparity. This was true in 86 years for female life expectancy and disparity. In all years, the top several life expectancy leaders were also the top life disparity leaders. Although only 38% of deaths were premature, fully 84% of the increase in life expectancy resulted from averting premature deaths. The reduction in life disparity resulted from reductions in early-life disparity, i.e., disparity caused by premature deaths; late-life disparity levels remained roughly constant.
- **conclusions** – The countries that have been the most successful in averting premature deaths have consistently been the life expectancy leaders. Greater longevity and greater equality of individuals' lifespans are not incompatible goals. Countries can achieve both by reducing premature deaths.

Article focus

- We examined the relationship between high life expectancy and low life disparity.
- We determined the relative importance of premature vs. late deaths in increasing life expectancy and reducing life disparity.
- We examined whether policies to increase life expectancy were compatible with those to reduce lifespan variation.

Key messages

- Most of the gains in life expectancy have come from reducing disparities in how long people live, by averting premature mortality.
- Progress in reducing death rates for people who live longer than average has had little effect on life disparity levels, and its contribution to life expectancy gains has been modest.
- The countries that have been most successful at reducing premature mortality enjoy the highest life expectancies and the greatest equality in individuals' lifespans.

Strengths and limitations

- We are the first to examine this issue using a large, comparable database of 40 developed countries from 1840 to 2009 containing 6940 lifetables.
- Our analysis was limited to countries with high enough quality data to be included in the database. Although this database contains high mortality lifetables from historic populations, it is unknown whether the patterns we observed would also be seen in contemporary emerging and developing countries.

Introduction

The rise in life expectancy, from under 40 years in all areas of the world two centuries ago to over 80 years today in many developed countries, has fundamentally improved the human condition.[1 2] Equally significant and closely linked to the increase in life expectancy has been the reduction of differences among individuals in the age at death.[3-6] Even in the most egalitarian societies before the mid-19th century the fate of most newborns was to die young but a fortunate minority survived to old age. Death rates today in health leaders such as Japan, Spain and Sweden imply that three-quarters of babies will survive to celebrate their 75th birthdays.[2]

The negative correlation between high life expectancy and low lifespan variation has been investigated for several countries, including the United States,[4 6 7] England and Wales[7], Sweden[6] and Japan[6]. The correlation is strong but there are discrepancies. Some countries, notably the United States, have substantially greater lifespan dispersion than might be predicted from their high levels of life expectancy.[3-5]

Progress in reducing premature deaths reduces variation in lifespans, whereas progress in reducing deaths at older ages increases variation in lifespans. A recently-developed demographic formula permits ready determination of the ages at which deaths are premature.[8] We use this new formula and apply it to a large dataset on developed countries to gain a deeper understanding of the relationship between high life expectancy and low lifespan variation. We find that the countries that have been the most successful in reducing premature deaths, and consequently in reducing lifespan variation, have consistently been the life expectancy leaders.

Methods

Our calculations are based on all period lifetables of the Human Mortality Database (*HMD*), from 1840 to the most recent year available in the data set.[2] This is a freely available database with reliable, comparable data covering 40 countries and areas. (Table 1 in the Supplementary Appendix lists the countries or regions and years used in the analysis.)

We measure dispersion in age-at-death by the life disparity measure, $e^{\dagger}$ (technical description in the Supplementary Appendix).[8 9] Life disparity is defined as the average remaining life expectancy at the ages when death strikes; it is a measure of life years lost due to death. The more egalitarian the lifespan distribution is, the lower the life disparity. In the Swedish female life table for 2008 life expectancy reached 83 years; for those women who survived to age 83, remaining life expectancy was 7.5 additional years. Hence a death shortly after birth would contribute 83 years whereas a death at age 83 would contribute 7.5 years. The average of such values over the Swedish female population, weighted by the number of deaths at each age, gives a life disparity of 9. In 1840 life expectancy for Swedish women was only 46 and life disparity was 24. Over time, as deaths became concentrated at later ages, the average gap was reduced between the age at which a person died and the remaining lifespans of people who survived beyond this age.

Saving lives (i.e., averting deaths) at any age increases life expectancy. Lifespan disparity, on the other hand, narrows or widens depending on the balance between saving lives at 'early' ages, which compresses the distribution of lifespans, and saving lives at 'late' ages, which expands this distribution by increasing the average remaining life expectancy of survivors. Separating the two is a unique threshold age, $a^{\dagger}$, sitting generally just below the life expectancy. Henceforth, we refer to deaths occurring before the threshold age as 'premature deaths', while those occurring after this age are 'late deaths'. Thus 'premature' deaths according to our definition are defined relative to the mortality level of the population. This is in contrast to other definitions which use fixed upper age limits that would seem arbitrary over the long sweep of time. This new definition implies that deaths at surprisingly old ages can be premature deaths. In 2008 deaths up to age 82 were premature deaths for Swedish females (Table 1).

Deleted: .

Deleted: .

Deleted: T

The life disparity measure has the property that it can be additively decomposed at any age such that the components before and after this age sum to the total life disparity.[8] When it is decomposed at the threshold age, the components are defined as 'early-life disparity' and 'late-life disparity'.

While it is known that high life expectancy is associated with low lifespan variation, we wanted to establish whether life expectancy leaders had the most egalitarian lifespan distributions. For each sex, year, and for up to 40 countries depending on the year, we determined the male and female record high life expectancy and record low life disparity. We calculated how many fewer years of life expectancy and additional years of life disparity each country experienced compared with the record-holding country in that year.

We next investigated the relative importance of premature vs. late deaths in determining the relationship between high life expectancy and low life disparity. To do so, we calculated first the number of premature and late deaths as a proportion of all deaths, measured by 10-year averages across all countries and years. We then compared this to the respective contributions of averting premature and late deaths to increases in life expectancy,[8 9] using a 20-year moving average to smooth mortality trends over exceptional years of war, pandemics or famine (technical description in the Supplementary Appendix).

Finally, we ranked countries according to their life expectancy and life disparity for the latest year for which we had data.

Results

Populations with high life expectancy enjoy low life disparity. In 89 out of 170 years, holders of record life expectancy for males also enjoyed the lowest life disparity (fig 1). For females this happened 86 times (appendix fig 1 on bmjopen.bmj.com). These countries increased life expectancy not because of a general decrease in mortality at all ages, but because of a decrease in premature mortality. Figure 2 shows that the reduction in life disparity—from around 25 years in 1840 to between 9 and 15 years at present—is overwhelmingly due to reductions in early-life disparity caused by tackling premature mortality. Although mortality rates at old ages have come down considerably (which might cause one to expect increases in late-life disparity), the shifting of the

Deleted: life disparity

Deleted: early-life disparity

Deleted: 12

Deleted: has

threshold age to higher ages has caused late-life disparity to stay roughly constant at around or just under five years.

For females since 1840, premature deaths have accounted for only 38 percent of all deaths, but fully 84 percent of the increase in life expectancy resulted from decreases in premature deaths (appendix fig 2 on bmj.com). During this time the threshold age rose considerably, rising from 47 for Swedish women in 1840 to 85 for Japanese women in 2009. Historically (and today in less developed countries) infants, children and younger adults suffered most premature deaths. In today's more developed countries, premature deaths have shifted primarily to older adults in their sixties and seventies. The rise in the threshold age is highly correlated with the rise in life expectancy (correlation coefficient is 0.96 (males), 0.98 (females)).

Table 1 displays the latest period life expectancy, threshold age and life disparity calculated for each country. In Russia life expectancy is extraordinarily low and life disparity is very high. In the United States, life expectancy is much longer than in Russia but short compared with countries of similar income per capita. Females in most Eastern European countries, and males in some of them, do better than the U.S. in life disparity and hence face more certainty in their lifetimes. In contrast Japanese females are remarkably successful. They hold the record for life expectancy, 86.4 years in the lifetable for 2009. Half of deaths occurred after age 88 and the most common age of death was 93: deaths up to age 85 were premature in the sense that averting such deaths would decrease life disparity.

Deleted: Life disparity in the U.S. is worse than in many Eastern European countries for both males and females

Discussion

These findings make clear that the correlation between high life expectancy and low lifespan variation is due to progress in reducing premature mortality. The countries that have the highest life expectancy today are those who have been most successful at postponing the premature deaths that contribute to early-life disparity.

Deleted: early-life disparity

In addition to life disparity, several other measures of lifespan dispersion have been proposed.[3 4 6 10] We analyzed the extent to which our findings depend on our use of life disparity as our measure of lifespan variation. We calculated Pearson correlation coefficients between pairs of the more commonly used measures of lifespan variation, based on all male and female period life tables available from the Human Mortality Database (appendix table 1 on bmj.com). As shown in Table 2 of the Supplementary Material, these measures are highly correlated with each other. In particular, the correlation of life disparity with the other measures never falls below 0.966 for females and 0.940 for males. Hence life disparity can be viewed as a surrogate for the other measures. Although the various measures are highly correlated, they differ somewhat in their sensitivity to deaths at different ages in the lifespan distribution.[4 11] The use of an alternate measure of lifespan variation would result in some changes in the ranking of countries with similar life disparity levels, but the high correlation between measures implies that such changes would be minor.

Some researchers have examined whether lifespan variation above the adult modal age at death has changed with increased survivorship. These studies also tend to find a gradual decline in later life mortality variation.[10 12-14] Exploring the relationship between life disparity and compression around the modal age at death could be an interesting avenue for further research. More generally, whether expansion or compression of the lifespan distribution is observed over time can depend on the age range examined.[15-17] While being a life expectancy leader is associated with low life disparity when the entire lifetime is examined, this relationship might not hold for selected age ranges.

Reducing early life disparities helps people plan their less-uncertain lifetimes. A higher likelihood of surviving to old age makes savings more worthwhile, raises the value of individual and public investments in education and training, and increases the prevalence of long-term relationships. Hence, healthy longevity is a prime driver of a country’s wealth and well-being.[18]

While some degree of income inequality might create incentives to work harder, premature deaths bring little benefit and impose major costs.[19]

Moreover, equity in the capability to maintain good health is central to any larger concept of societal justice.[20] The tenet that everyone should be entitled to a long, healthy lifespan has gained support as mortality at younger ages has declined. Currently, rates of change for adult mortality vary more across countries than those for infants and children.[21] In Williams' concept of *fair innings*,[22] individuals dying early are "cheated" while those living beyond a "normal" lifespan are "living on borrowed time". Groups and areas with lower socioeconomic status account for a disproportionate share of lifespan variation:[3 4 7] this compounds the inequity of premature death.

If death rates continue to decline, most babies born in advanced nations today may live to enjoy their 100th birthday.[23] As we celebrate this progress in extending lives it is reasonable to question whether we ought to continue aiming for ever longer lives *on average* or to ensure that more individuals avoid premature death. Policymakers face a choice of where to target health care spending. Reducing life disparity would lead to health policies that prioritize early mortality and to social protection schemes designed to shield vulnerable individuals and groups. We are not the first to make this argument. Heath poignantly reasoned that if health care services were serious about reducing health inequality they should direct their attentions to reducing premature mortality—even if this meant reducing expensive medical treatments for the elderly.[24] The accompanying editorial in *BMJ* proclaimed that "premature deaths should be the priority for prevention".[25]

Russia, the U.S. and other laggards can learn much from research on the reasons why various countries (including Japan, France, Italy, Spain, Sweden and Switzerland) have been more successful in reducing premature deaths. The reasons involve health care, social policies, personal behavior (especially cigarette smoking and alcohol abuse), and the safety and salubriousness of the environment.[26-33] Genetic variation plays a modest role in determining variation in how long we live[34 35] and cannot account for the major declines in life disparity and increases in life expectancy or the large differences in life expectancy and disparity among countries.

Smits and Monden[5] recently showed that countries achieving some level of life expectancy earlier than others did so with higher levels of lifespan variation. This led them to conclude that "reducing inequality and gaining increases in life expectancy might be alternative goals that require different policy measures to be achieved". Our results differ because we examine differences between countries in lifespan variation for each year whereas they examine differences over time in lifespan variation within each country. These different set-ups can lead to different conclusions. In a study comparing the United States to England and Wales, reductions in circulatory diseases were causing most of the changes in lifespan variation over time (in each country) whereas differences in external mortality explained much of the difference in life disparity between countries at any given time.[7] As can be seen in Figure 3 the relationship between being pioneers in life expectancy and having high life disparity is weak, especially after 1960. We take issue with Smits and Monden's conclusion which our cross-sectional results do not support. Over the past 170 years, the country with the lowest life disparity most often had the highest life expectancy. Even today, the most egalitarian countries are all among the longest living.

Deleted: were contributing most

Formatted: Not Highlight

Deleted: s

The increase in life expectancy is given by the product of two factors—life disparity and the rate of progress in reducing age-specific death rates.[9] The lower life disparity is, the greater is the rate of progress needed to achieve an additional year of life expectancy. Consequently it might be thought that countries would aim for life expectancy increases by maintaining high levels of inequality in the lifespan distribution. The opposite is true (Figure 1). The reason is that the countries with long life expectancy have gained this victory by focusing on reductions in premature deaths—and reductions in premature deaths reduce life disparity. It is not a question of either long life or low disparity: countries can achieve both by averting premature deaths.

Deleted: countries with long life expectancy would tend to have high life disparity.

We thank A. Baudisch, J. R. Goldstein , E. Loichinger, J. Oeppen, V. M. Shkolnikov, K. W. Wachter and H. Wilkoszewski for helpful comments. We are grateful to V. Canudas-Romo, A. Leyland, and M. Murphy for reviewing the paper.

Deleted: M. Murphy and

Contributors: JWV conceived the research idea and co-wrote the drafts, ZZ managed the data analysis and commented on the drafts, AvR contributed to data analysis and co-wrote the drafts.

Funding: We acknowledge support from the Max Planck Society and the U.S. National Institute on Aging (NIA P01-08761).

Competing interests: "All authors declare that the answer to the questions on your competing interest form are all No and therefore have nothing to declare"

Ethics approval was not required for this study.

References

1. Oeppen J, Vaupel JW. Broken Limits to Life Expectancy. *Science* 2002;296(5570):1029-1031.
2. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org (data downloaded on 18/02/2011)
3. Edwards RD, Tuljapurkar S. Inequality in life spans and a new perspective on mortality convergence across industrialized countries. *Popul Dev Rev* 2005;31:645-74.
4. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-58.
5. Smits J, Monden C. Length of life inequality around the globe. *Soc SciMed* 2009;68:1114-236.
6. Wilmoth JR, Horiuchi S. Rectangularization Revisited: Variability of Age at Death within Human Populations. *Demography* 1999;36:475-95.
7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* 2011;48:211-239
8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.
9. Vaupel JW, Canudas Romo V. Decomposing Change in Life Expectancy: A Bouquet of Formulas in Honor of Nathan Keyfitz's 90th Birthday. *Demography* 2003;40:201-16.
10. Cheung SL, Robine JM, Tu EJ, Caselli G. Three dimensions of the survival curve: horizontalization, verticalization, and longevity extension. *Demography* 2005;42:243-58.
11. Anand S, Diderichsen F, Evans T, Shkolnikov V, Wirth M. Measuring Disparities in Health: Methods and Indicators. In: T. Evans MW, F. Diderichsen, A. Bhuiya, M. Wirth editor. *Challenging inequities in health: from ethics to action*. New York: Oxford University Press, 2001.
12. Thatcher AR, Cheung SLK, Horiuchi S, Robine J-M. The compression of deaths above the mode. *Demogr Res* 2010;22:505-538.
13. Cheung SL, Robine JM. Increase in common longevity and the compression of mortality: the case of Japan. *Popul Stud (Camb)* 2007;61:85-97.
14. Kannisto V. Mode and Dispersion of the Length of Life. *Population* 2001;13:159-171.
15. Robine J-M. Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France. *Population* 2001;13:173-193.
16. Nusselder WJ, Mackenbach JP. Rectangularization of the survival curve in The Netherlands, 1950-1992. *Gerontologist* 1996;36(6):773-782.
17. Engelman M, Canudas-Romo V, Agree EM. The Implications of Increased Survivorship for Mortality Variation in Aging Populations. *Popul Dev Rev* 2010;36:511-539.
18. Bloom DE, Canning D. The Health and Wealth of Nations. *Science* 2000;287:1207-09.
19. Anand S. The concern for equity in health. *J Epidemiol Community Health* 2002;56:485-87.
20. Sen A. Why health equity? *Health Econ* 2002;11:659-66.
21. Rajaratnam JK, Marcus JR, Levin-Rector A, Chalupka AN, Wang H, Dwyer L, et al. Worldwide mortality in men and women aged 15-59 years from 1970 to 2010: a systematic analysis. *Lancet* 2010;375:1704-17.
22. Williams A. Intergenerational Equity: An Exploration of the Fair Innings Argument. *Health Econ* 1997;6:117-32.
23. Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. *Lancet* 2009;374:1196-1208.
24. Heath I. What do we want to die from? *BMJ* 2010;341:c3883.
25. Godlee F. Premature deaths should be the priority for prevention. *BMJ* 2010;341:c3946.
26. Doll R, Peto R, Boreham J, Sutherland I. Mortality in relation to smoking: 50 years' observations on male British doctors. *BMJ* 2004;328:1519.

Deleted: in press.¶

27. Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL. Selected major risk factors and global and regional burden of disease. *Lancet* 2002;360:1347-1360.
28. Kauhanen J, Kaplan GA, Goldberg DE, Salonen JT. Beer binging and mortality: results from the kuopio ischaemic heart disease risk factor study, a prospective population based study *BMJ* 1997;315:846.
29. Lundberg O, Yngwe MÅ, Stjärne MK, Elstad JI, Ferrarini T, Kangas O, et al. The role of welfare state principles and generosity in social policy programmes for public health: an international comparative study. *Lancet* 2008;372:1633-1640.
30. Marmot M, Friel S, Bell R, Houweling TAJ, Taylor S. Closing the gap in a generation: health equity through action on the social determinants of health. *Lancet* 2008;372:1661-1669.
31. Peto R, Boreham J, Lopez AD, Thun M, Heath C. Mortality from tobacco in developed countries: indirect estimation from national vital statistics. *Lancet* 1992;339:1268-1278.
32. Rehm J, Mathers C, Popova S, Thavorncharoensap M, Teerawattananon Y, Patra J. Global burden of disease and injury and economic cost attributable to alcohol use and alcohol-use disorders. *Lancet* 2009;373:2223-2233.
33. Whitehead M, Dahlgren G. Concepts and principles for tackling social inequities in health: Levelling up Part 1. *WHO, Copenhagen* 2007:1-45.
34. McGue M, Vaupel JW, Holm NV, Harvald B. Longevity is moderately heritable in a sample of Danish twins born 1870- 1880. *J Gerontol* 1993;48:237-44.
35. Herskind A, McGue M, Holm N, Sørensen T, Harvald B, Vaupel J. The heritability of human longevity: A population-based study of 2872 Danish twin pairs born 1870–1900. *Hum Genet* 1996;97:319-23.

Tables and Figures

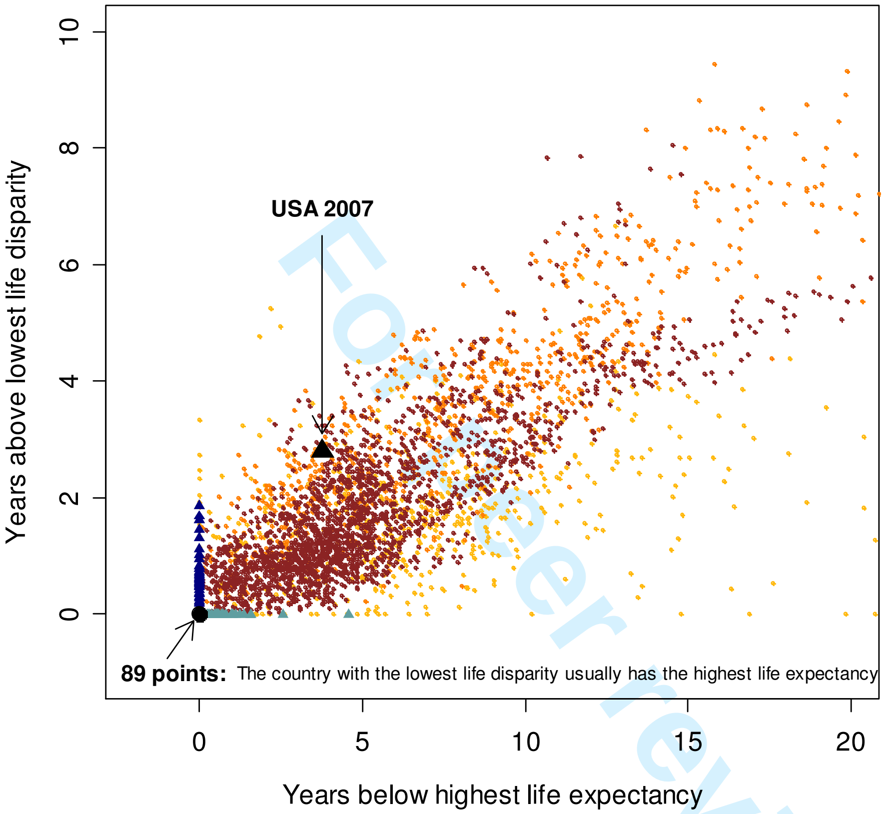

Fig 1: The association between life disparity in a specific year and life expectancy in that year for males in 40 countries and regions, 1840-2009 (Table 1 in the Supplementary Material). The correlation coefficient between them is 0.77 (95% confidence interval 0.76 to 0.78). The black triangle represents the United States in 2007: the U.S. had a male life expectancy 3.78 years lower than the international record in 2007 and a life disparity 2.8 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 89 holders of record life expectancy also enjoyed the lowest life disparity. The equivalent figure for females is presented as Fig 2 in the Supplementary Material.

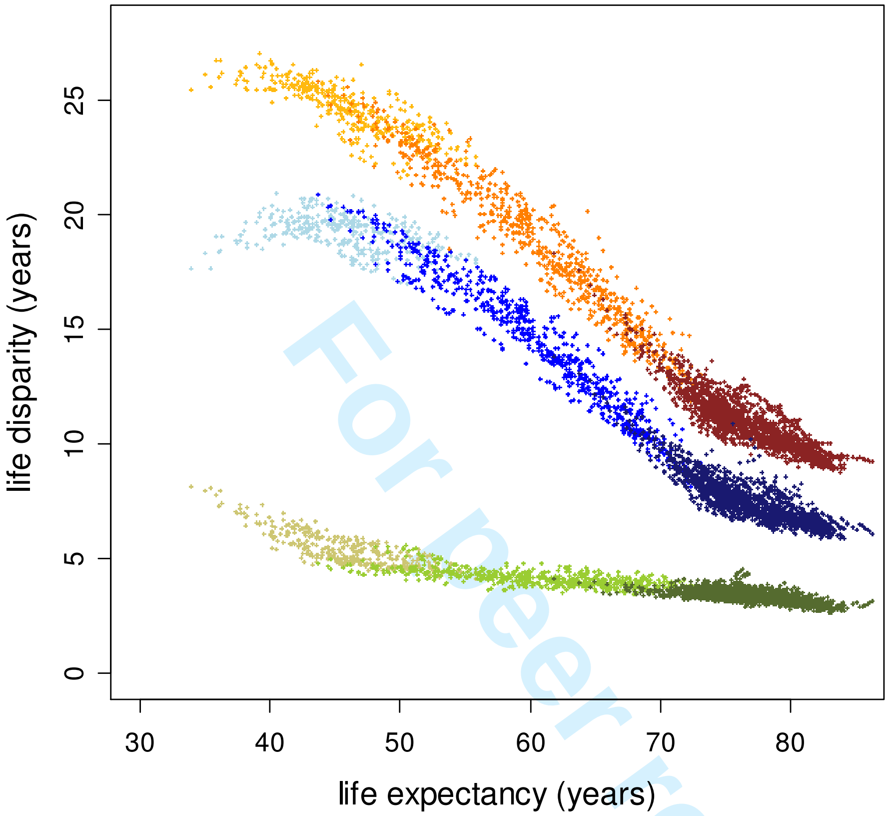

Fig 2: The relationship between total life disparity (red), early life disparity up to the threshold age (blue) and late life disparity after the threshold age (green). The darkest hues relate to data from 1950-2009, middle hues 1900-1949 and lightest hues 1840-1899. Total disparity is an additive function of early life disparity and late life disparity. Since 1840 the decrease in total life disparity has resulted from reductions in early life disparity. The correlation coefficient between early life disparity and total life disparity is 0.997 (0.997, 0.997). Late life disparity has remained remarkably constant at about 5 years across a wide range of life expectancies. Hence, according to this measure, there has been neither a marked compression nor expansion of mortality at advanced ages as life expectancy has increased. Data are for females from the 40 countries and regions of the Human Mortality Database (Table 1 in the Supplementary Material).

Deleted: The three curves can be fit by linear regression. The adjusted R^2 is .97 with slope -0.438 (95% confidence interval -0.440 to -0.435) for the red curve, 0.96 with slope -0.376 (-0.379, -0.373) for the blue curve, and 0.77 with slope -0.061 (-0.062, -0.060) for the green curve.

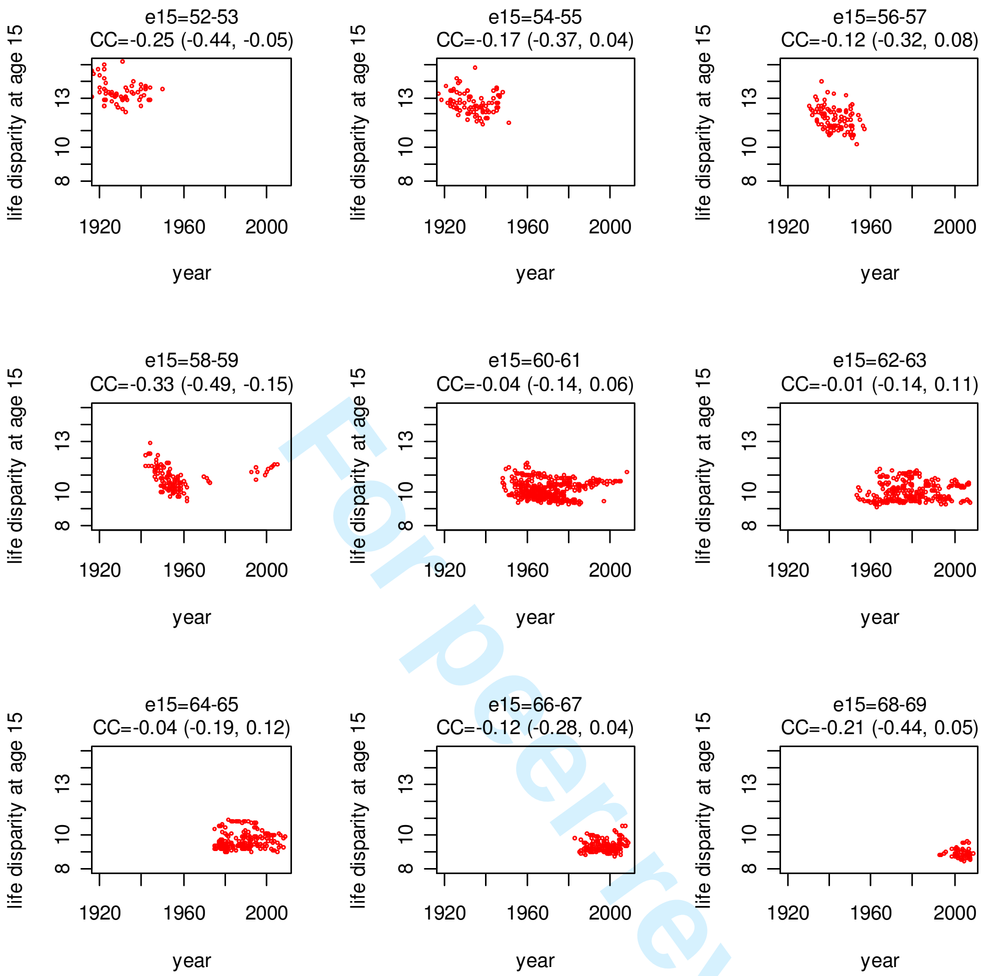

Fig 3: The relationship between remaining life expectancy at age 15 (e_{15}) and life disparity at age 15, according to the year in which e_{15} was first reached. Up until 1960 and for e_{15} from 54 to 59, the pioneers in first attaining a level of remaining life expectancy did so with higher levels of life disparity than the laggards. Since 1960 and at higher remaining life expectancies, the relationship between remaining life expectancy and life disparity at age 15 are not correlated. Ages 15 and over were examined to make the results comparable to those obtained by Smits and Monden.[5] Data are for females from the 40 countries and regions in the Human Mortality Database (Table 1 in the Supplementary Material).

Country or region	Females			Males		
	e_0	$e^\dagger$	$a^\dagger$	e_0	$e^\dagger$	$a^\dagger$
Japan	86.4 *(86.3, 86.4)*	9.2 *(9.1 ,9.2)*	85.3 *(85.3, 85.4)*	79.6 *(79.6, 79.6)*	10.6 *(10.6, 10.6)*	78.0 *(77.9, 78.0)*
France	84.4 *(84.3, 84.4)*	9.3 *(9.3, 9.4)*	83.8 *(83.7, 83.8)*	77.4 *(77.4, 77.5)*	11.4 *(11.3, 11.4)*	76.5 *(76.5, 76.6)*
Switzerland	84.1 *(83.9, 84.2)*	9.0 *(8.9, 9.1)*	83.2 *(83.1, 83.4)*	79.3 *(79.2, 79.5)*	10.2 *(10.1, 10.3)*	78.0 *(77.9, 78.3)*
Italy	84.1 *(84.0, 84.1)*	8.8 *(8.8, 8.9)*	82.9 *(82.8, 82.9)*	78.8 *(78.8, 78.9)*	10.2 *(10.1, 10.2)*	77.3 *(77.2, 77.3)*
Spain	84.1 *(84.0, 84.1)*	8.8 *(8.7, 8.8)*	82.9 *(82.9, 83.0)*	77.6 *(77.5, 77.6)*	11.1 *(11.0, 11.1)*	76.0 *(76.0, 76.1)*
Australia	83.7 *(83.7, 83.8)*	9.3 *(9.2, 9.3)*	82.9 *(82.8, 83.0)*	79.3 *(79.2, 79.4)*	10.6 *(10.5, 10.6)*	78.0 *(77.9, 78.1)*
Finland	83.1 *(83.0, 83.3)*	9.1 *(9.0, 9.2)*	82.4 *(82.2, 82.6)*	76.5 *(76.3, 76.7)*	11.2 *(11.1, 11.3)*	75.3 *(75.1, 75.5)*
Sweden	83.1 *(83.0, 83.2)*	8.9 *(8.8, 8.9)*	82.2 *(82.1, 82.3)*	79.1 *(79.0, 79.2)*	9.8 *(9.7, 9.8)*	77.9 *(77.7, 78.0)*
Austria	83.0 *(82.9, 83.0)*	8.9 *(8.8, 8.9)*	82.1 *(82.0, 82.2)*	77.6 *(77.5, 77.7)*	10.6 *(10.5, 10.7)*	76.6 *(76.4, 76.8)*
Norway	83.0 *(82.8 ,83.1)*	9.1 *(9.0, 9.2)*	81.9 *(81.7, 82.0)*	78.3 *(78.2, 78.5)*	10.0 *(9.9, 10.1)*	77.2 *(77.0, 77.4)*
Iceland	83.0 *(82.5, 83.7)*	8.7 *(8.3, 9.1)*	81.9 *(81.4, 82.6)*	79.7 *(79.0, 80.4)*	9.8 *(9.3, 10.3)*	78.2 *(77.1, 79.2)*
Canada	82.9 *(82.9 ,83.0)*	10.0 *(9.9, 10.0)*	81.9 *(81.8, 82.0)*	78.3 *(78.3, 78.4)*	11.0 *(10.9, 11.0)*	76.9 *(76.8, 77.0)*
Israel	82.9 *(82.7, 83.0)*	9.2 *(9.1, 9.3)*	81.1 *(81.0, 81.3)*	79.0 *(78.8, 79.2)*	10.9 *(10.7, 11.0)*	77.0 *(76.8, 77.2)*
England & Wales	82.5 *(82.4, 82.5)*	9.8 *(9.8, 9.8)*	81.1 *(81.1, 81.2)*	78.3 *(78.3, 78.4)*	10.9 *(10.9, 10.9)*	76.6 *(76.6, 76.7)*
West Germany	82.4 *(82.4, 82.5)*	8.9 *(8.9, 9.0)*	81.7 *(81.7, 81.8)*	77.5 *(77.5, 77.6)*	10.5 *(10.4, 10.5)*	76.1 *(76.0, 76.1)*
East Germany	82.4 *(82.2, 82.5)*	9.1 *(9.0, 9.1)*	81.2 *(81.1, 81.2)*	76.5 *(76.4, 76.6)*	11.0 *(10.9, 11.1)*	74.8 *(74.7, 74.9)*
Portugal	82.4 *(82.4 ,82.5)*	8.9 *(8.8, 8.9)*	81.5 *(81.4, 81.6)*	76.4 *(76.3, 76.5)*	11.0 *(10.9, 11.0)*	75.5 *(75.3, 75.6)*
Belgium	82.3 *(82.2, 82.4)*	9.5 *(9.4, 9.5)*	81.6 *(81.5, 81.7)*	76.9 *(76.8, 77.0)*	10.9 *(10.8, 10.9)*	75.7 *(75.5, 75.8)*
Netherlands	82.3 *(82.3, 82.4)*	9.6 *(9.5, 9.7)*	80.9 *(80.8, 81.0)*	78.3 *(78.2, 78.4)*	9.8 *(9.8,9.9)*	76.7 *(76.6, 76.8)*
Slovenia	82.2 *(82.0, 82.5)*	8.9 *(8.8, 9.1)*	81.0 *(80.7, 81.2)*	75.7 *(75.5, 76.0)*	11.0 *(10.8, 11.2)*	73.9 *(73.5, 74.2)*
Luxembourg	82.1 *(81.6, 82.6)*	9.2 *(8.9, 9.6)*	81.4 *(80.8, 82.0)*	76.6 *(76.1, 77.2)*	10.0 *(9.7, 10.4)*	76.0 *(75.2, 76.7)*
New Zealand non-Maori	82.1 *(81.9, 82.3)*	9.6 *(9.4, 9.7)*	81.2 *(81.0, 81.4)*	77.8 *(77.6, 78.0)*	10.4 *(10.3, 10.6)*	76.6 *(76.3, 76.8)*
Taiwan	82.0 *(81.9,82.1)*	10.1 *(10.0, 10.2)*	80.5 *(80.4, 80.6)*	75.9 *(75.8, 76.0)*	12.6 *(12.5, 12.7)*	73.7 *(73.6, 73.9)*
Ireland	81.9 *(81.7, 82.1)*	9.4 *(9.3, 9.6)*	80.3 *(80.1, 80.6)*	77.3 *(77.1, 77.4)*	10.2 *(10.1, 10.4)*	75.5 *(75.3, 75.8)*
Northern Ireland	81.3 *(81.0,81.6)*	9.9 *(9.7, 10.1)*	80.6 *(80.3, 80.9)*	77.2 *(76.9, 77.5)*	11.0 *(10.8, 11.3)*	76.1 *(75.7, 76.4)*
Denmark	80.9 *(80.8, 81.0)*	9.9 *(9.8, 10.0)*	79.4 *(79.2, 79.6)*	76.5 *(76.3, 76.6)*	10.7 *(10.6, 10.8)*	74.9 *(74.7, 75.1)*
USA	80.8 *(80.7, 80.8)*	11.1 *(11.0, 11.1)*	79.8 *(79.8, 79.8)*	75.6 *(75.6, 75.6)*	12.5 *(12.5, 12.5)*	74.5 *(74.4, 74.5)*
Chile	80.7 *(80.6, 80.8)*	10.7 *(10.6, 10.8)*	78.9 *(78.8, 79.0)*	75.0 *(74.9, 75.1)*	12.7 *(12.5, 12.8)*	72.3 *(72.0, 72.5)*
Scotland	80.4 *(80.3, 80.6)*	10.3 *(10.2, 10.4)*	78.9 *(78.7, 79.1)*	75.9 *(75.7, 76.0)*	11.6 *(11.5, 11.7)*	74.0 *(73.8, 74.2)*
Czech Republic	80.3 *(80.2, 80.4)*	9.3 *(9.2, 9.4)*	78.9 *(78.8, 79.0)*	74.0 *(73.9, 74.1)*	11.2 *(11.2, 11.3)*	71.7 *(71.6, 71.9)*
Estonia	80.0 *(79.7,80.3)*	9.9 *(9.6, 10.1)*	79.0 *(78.8, 79.3)*	69.7 *(69.4, 70.1)*	12.9 *(12.7, 13.2)*	66.3 *(65.8, 66.9)*
Poland	79.9 *(79.8, 80.0)*	10.0 *(9.9, 10.0)*	78.9 *(78.8, 79.0)*	71.5 *(71.4, 71.5)*	12.5 *(12.5, 12.6)*	68.7 *(68.6, 68.8)*
Slovakia	78.8 *(78.7, 79.0)*	9.8 *(9.6, 9.9)*	77.2 *(77.0, 77.3)*	70.8 *(70.6, 71.0)*	12.2 *(12.1, 12.3)*	67.8 *(67.6, 68.0)*

Lithuania	78.6 *(78.4,78.7)*	10.2 *(10.1, 10.4)*	78.0 *(77.8, 78.2)*	67.5 *(67.3, 67.7)*	13.6 *(13.4, 13.7)*	64.0 *(63.6,64.3)*
*China**	*78.2*	*11.7*	*76.5*	*73.4*	*12.6*	*72.0*
Latvia	78.0 *(77.8,78.3)*	10.5 *(10.4, 10.7)*	77.5 *(77.2, 77.7)*	68.3 *(68.0, 68.5)*	13.2 *(13.0, 13.3)*	64.8 *(64.5, 65.1)*
Hungary	77.7 *(77.5, 77.8)*	10.7 *(10.7, 10.8)*	76.1 *(76.0, 76.2)*	69.2 *(69.0, 69.3)*	12.9 *(12.8, 13.0)*	65.0 *(64.8, 65.1)*
Bulgaria	77.3 *(77.1,77.4)*	10.1 *(10.0, 10.2)*	76.3 *(76.1, 76.4)*	70.0 *(69.9, 70.2)*	12.6 *(12.5, 12.7)*	67.3 *(67.2, 67.5)*
Belarus	76.1 *(76.0, 76.3)*	10.9 *(10.8, 11.0)*	74.7 *(74.6, 74.9)*	64.5 *(64.4, 64.7)*	13.7 *(13.6, 13.7)*	60.4 *(60.2, 60.6)*
Russia	74.2 *(74.1, 74.2)*	11.9 *(11.9, 11.9)*	73.4 *(73.4, 73.5)*	61.8 *(61.7, 61.8)*	15.0 *(15.0, 15.1)*	57.4 *(57.3, 57.4)*
Ukraine	73.8 *(73.7, 73.9)*	11.6 *(11.6, 11.7)*	72.9 *(72.8, 72.9)*	62.3 *(62.2, 62.4)*	14.7 *(14.7, 14.8)*	58.0 *(57.9, 58.0)*
*India**	*63.8*	*18.2*	*72.8*	*61.8*	*18.2*	*69.7*
*South Africa**	*52.6*	*20.7*	*60.6*	*50.0*	*19.8*	*56.8*

Data sources: * Data for 2006 from World Health Organization (WHO), not used in the analysis but shown here for comparative purposes. All other data are from the Human Mortality Database 2011; see Table 1 in the Supplementary Material for latest year available.

Table 1: Countries and regions of the Human Mortality Database[2] used in our analysis, ranked by female life expectancy for the latest year available. Life expectancy is denoted by e_0, the threshold age separating 'premature' from 'late' deaths by $a^\dagger$, and life disparity by $e^\dagger$, with 95% confidence intervals given in brackets (see supplementary material). Information for Eastern European countries is shown in red and for the United States in blue. The countries used in our analyses are in regular type face. The countries in italics are shown for comparison; data are less reliable for these countries.

Supplementary Material

Life Disparity

Life disparity, $e^{\dagger}$, is the life expectancy lost due to death, $e^{\dagger} = \int_0^{\omega} e(x,t) f(x,t) dx$, where $e(a,t) = \frac{\int_a^{\omega} l(x,t) dx}{l(a,t)}$ is remaining life expectancy at age a and time t, $l(a,t) = \exp(-\int_0^a \mu(x,t) dx)$ gives the probability of survival to age a and $\mu(a,t)$ denotes the age-specific hazard of death. The life table distribution of deaths is given by $f(a,t) = l(a,t)\mu(a,t)$. Maximum lifespan is denoted by ω.

Conceptually, this measure is similar to Greville's 1948 variant of the Potential Years of Life Lost (PYLL) measure,[S1] which weights the death counts from a given disease at each age by remaining life expectancy in order to assess the importance of major causes of death. In this way the age profile of disease mortality is taken into account, which can lead to different conclusions than assessments that compare diseases strictly on the basis of death counts or on their average effect on lifespan.

When all causes of death are taken into account, life disparity functions in much the same way. Saving lives at ages with both many remaining life years and a high number of death counts has the greatest impact on lifespan variation. This was first observed by Keyfitz,[S2,S3] who derived the formula for the elasticity of life expectancy to a proportional change in mortality (also known as the entropy of the life table, or Keyfitz' *H*), which he observed was related to variation in age-at-death. Life disparity equals the entropy of the life table multiplied by life expectancy.[S4-S6] It is only in recent years that the full potential of life disparity as a measure of lifespan variation has been realized.[S7,S8]

Methods to calculate the contribution of premature and late mortality to changes in life expectancy

Let $\rho(a,t)$ represent the rate of progress in reducing mortality:

$$\rho(a,t) = -\frac{\frac{\partial}{\partial t}\mu(a,t)}{\mu(a,t)}$$

Vaupel and Canudas Romo[S9] showed that the change in life expectancy at birth, $\dot{e}(0,t)$ could be decomposed as:

$$\dot{e}(0,t) = \int_0^{\omega} e(a,t)\rho(a,t)f(a,t)da$$

Meanwhile, Zhang and Vaupel[S8] proved that this relationship could be further decomposed by age components, for instance premature and late life mortality components separated by the threshold age:

$$\dot{e}(0,t) = \int_0^{a^{\dagger}(t)} e(a,t)\rho(a,t)f(a,t)da + \int_{a^{\dagger}(t)}^{\omega} e(a,t)\rho(a,t)f(a,t)da$$

We used these relationships to calculate the yearly contributions of averting premature and late deaths to increases in life expectancy, which we then smoothed using a 20-year moving average.

Methods to obtain confidence intervals

To be sure that random fluctuation was not substantially affecting our rankings of life expectancy, life disparity and the threshold age in Table 1, we estimated 95 % confidence intervals around our results. This was done by Monte Carlo simulation, assuming a binomial distribution of death counts. For each age interval the number of observations in each simulation round was based on the observed number of deaths, D_x, divided by the probability of dying, q_x. The simulated death counts, d_x^{sim}, divided by the observed population at risk, N_x, gave us simulated death probabilities q_x^{sim}. From these values we simulated 1000 life tables that we used to generate confidence intervals around our life-table-based estimates. Others have used similar methods to generate confidence

Formatted: Underline

Formatted: Line spacing: Double

Formatted: English (U.K.), Lowered by 5 pt

Formatted: Centered, Line spacing: Double

Formatted: English (U.K.), Lowered by 12 pt

Formatted: Line spacing: Double

Formatted: English (U.K.), Lowered by 5 pt

Formatted: Centered, Line spacing: Double

Formatted: English (U.K.), Lowered by 16 pt

Formatted: Line spacing: Double

Formatted: Centered, Line spacing: Double

Formatted: English (U.K.), Lowered by 17 pt

Deleted: ¶
Page Break

intervals around life expectancy and healthy life expectancy for small populations.S10-S13

Deleted: S9

Deleted: S12

Deleted: ¶

Country or region	Earliest year	Latest year
Australia	1921	2007
Austria	1947	2008
Belgium*	1841	2007
Bulgaria	1970	2009
Belarus	1970	2007
Canada	1921	2007
Switzerland	1876	2007
Chile	1992	2005
Czech	1950	2009
West Germany	1956	2008
East Germany	1956	2008
Denmark	1840	2008
Spain	1908	2006
Estonia	1959	2009
Finland	1878	2009
France	1840	2007
England & Wales	1841	2009
North Ireland	1922	2009
Scotland	1855	2009
Hungry	1950	2006
Ireland	1950	2006
Iceland	1840	2008
Israel	1983	2008
Italy	1872	2007
Japan	1947	2009
Latvia	1970	2009
Luxembourg	1960	2007
Lithuania	1959	2009
Netherlands	1850	2008
Norway	1846	2008
New Zealand non-Maori	1901	2008
Poland	1958	2009
Portugal	1940	2009
Russia	1959	2008
Slovakia	1950	2009
Slovenia	1983	2009
Sweden	1840	2008
Taiwan	1970	2009
Ukraine	1970	2006
USA	1933	2007
Australia	1921	2007

Table S1: Countries and regions of the Human Mortality Database used in our analysis. We used data from the earliest year given in the table through the latest year. *No data was available for 1914-1918.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.993	1.000						
Standard deviation (σ)	0.985	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.972	0.964	0.961	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.966	0.936	0.919	0.916	1.000			
Gini coefficient (G)	0.983	0.961	0.946	0.937	0.997	1.000		
Inter-Quartile Range (IQR)	0.967	0.944	0.917	0.921	0.966	0.974	1.000	
Inter-individual difference (AID)	0.995	0.998	0.996	0.973	0.937	0.962	0.945	1.000

Table S2(a): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3474 female period life tables available from the Human Mortality Database, 1840-2009.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.986	1.000						
Standard deviation (σ)	0.979	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.940	0.909	0.908	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.958	0.913	0.898	0.879	1.000			
Gini coefficient (G)	0.979	0.946	0.933	0.898	0.996	1.000		
Inter-Quartile Range (IQR)	0.965	0.937	0.913	0.890	0.948	0.964	1.000	
Inter-individual difference (AID)	0.992	0.997	0.995	0.930	0.917	0.950	0.941	1.000

Table S2(b): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3474 male period life tables available from the Human Mortality Database, 1840-2009.

Males								
Year	Record e†	Country	Average e†	Difference	Record e_0	Country	Average e_0	Difference
1840	23.8	Sweden	25.0	1.3	41.8	Sweden	40.4	1.4
1841	23.8	Sweden	25.1	1.3	43.0	Sweden	41.2	1.8
1842	24.5	Sweden	25.3	0.8	41.0	Denmark	40.3	0.7
1843	24.0	Sweden	25.0	1.0	42.6	Denmark	41.1	1.5
1844	24.2	Sweden	24.9	0.7	42.9	Denmark	41.6	1.4
1845	23.8	Sweden	24.9	1.1	43.5	Sweden	42.5	1.0
1846	24.3	Sweden	25.3	1.0	46.4	Norway	40.9	5.5
1847	24.1	Sweden	25.0	0.9	43.5	Norway	39.6	3.9
1848	23.4	Sweden	25.0	1.6	43.3	Norway	40.7	2.6
1849	23.9	Norway	25.0	1.1	46.3	Norway	39.5	6.8
1850	23.6	Norway	24.7	1.0	47.8	Norway	43.2	4.5
1851	23.7	Norway	24.8	1.1	48.0	Norway	42.7	5.3
1852	23.9	Norway	25.0	1.0	47.0	Norway	41.6	5.3
1853	24.0	Norway	24.8	0.8	46.5	Norway	40.6	5.9
1854	23.4	Norway	24.9	1.5	49.9	Norway	41.8	8.1
1855	23.1	Denmark	24.3	1.2	48.6	Norway	42.1	6.5
1856	23.6	Norway	24.8	1.2	48.8	Norway	43.2	5.7
1857	23.6	Norway	25.2	1.6	48.8	Norway	40.6	8.2
1858	23.6	Norway	25.3	1.7	50.0	Norway	41.5	8.5
1859	24.5	Norway	25.4	0.9	48.5	Norway	41.7	6.8
1860	23.5	Sweden	24.3	0.8	48.7	Norway	44.8	3.9
1861	23.5	Denmark	25.0	1.5	46.2	Denmark	43.5	2.8
1862	23.5	Denmark	25.2	1.8	46.7	Denmark	42.9	3.7
1863	23.8	Denmark	25.2	1.4	46.6	Denmark	43.2	3.4
1864	24.5	Norway	25.1	0.6	47.6	Norway	41.9	5.7
1865	24.3	Norway	25.2	0.9	49.0	Norway	42.0	7.0
1866	24.0	Norway	25.0	1.0	48.3	Norway	42.7	5.7
1867	23.5	Sweden	24.5	1.0	46.2	Norway	43.4	2.8
1868	24.4	Sweden	25.1	0.7	45.4	Norway	42.3	3.1
1869	24.2	Norway	24.9	0.7	47.5	Norway	42.5	5.0
1870	23.4	Norway	24.5	1.1	49.2	Norway	42.3	6.9
1871	23.1	Sweden	24.6	1.5	48.0	Norway	39.9	8.1
1872	23.6	Sweden	24.9	1.3	48.5	Norway	43.5	4.9
1873	23.6	Denmark	24.7	1.1	48.2	Norway	43.8	4.4
1874	23.9	Denmark	24.9	1.0	46.3	Norway	42.9	3.4
1875	24.3	Denmark	24.8	0.5	46.1	Norway	42.0	4.1
1876	24.3	Denmark	25.0	0.7	45.3	Norway	42.7	2.6
1877	24.2	Denmark	24.8	0.6	48.3	Norway	44.0	4.3
1878	24.2	Norway	25.0	0.7	50.4	Norway	43.3	7.1
1879	23.4	Norway	24.3	0.9	51.9	Norway	44.6	7.4
1880	23.6	Norway	24.9	1.3	50.5	Norway	42.6	7.9
1881	23.6	Denmark	24.5	1.0	49.0	Norway	43.6	5.5
1882	24.0	Switzerland	25.0	1.0	46.9	Sweden	43.5	3.4
1883	23.4	Switzerland	24.5	1.1	48.5	Norway	44.1	4.3
1884	23.6	Switzerland	24.7	1.1	49.5	Norway	44.1	5.4
1885	23.3	Denmark	24.4	1.1	49.8	Norway	44.6	5.2
1886	23.4	Switzerland	24.5	1.1	50.5	Norway	44.4	6.1
1887	23.2	Switzerland	24.2	1.0	50.6	Norway	45.6	5.0
1888	22.9	Sweden	24.1	1.2	51.0	Sweden	45.4	5.6
1889	23.0	Sweden	24.3	1.4	51.1	Sweden	45.3	5.8
1890	23.0	Switzerland	24.3	1.4	49.1	Sweden	44.2	4.8
1891	23.5	GBR_SCO	24.2	0.7	49.6	Sweden	44.1	5.5
1892	22.9	Switzerland	24.1	1.2	49.3	Sweden	44.2	5.1
1893	22.9	Switzerland	24.2	1.3	50.0	Sweden	44.8	5.2
1894	23.0	Switzerland	23.9	0.9	50.9	Sweden	46.4	4.5
1895	22.5	Sweden	23.7	1.3	52.8	Sweden	46.5	6.3
1896	22.3	Switzerland	23.5	1.2	52.2	Sweden	48.0	4.1
1897	22.3	Switzerland	23.3	1.1	52.8	Sweden	48.1	4.8
1898	22.3	Sweden	23.5	1.2	53.2	Sweden	47.9	5.3
1899	22.4	Switzerland	23.7	1.3	49.8	Norway	46.5	3.3
1900	22.1	Denmark	23.4	1.3	51.8	Norway	46.3	5.4
1901	22.5	Switzerland	23.5	1.1	52.7	Norway	47.5	5.2
1902	19.9	New Zealand*	22.5	2.6	56.6	New Zealand*	49.9	6.7
1903	20.3	New Zealand*	22.6	2.3	56.9	New Zealand*	50.1	6.8
1904	19.3	New Zealand*	22.4	3.1	58.9	New Zealand*	50.3	8.6
1905	18.4	New Zealand*	22.5	4.0	60.2	New Zealand*	49.9	10.3
1906	18.1	New Zealand*	22.3	4.2	60.0	New Zealand*	50.7	9.3
1907	19.9	New Zealand*	22.0	2.1	56.8	New Zealand*	50.7	6.1
1908	19.1	New Zealand*	22.2	3.2	59.4	New Zealand*	50.5	8.9
1909	18.9	New Zealand*	21.7	2.8	60.3	New Zealand*	51.8	8.5
1910	18.4	New Zealand*	21.6	3.2	59.9	New Zealand*	52.4	7.5
1911	17.9	New Zealand*	21.9	4.1	60.4	New Zealand*	51.3	9.1
1912	17.4	New Zealand*	21.1	3.7	61.6	New Zealand*	53.2	8.4
1913	18.0	New Zealand*	21.2	3.2	60.3	New Zealand*	53.1	7.2

1914	17.6	New Zealand*	21.1	3.5	60.6	New Zealand*	53.2	7.4
1915	17.9	New Zealand*	21.3	3.4	61.3	New Zealand*	51.3	10.0
1916	18.7	New Zealand*	21.4	2.7	60.0	New Zealand*	51.0	9.0
1917	17.6	New Zealand*	21.2	3.6	61.3	New Zealand*	50.6	10.6
1918	20.1	Finland	22.8	2.7	55.2	Denmark	44.1	11.0
1919	17.1	New Zealand*	21.6	4.4	61.7	New Zealand*	51.4	10.3
1920	18.0	New Zealand*	21.3	3.4	60.2	New Zealand*	53.2	7.0
1921	17.5	New Zealand*	20.2	2.8	62.4	New Zealand*	55.8	6.6
1922	16.7	New Zealand*	19.7	3.0	63.0	New Zealand*	56.1	6.9
1923	16.5	New Zealand*	19.5	2.9	62.5	New Zealand*	57.1	5.4
1924	16.5	New Zealand*	19.5	3.0	63.6	New Zealand*	56.8	6.8
1925	16.2	New Zealand*	19.2	3.1	63.9	New Zealand*	57.6	6.3
1926	16.0	New Zealand*	19.1	3.1	63.3	New Zealand*	57.8	5.5
1927	16.0	New Zealand*	19.2	3.1	64.1	New Zealand*	57.6	6.6
1928	16.3	New Zealand*	18.9	2.6	64.1	New Zealand*	58.3	5.8
1929	15.9	New Zealand*	19.0	3.1	63.7	New Zealand*	57.3	6.4
1930	15.7	New Zealand*	18.8	3.1	64.3	New Zealand*	58.8	5.5
1931	15.7	New Zealand*	18.3	2.6	64.9	New Zealand*	59.1	5.8
1932	15.0	New Zealand*	18.1	3.2	66.4	New Zealand*	59.7	6.6
1933	15.1	New Zealand*	18.0	2.9	66.2	New Zealand*	60.1	6.1
1934	14.9	New Zealand*	17.9	3.0	65.9	Netherlands	60.5	5.4
1935	15.0	New Zealand*	17.8	2.8	66.4	New Zealand*	60.3	6.2
1936	15.0	Netherlands	17.7	2.7	66.1	Netherlands	60.3	5.8
1937	14.7	Netherlands	17.6	2.9	66.2	Netherlands	60.5	5.7
1938	14.8	Netherlands	17.4	2.6	66.5	Netherlands	61.1	5.5
1939	14.2	Netherlands	16.9	2.7	66.9	Netherlands	61.4	5.5
1940	14.8	New Zealand*	17.9	3.1	66.1	New Zealand*	58.6	7.5
1941	14.7	New Zealand*	18.1	3.4	65.8	New Zealand*	58.2	7.5
1942	14.7	New Zealand*	17.9	3.2	67.6	Sweden	59.5	8.0
1943	14.9	New Zealand*	18.0	3.1	67.3	Sweden	59.7	7.6
1944	14.6	New Zealand*	18.2	3.7	66.3	Australia	58.7	7.6
1945	14.2	New Zealand*	17.8	3.6	67.2	Sweden	60.4	6.8
1946	13.8	Sweden	16.7	2.9	68.3	Sweden	62.8	5.5
1947	13.4	Sweden	16.5	3.0	68.3	Norway	62.7	5.6
1948	13.4	Sweden	16.2	2.8	69.7	Netherlands	63.6	6.1
1949	13.1	Sweden	15.8	2.6	70.0	Norway	63.8	6.2
1950	12.7	Sweden	15.5	2.8	70.3	Netherlands	64.3	6.0
1951	12.6	Sweden	15.2	2.5	70.8	Norway	64.6	6.2
1952	12.6	Sweden	14.9	2.3	71.0	Norway	65.4	5.6
1953	12.6	Sweden	14.6	2.0	71.2	Norway	65.7	5.5
1954	12.4	Sweden	14.4	2.0	71.3	Norway	66.3	5.0
1955	12.3	Sweden	14.4	2.0	71.5	Norway	66.5	5.0
1956	12.3	Netherlands	14.0	1.8	71.5	Iceland	66.5	5.0
1957	12.3	Sweden	14.1	1.9	71.7	Iceland	66.4	5.4
1958	12.0	Sweden	14.1	2.1	71.5	Sweden	67.0	4.5
1959	12.1	Sweden	14.1	2.0	71.6	Sweden	66.8	4.7
1960	12.0	Sweden	13.8	1.8	72.5	Iceland	67.1	5.4
1961	12.0	Sweden	13.9	1.9	71.6	Sweden	67.2	4.4
1962	11.9	Sweden	13.6	1.7	71.4	Iceland	67.2	4.2
1963	11.9	Sweden	13.6	1.7	71.5	Sweden	67.3	4.2
1964	12.0	Sweden	13.5	1.6	71.6	Sweden	67.7	3.9
1965	11.8	Sweden	13.3	1.6	71.7	Sweden	67.7	4.0
1966	11.8	Sweden	13.3	1.5	71.9	Sweden	67.8	4.1
1967	11.8	Sweden	13.3	1.5	71.9	Sweden	68.0	3.9
1968	11.8	Sweden	13.1	1.3	71.7	Sweden	67.9	3.9
1969	11.8	Sweden	13.1	1.3	71.7	Sweden	67.7	4.1
1970	11.9	Sweden	13.5	1.5	72.2	Sweden	67.6	4.6
1971	11.9	Sweden	13.4	1.5	72.0	Sweden	67.7	4.2
1972	11.9	Sweden	13.3	1.4	72.1	Iceland	68.1	4.1
1973	11.6	Sweden	13.2	1.6	72.2	Sweden	68.1	4.0
1974	11.6	Japan	13.2	1.6	72.2	Sweden	68.3	3.9
1975	11.5	Japan	13.2	1.6	72.2	Iceland	68.2	4.0
1976	11.4	Japan	13.0	1.6	73.7	Iceland	68.4	5.3
1977	11.4	Japan	13.1	1.6	73.2	Iceland	68.6	4.5
1978	11.4	Japan	13.0	1.6	73.7	Iceland	68.7	4.9
1979	11.4	Japan	13.0	1.6	74.0	Iceland	68.9	5.1
1980	11.2	Japan	12.8	1.6	73.4	Iceland	68.9	4.5
1981	11.1	Japan	12.8	1.6	73.8	Japan	69.1	4.7
1982	11.2	Japan	12.7	1.5	74.5	Iceland	69.5	5.1
1983	11.1	Sweden	12.6	1.5	74.2	Japan	69.6	4.7
1984	11.1	Japan	12.6	1.5	74.7	Iceland	69.8	4.9
1985	11.0	Japan	12.4	1.4	74.9	Japan	69.9	4.9
1986	11.0	Ireland	12.3	1.3	75.4	Iceland	70.4	5.0
1987	11.0	Japan	12.3	1.4	75.6	Japan	70.6	5.0
1988	10.8	Japan	12.3	1.5	75.6	Japan	70.7	4.9
1989	10.8	Iceland	12.4	1.5	76.1	Iceland	70.8	5.4
1990	10.8	Japan	12.3	1.6	75.9	Japan	70.8	5.2
1991	10.8	Japan	12.4	1.6	76.2	Japan	70.8	5.4
1992	10.7	Sweden	12.4	1.7	76.7	Iceland	70.9	5.8

1993	10.5	Sweden	12.3	1.8	77.0	Iceland	70.8	6.2
1994	10.6	Sweden	12.3	1.7	77.1	Iceland	71.0	6.1
1995	10.4	Sweden	12.3	1.9	76.4	Japan	71.1	5.3
1996	10.3	Sweden	12.1	1.8	77.0	Japan	71.5	5.5
1997	10.3	Sweden	12.1	1.8	77.2	Japan	71.9	5.3
1998	10.0	Iceland	12.0	2.0	77.7	Iceland	72.1	5.5
1999	10.1	Sweden	11.9	1.8	77.4	Iceland	72.3	5.1
2000	10.1	Sweden	11.9	1.8	77.9	Iceland	72.7	5.1
2001	10.1	Sweden	11.8	1.7	78.3	Iceland	73.2	5.1
2002	10.0	Sweden	11.8	1.8	78.5	Iceland	73.3	5.2
2003	9.6	Iceland	11.6	2.1	79.5	Iceland	73.6	5.9
2004	9.8	Iceland	11.7	1.8	78.9	Iceland	74.0	4.9
2005	9.7	Iceland	11.6	1.9	79.5	Iceland	74.1	5.3
2006	9.9	Sweden	11.6	1.7	79.4	Iceland	74.5	4.9
2007	9.7	Iceland	11.5	1.8	79.4	Iceland	74.5	4.9
2008	10.5	West Germany	11.6	1.1	79.3	Japan	74.7	4.6

Females

Year	Record $e^{\dagger}$	Country	Average $e^{\dagger}$	Difference	Record e_0	Country	Average e_0	Difference
1840	23.6	Sweden	24.9	1.3	46.1	Sweden	43.2	2.9
1841	23.6	Sweden	25.1	1.5	47.2	Sweden	43.8	3.4
1842	24.3	Sweden	25.2	0.9	45.0	Sweden	43.0	2.0
1843	23.8	Sweden	25.0	1.2	45.1	Denmark	43.5	1.6
1844	23.7	Sweden	24.8	1.1	46.9	Sweden	44.4	2.5
1845	23.5	Sweden	24.9	1.4	48.5	Sweden	45.2	3.3
1846	24.4	Sweden	25.4	0.9	49.7	Norway	43.5	6.2
1847	24.5	Sweden	25.1	0.6	46.1	Norway	42.0	4.1
1848	23.1	Sweden	24.9	1.9	47.3	Sweden	43.6	3.7
1849	23.2	Norway	24.8	1.6	49.8	Norway	42.6	7.2
1850	23.2	Norway	24.6	1.3	51.3	Norway	46.3	5.0
1851	23.3	Norway	24.7	1.4	51.5	Norway	45.7	5.8
1852	23.9	Norway	25.0	1.2	49.9	Norway	44.4	5.6
1853	23.5	Norway	24.7	1.2	49.3	Norway	43.2	6.1
1854	22.8	Norway	24.7	1.9	53.3	Norway	44.7	8.6
1855	22.5	Norway	24.0	1.5	52.3	Norway	45.1	7.1
1856	23.3	Norway	24.7	1.4	51.9	Norway	45.9	6.0
1857	23.1	Norway	25.2	2.2	51.6	Norway	42.9	8.7
1858	23.0	Norway	25.2	2.2	53.1	Norway	43.7	9.4
1859	24.0	Norway	25.3	1.4	51.3	Norway	44.1	7.1
1860	23.2	Sweden	24.4	1.1	51.3	Norway	47.1	4.2
1861	23.6	Denmark	25.0	1.4	49.0	Denmark	45.8	3.2
1862	23.9	Denmark	25.4	1.5	48.5	Denmark	45.0	3.4
1863	24.0	Denmark	25.2	1.2	48.5	Denmark	45.5	3.0
1864	24.0	Norway	25.0	1.0	50.0	Norway	44.3	5.6
1865	24.0	Norway	25.3	1.3	51.9	Norway	44.6	7.3
1866	23.6	Norway	25.0	1.4	51.5	Norway	45.2	6.3
1867	23.2	Sweden	24.4	1.2	49.5	Norway	46.1	3.4
1868	24.6	Norway	25.2	0.6	48.9	Norway	45.0	4.0
1869	23.7	Norway	25.0	1.3	51.0	Norway	45.1	5.9
1870	23.0	Norway	24.5	1.5	52.6	Norway	45.4	7.1
1871	22.7	Sweden	24.7	2.0	51.4	Norway	43.0	8.4
1872	23.1	Sweden	24.8	1.7	51.9	Sweden	46.3	5.7
1873	23.7	Sweden	24.6	0.9	51.2	Norway	46.4	4.8
1874	23.9	Denmark	24.8	0.9	49.2	Norway	45.7	3.5
1875	24.2	Norway	24.8	0.6	49.2	Norway	44.6	4.5
1876	24.6	Engl. and Wales	25.1	0.5	48.3	Norway	45.4	2.9
1877	24.2	Engl. and Wales	24.8	0.6	51.2	Norway	46.8	4.4
1878	23.6	Norway	25.0	1.4	53.2	Norway	45.7	7.5
1879	22.9	Norway	24.3	1.3	54.4	Norway	47.1	7.3
1880	23.1	Norway	24.9	1.8	53.3	Norway	45.3	8.0
1881	23.6	Norway	24.6	1.0	51.9	Norway	46.2	5.6
1882	23.5	Switzerland	24.9	1.4	50.1	Sweden	46.2	3.9
1883	23.1	Switzerland	24.5	1.4	50.7	Norway	46.8	3.9
1884	23.2	Switzerland	24.7	1.4	52.0	Norway	46.7	5.3
1885	23.3	Switzerland	24.3	1.0	52.3	Norway	47.2	5.1
1886	23.2	Switzerland	24.5	1.3	52.9	Norway	47.0	5.9
1887	22.8	Switzerland	24.1	1.3	52.9	Sweden	48.2	4.7
1888	22.5	Switzerland	23.9	1.4	53.5	Sweden	48.1	5.4
1889	22.8	Sweden	24.3	1.5	53.4	Sweden	48.0	5.4
1890	22.6	Switzerland	24.2	1.6	51.8	Sweden	47.1	4.6
1891	23.1	Switzerland	24.0	0.9	52.5	Sweden	47.0	5.5
1892	22.2	Switzerland	23.8	1.6	51.8	Sweden	47.2	4.7
1893	22.4	Switzerland	24.1	1.7	53.3	Norway	47.7	5.6
1894	22.6	Switzerland	23.7	1.2	53.2	Sweden	49.3	3.9
1895	22.2	Sweden	23.4	1.2	55.4	Sweden	49.5	5.8
1896	21.8	Switzerland	23.2	1.5	55.9	Norway	51.1	4.8
1897	22.0	Switzerland	23.1	1.1	55.7	Norway	51.2	4.4
1898	21.9	Sweden	23.2	1.3	56.1	Sweden	51.0	5.0
1899	21.6	Switzerland	23.4	1.7	53.4	Norway	49.7	3.7

Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Font: 8 pt
Formatted: Pattern: Clear (Gray-15%)
Formatted: Font: Italic
Formatted: Font: Italic
Formatted: Font: Italic
Formatted: Font: Italic
Formatted: Right, Pattern: Clear (Gray-15%)
Formatted: Font: 8 pt
Formatted Table

1900	21.7	Denmark	23.1	1.3	55.2	Norway	49.6	5.6
1901	21.7	Switzerland	23.2	1.4	56.5	Norway	50.8	5.7
1902	19.8	New Zealand*	22.2	2.4	59.3	New Zealand*	52.9	6.4
1903	19.9	New Zealand*	22.3	2.4	59.5	New Zealand*	53.2	6.3
1904	18.7	New Zealand*	22.1	3.4	61.8	New Zealand*	53.2	8.6
1905	17.9	New Zealand*	22.2	4.3	62.4	New Zealand*	52.7	9.8
1906	18.1	New Zealand*	22.1	4.0	62.8	New Zealand*	53.4	9.3
1907	19.4	New Zealand*	21.7	2.3	58.9	New Zealand*	53.4	5.5
1908	18.2	New Zealand*	21.8	3.6	62.5	New Zealand*	53.3	9.2
1909	18.8	New Zealand*	21.3	2.6	63.3	New Zealand*	54.7	8.6
1910	17.8	New Zealand*	21.2	3.4	62.5	New Zealand*	55.3	7.2
1911	17.5	New Zealand*	21.6	4.1	63.3	New Zealand*	54.3	9.0
1912	16.3	New Zealand*	20.7	4.4	64.4	New Zealand*	56.2	8.3
1913	17.5	New Zealand*	20.7	3.2	63.1	New Zealand*	56.2	7.0
1914	17.0	New Zealand*	20.6	3.5	64.2	New Zealand*	56.5	7.7
1915	17.3	New Zealand*	20.6	3.3	64.6	New Zealand*	55.8	8.8
1916	17.4	New Zealand*	20.6	3.2	63.9	New Zealand*	56.1	7.8
1917	16.9	New Zealand*	20.5	3.6	64.2	New Zealand*	56.0	8.2
1918	19.3	New Zealand*	23.0	3.7	57.4	New Zealand*	50.3	7.1
1919	16.4	New Zealand*	20.9	4.5	64.9	New Zealand*	55.2	9.6
1920	17.8	New Zealand*	20.9	3.1	62.4	New Zealand*	56.3	6.1
1921	16.6	New Zealand*	19.6	2.9	65.5	New Zealand*	59.1	6.5
1922	15.9	New Zealand*	19.1	3.2	65.4	New Zealand*	59.2	6.2
1923	15.9	New Zealand*	18.8	3.0	64.9	New Zealand*	60.3	4.7
1924	15.8	New Zealand*	18.9	3.2	66.6	New Zealand*	60.0	6.5
1925	15.8	New Zealand*	18.7	2.9	66.4	New Zealand*	60.7	5.7
1926	15.6	New Zealand*	18.6	3.0	66.1	New Zealand*	60.9	5.2
1927	15.5	New Zealand*	18.5	3.0	66.9	New Zealand*	60.7	6.2
1928	15.5	New Zealand*	18.4	2.9	66.8	New Zealand*	61.3	5.6
1929	15.0	New Zealand*	18.3	3.3	67.0	New Zealand*	60.4	6.6
1930	15.1	New Zealand*	18.1	3.0	67.3	New Zealand*	62.3	5.1
1931	14.7	New Zealand*	17.6	2.9	67.8	New Zealand*	62.3	5.5
1932	14.6	New Zealand*	17.5	2.9	68.3	New Zealand*	62.8	5.5
1933	14.5	New Zealand*	17.2	2.7	69.1	New Zealand*	63.5	5.5
1934	14.2	New Zealand*	17.1	2.9	68.5	New Zealand*	63.9	4.7
1935	14.4	New Zealand*	17.0	2.6	69.2	New Zealand*	63.7	5.5
1936	14.4	Netherlands	16.8	2.4	68.5	New Zealand*	64.1	4.4
1937	13.9	Netherlands	16.6	2.7	68.6	New Zealand*	64.1	4.5
1938	14.1	Netherlands	16.4	2.2	69.0	Norway	65.0	4.0
1939	13.6	Netherlands	15.9	2.2	69.3	New Zealand*	65.5	3.8
1940	13.7	New Zealand*	16.4	2.7	69.7	New Zealand*	64.2	5.5
1941	14.0	New Zealand*	16.6	2.6	69.2	New Zealand*	64.2	5.0
1942	13.5	New Zealand*	16.4	2.9	70.4	Sweden	65.0	5.4
1943	13.6	New Zealand*	16.5	2.9	70.1	Sweden	65.1	5.0
1944	13.9	New Zealand*	16.6	2.7	70.0	New Zealand*	65.0	5.1
1945	13.4	New Zealand*	16.4	3.0	70.5	Norway	65.5	4.9
1946	12.9	Sweden	15.6	2.7	71.7	Iceland	67.2	4.6
1947	12.5	Sweden	15.4	2.9	71.7	Norway	67.1	4.6
1948	12.2	Sweden	15.2	3.0	72.9	Norway	67.7	5.2
1949	11.9	Sweden	14.7	2.8	73.2	Iceland	67.7	5.5
1950	11.6	Sweden	14.4	2.9	73.5	Iceland	68.6	5.0
1951	11.5	Sweden	14.0	2.5	74.3	Norway	68.9	5.4
1952	11.4	Sweden	13.7	2.4	74.9	Iceland	69.7	5.2
1953	11.3	Sweden	13.4	2.1	75.1	Norway	70.2	4.8
1954	11.1	Sweden	13.1	2.1	75.6	Iceland	71.0	4.6
1955	11.2	Sweden	13.0	1.8	75.9	Iceland	71.2	4.7
1956	10.9	Netherlands	12.8	1.8	75.5	Norway	71.3	4.3
1957	10.9	Sweden	12.7	1.9	75.5	Norway	71.3	4.2
1958	10.8	Sweden	12.7	1.9	76.0	Iceland	72.0	3.9
1959	10.7	Sweden	12.6	1.8	75.8	Norway	72.0	3.7
1960	10.7	Sweden	12.2	1.5	75.9	Norway	72.4	3.5
1961	10.6	Sweden	12.3	1.7	76.2	Iceland	72.7	3.5
1962	10.5	Sweden	12.1	1.6	76.1	Iceland	72.7	3.4
1963	10.4	Norway	12.0	1.6	76.0	Iceland	73.0	3.1
1964	10.6	Norway	12.0	1.3	76.4	Iceland	73.5	2.9
1965	10.5	Sweden	11.8	1.3	76.5	Norway	73.5	3.0
1966	10.4	Sweden	11.8	1.4	76.7	Norway	73.7	3.0
1967	10.4	Sweden	11.7	1.3	76.9	Norway	74.0	2.9
1968	10.4	Sweden	11.5	1.1	76.8	Norway	73.9	2.9
1969	10.4	Sweden	11.6	1.2	76.7	Norway	73.9	2.7
1970	10.0	Iceland	11.7	1.6	77.3	Norway	74.2	3.1
1971	10.3	Norway	11.6	1.3	77.4	Sweden	74.5	2.9
1972	10.2	Norway	11.5	1.3	77.5	Sweden	74.8	2.8
1973	10.1	Norway	11.4	1.3	77.7	Sweden	74.9	2.8
1974	10.1	Norway	11.4	1.3	77.9	Norway	75.2	2.7
1975	10.1	Norway	11.4	1.2	78.7	Iceland	75.3	3.4
1976	10.1	Japan	11.2	1.1	79.9	Iceland	75.5	4.4
1977	10.0	Japan	11.2	1.2	79.2	Iceland	75.8	3.4
1978	10.0	Japan	11.2	1.2	79.3	Iceland	76.0	3.3

1979	9.9	Norway	11.2	1.3	79.4	Iceland	76.2	3.2
1980	9.7	Japan	11.1	1.3	80.1	Iceland	76.1	4.0
1981	9.7	Japan	11.0	1.3	79.6	Iceland	76.4	3.2
1982	9.7	Japan	11.0	1.3	79.7	Japan	76.6	3.1
1983	9.6	Japan	10.9	1.3	80.4	Iceland	76.7	3.7
1984	9.6	Japan	10.9	1.3	80.3	Japan	76.9	3.3
1985	9.5	Japan	10.7	1.2	80.5	Japan	76.9	3.6
1986	9.5	Japan	10.7	1.2	81.0	Japan	77.3	3.7
1987	9.5	Japan	10.7	1.2	81.4	Japan	77.4	4.0
1988	9.3	Japan	10.6	1.3	81.3	Japan	77.6	3.8
1989	9.4	Japan	10.6	1.2	81.8	Japan	77.7	4.1
1990	9.3	Japan	10.6	1.4	81.9	Japan	77.8	4.1
1991	9.3	Japan	10.6	1.3	82.2	Japan	78.0	4.2
1992	9.4	Japan	10.6	1.3	82.3	Japan	78.2	4.1
1993	9.4	Japan	10.5	1.2	82.4	Japan	78.0	4.4
1994	9.3	Japan	10.6	1.3	82.9	Japan	78.3	4.6
1995	9.4	Japan	10.6	1.2	82.8	Japan	78.4	4.4
1996	9.3	Finland	10.4	1.1	83.5	Japan	78.6	4.9
1997	9.4	Spain	10.3	1.0	83.8	Japan	78.9	4.9
1998	9.2	Spain	10.3	1.1	84.0	Japan	79.1	4.8
1999	9.1	Spain	10.2	1.1	84.0	Japan	79.2	4.8
2000	9.2	Spain	10.2	1.0	84.6	Japan	79.5	5.1
2001	9.2	Spain	10.1	1.0	84.9	Japan	79.8	5.1
2002	9.0	Spain	10.1	1.0	85.2	Japan	79.9	5.3
2003	8.9	Spain	10.0	1.0	85.3	Japan	80.1	5.3
2004	9.0	Spain	10.0	1.0	85.6	Japan	80.6	5.0
2005	8.8	Spain	9.9	1.1	85.5	Japan	80.7	4.8
2006	8.9	Spain	9.8	1.0	85.8	Japan	80.9	4.8
2007*	8.9	Portugal	9.7	0.8	86.0	Japan	81.1	4.8
2008*	8.9	Austria	9.6	0.6	86.0	Japan	81.4	4.6

* The New Zealand population includes only the non-Maori population

Table S3: The record and average life disparity, $e^{\dagger}$ and life expectancy e_0 for each year, based on data from the Human Mortality Database (Table S1).

Formatted: Font: 8 pt

Formatted: Font: 8 pt

Formatted: Font: Italic

Formatted: Superscript

Formatted: Font: Italic

Formatted: Indent: Left: 0 pt, First line: 0 pt

Formatted: Subscript

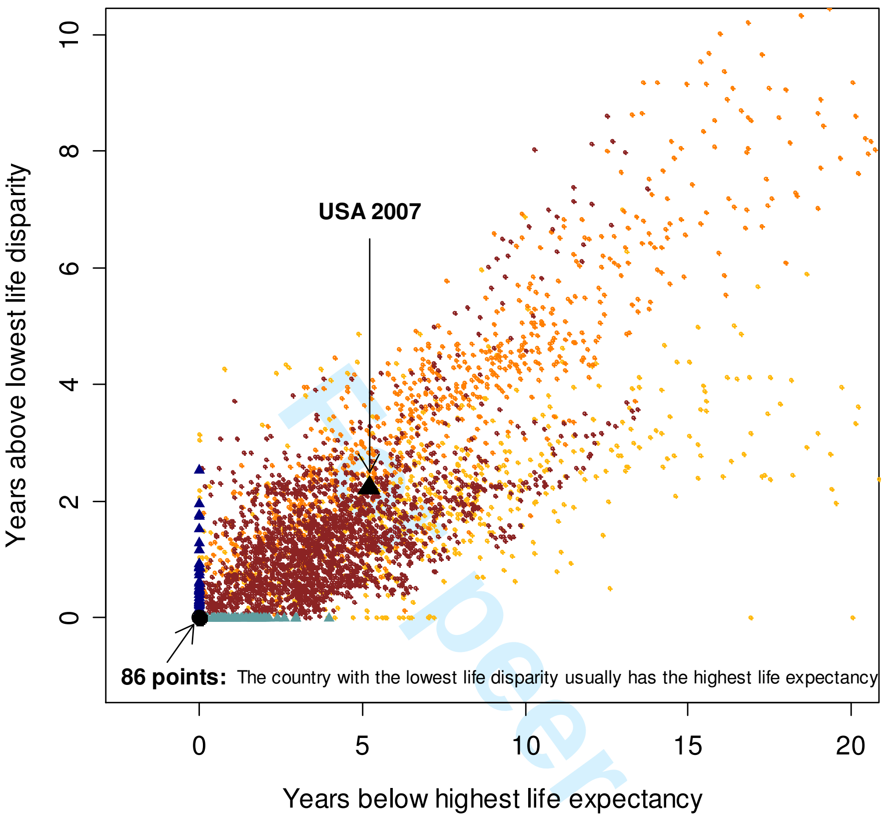

Fig. S1: The association between life disparity in a specific year and life expectancy for females in that year for the 40 countries and regions in the Human Mortality Database, 1840-2009 (Table S1). The correlation coefficient between them is 0.75 (95% confidence interval 0.73 to 0.76). The black triangle represents the United States in 2007: the U.S. had a female life expectancy 5.2 years lower than the international record in 2006 and a life disparity 2.2 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 86 holders of record life expectancy also enjoyed the lowest life disparity.

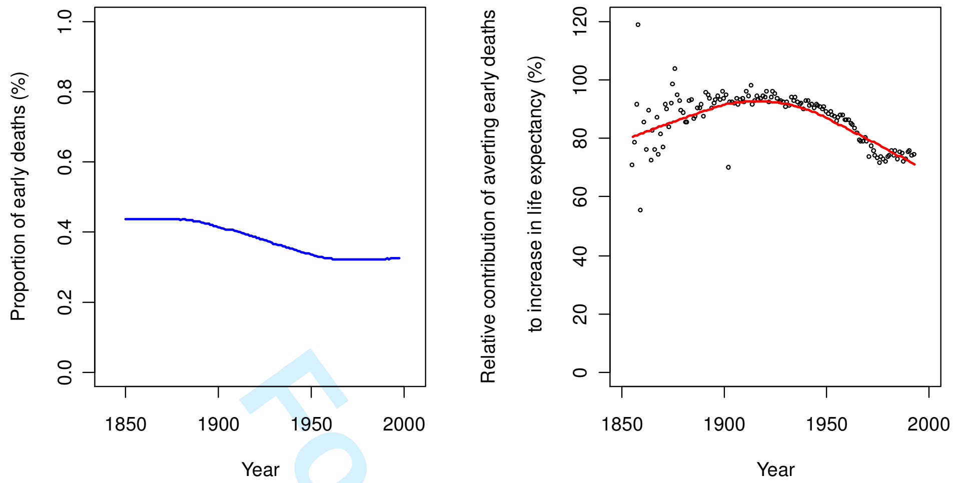

Figure S2: The left panel expresses early deaths as a proportion of all deaths, smoothed by 20-year averages. The right panel displays the 30-year moving average of the relative contribution of averting early deaths to the increase in life expectancy, with the red line marking the trend. The data pertain to females, 1840-2009, all 40 countries and regions of the HMD.

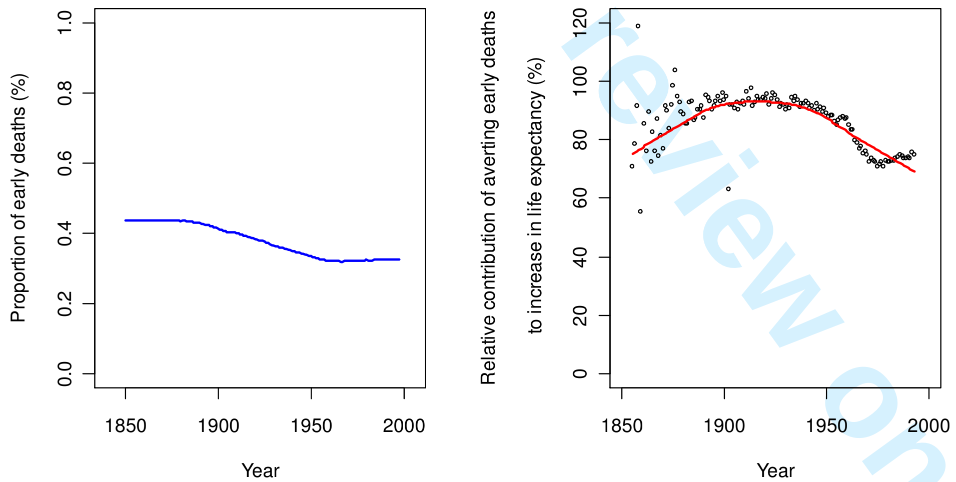

Figure S3: To show that the trends in Figure S2 above are not due to compositional change from new entrants into our dataset, we plotted the two relationships using only the eleven countries for which we had over 100 years of data (see Table S1).

The relationship between life expectancy and life disparity: comparing leaders and laggards

In Figure 3 we showed that reaching a level of life expectancy later was only sometimes associated with lower life disparity conditional upon survival to age 15. More often no clear relationship could be found.

Given the high correlation between life expectancy and life disparity, an interesting question is whether laggards in life expectancy at birth also have similar levels of life disparity to the leaders at the same level of life expectancy. The answer, seen in Figure S4, is yes. Thus while leaders are the first to reduce premature mortality, thereby reducing life disparity, laggards on average follow with similar reductions in life disparity alongside life expectancy increases.

Formatted: Font: Not Bold

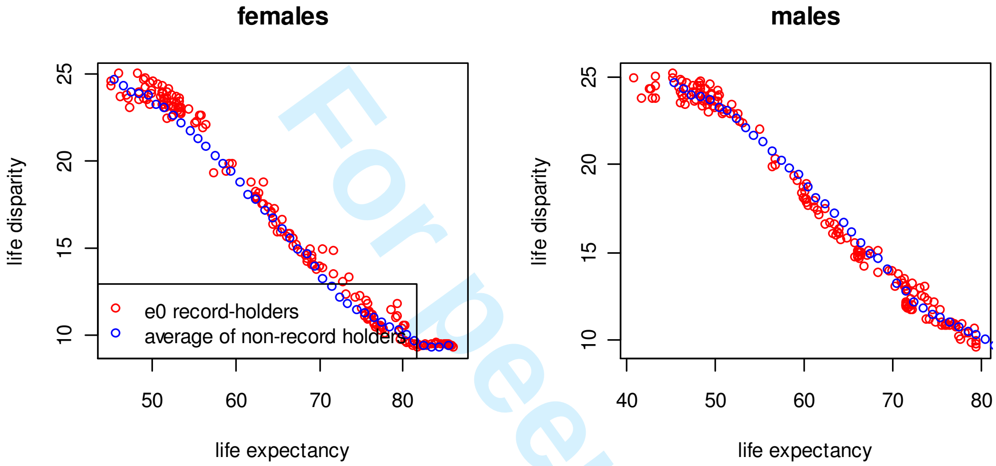

Figure S4: A comparison of the level of life disparity between (1) record-holders of life expectancy and (2) all other countries (averaged) once they had reached certain life expectancy levels (taken to be one year intervals).

Formatted: Font: (Default) Times New Roman, 12 pt, Bold

Formatted: Font: Bold

Formatted: Font: (Default) Times New Roman, 12 pt

Alternative calculations using the AID measure

Some concern might be raised about whether artefactual correlations are present in our findings since calculation of life disparity involves prior knowledge of life expectancy. We showed the high correlation between life disparity and other measures of lifespan variation in Table 2 of the supplementary material. Some of these other measures do not contain life expectancy in their formulation. To be sure that our results were robust to other measures, we ran our analysis with an alternative measure of lifespan variation, the absolute inter-individual difference (AID). While AID and life disparity are highly correlated, AID tends to be more sensitive to mortality change at younger ages than life disparity.[S7]

The AID is an alternative measure of lifespan variation that is related to the well-known Gini coefficient of inequality. There are many equivalent formulations to the AID, but the Kendall and Stuart definition is the most helpful for understanding the nature of the statistic, which essentially measures the average absolute distance in years between each pair of individuals' age at death (length of life) in the population.[S14] From the life table, it can be calculated as follows:

Deleted: [S13]

$$AID = \frac{1}{2}\int_0^{\omega}\int_0^{\omega}|x-y|f(x)f(y)dxdy \quad (1)$$

where $|x-y|$ is the absolute value of the distance in years between age x and age y, and f(x) and f(y) are the probabilities of death at ages x and y respectively.

Using the AID measure, the country with the highest life expectancy also had the lowest AID 74 times for females (Figure S5), and 67 times for males (Figure S6) out of 170 years. Differences in this relationship between the two measures were mostly owing to differences in historical populations, especially during war, famine and epidemic years, when certain countries had qualitatively different age at death distributions from other countries.

Deleted: S3

Deleted: S4

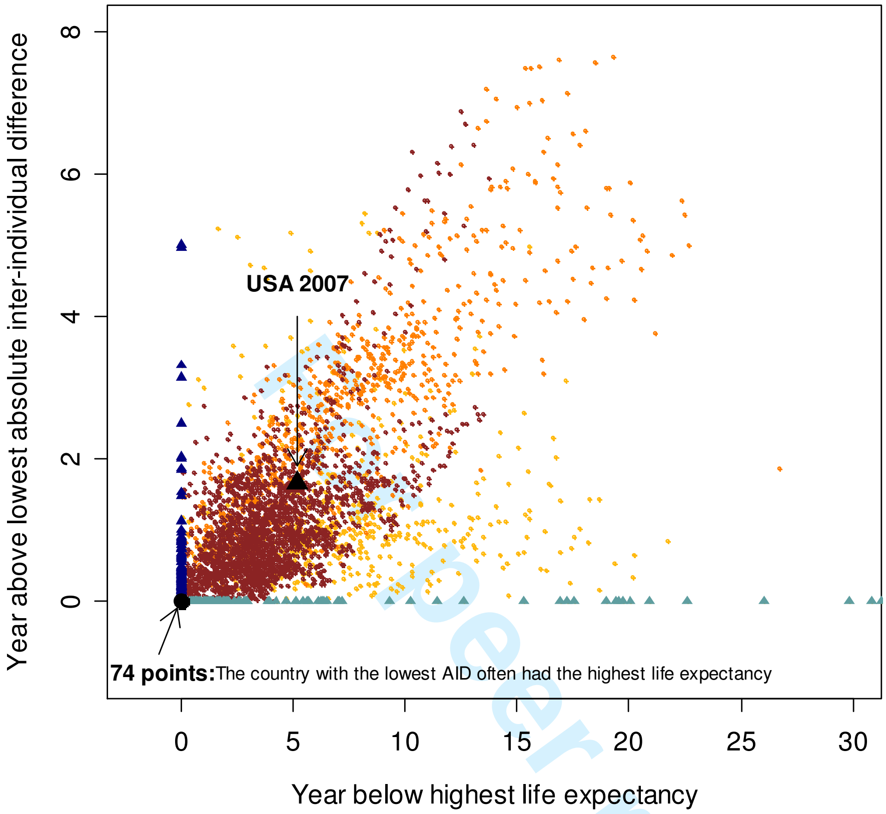

Figure S5: Alternative calculations using the AID measure, females. The correlation coefficient between them is 0.60 (0.58 to 0.62). The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year.

Deleted: S4

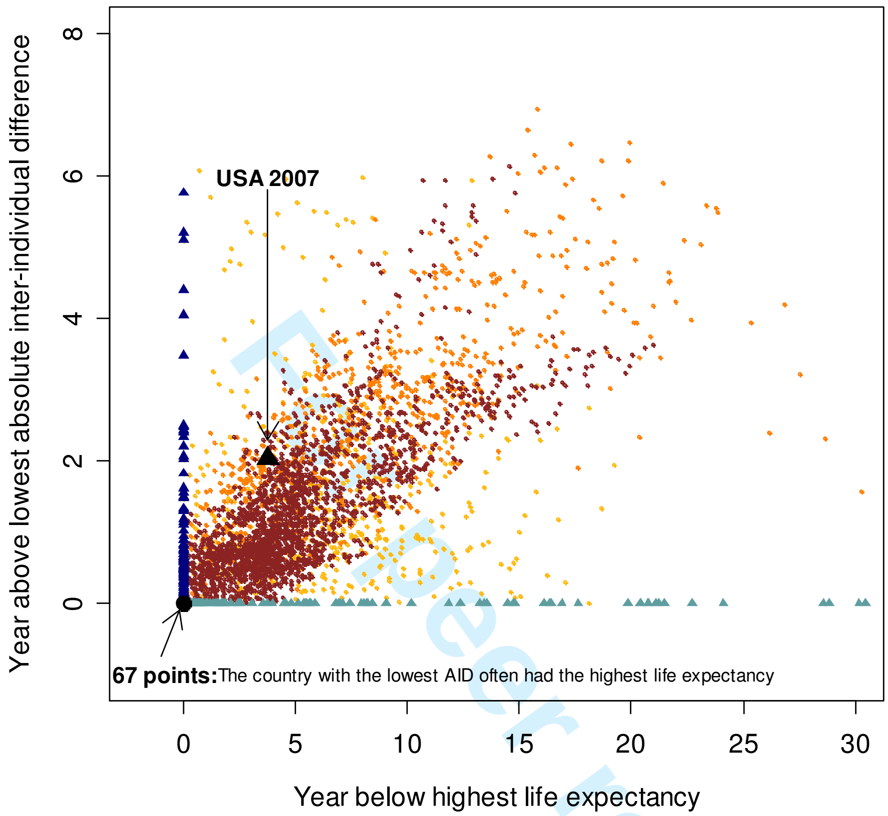

Figure S6: Alternative calculations using the AID measure, males. The correlation coefficient between them is 0.62 (0.60 to 0.64). The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year.

Deleted: S5

Supplementary References:

S1. Greville TNE. Comments on Mary Dempsey's article on decline in Tuberculosis: the death rate fails to tell the entire story. *Am Rev Tuberc* 1948;57:417-19.

S2. Keyfitz N, Golini A. Mortality comparisons: the male-female ratio. *Genus* 1975;31:1-34.

S3. Keyfitz N. Applied mathematical demography. 1st ed. New York: Wiley; 1977.

S4. Mitra S. A Short Note on the Taeuber Paradox. *Demography* 1978;15:621-23.

S5. Goldman N, Lord G. A New Look at Entropy and the Life Table. *Demography* 1986;23:275-82.

S6. Vaupel JW. How Change in Age-Specific Mortality Affects Life Expectancy. *Popul Stud* 1986;40:147-57.

S7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* 2011;48:211-239.

Deleted: in press.

S8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.

S9. Vaupel JW, Canudas Romo V. Decomposing Change in Life Expectancy: A Bouquet of Formulas in Honor of Nathan Keyfitz's 90th Birthday. *Demography* 2003;40:201-16.

S10. Veugelers PJ, Kim AL, Guernsey JR. Inequalities in health. Analytic approaches based on life expectancy and suitable for small area comparisons *J Epidemiol Community Health* 2000;54:375-380

Deleted: S9

S11. Salomon JA, Mathers CD, Murray CJ, Ferguson B. Methods for life expectancy and healthy life expectancy uncertainty analysis. *Global Programme on Evidence for Health Policy Working Paper No. 10, World Health Organization* 2001.

Deleted: S10

S12. Silcocks PBS, Jenner DA, Reza R. Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities *J Epidemiol Community Health* 2001;55:38-43.

Deleted: S11

S13. Eayres D, Williams ES. Evaluation of methodologies for small area life expectancy estimation *J Epidemiol Community Health* 2004;58:243-249

Deleted: S12

S14. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-358.

Deleted: S13

Page 23: [1] Formatted	**vanraalte**	**5/12/2011 2:16:00 PM**
Pattern: Clear (Gray-15%)		
Page 23: [2] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [3] Change	**vanraalte**	**5/12/2011 2:15:00 PM**
Formatted Table		
Page 23: [4] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [5] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [6] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [7] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [8] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [9] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [10] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [11] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [12] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [13] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [14] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [15] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [16] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [17] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [18] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [19] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [20] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		
Page 23: [21] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**
Font: 8 pt		

Page 23: [22] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [23] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [24] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [25] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [26] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [27] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [28] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [29] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [30] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [31] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [32] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [33] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [34] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [35] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [36] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [37] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [38] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [39] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [40] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [41] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [42] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [43] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [44] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [45] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [46] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [47] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [48] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [49] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [50] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [51] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [52] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [53] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [54] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [55] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [56] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [57] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [58] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [59] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [60] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [61] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [62] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [63] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [64] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [65] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [66] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 23: [67] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [68] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [69] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [70] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [71] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [72] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [73] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [74] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [75] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [76] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [77] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [78] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [79] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [80] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [81] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [82] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [83] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [84] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [85] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [86] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [87] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [88] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [89] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [90] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [91] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [92] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [93] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [94] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [95] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [96] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [97] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [98] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [99] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [100] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [101] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [102] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [103] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [104] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [105] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [106] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [107] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [108] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [109] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [110] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [111] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [112] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [113] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [114] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [115] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [116] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [117] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [118] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [119] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [120] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [121] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [122] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [123] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [124] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [125] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [126] Formatted	**vanraalte**	**5/12/2011 2:08:00 PM**

Font: 8 pt

Page 24: [127] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [128] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [129] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [130] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [131] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [132] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [133] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [134] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 24: [135] Formatted	vanraalte	5/12/2011 2:08:00 PM

Font: 8 pt

Page 26: [136] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [136] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [137] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [137] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [138] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [138] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [139] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [139] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [140] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [140] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [141] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [141] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [142] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [142] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [143] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [143] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [144] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [144] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [145] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [145] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [146] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [146] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [147] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [147] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [148] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [148] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [149] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [149] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [150] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [150] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [151] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [151] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [152] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [152] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [153] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [153] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [154] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [154] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [155] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [155] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [156] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [156] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [157] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [157] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [158] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [158] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [159] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [159] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [160] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [160] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [161] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [161] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [162] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [162] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [163] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [163] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [164] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [164] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [165] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [165] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [166] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [166] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [167] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [167] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [168] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [168] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [169] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [169] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [170] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [170] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [171] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [171] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [172] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

Page 26: [172] Formatted	vanraalte	5/12/2011 2:10:00 PM

Font: 8 pt

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	Report numbers of outcome events or summary measures
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Life expectancy and disparity

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2011-000128.R2
Article Type:	Research
Date Submitted by the Author:	17-Jun-2011
Complete List of Authors:	Vaupel, James; Max Planck Institute for Demographic Research, Survival and Longevity Zhang, Zhen; Max Planck Institute for Demographic Research, Survival and Longevity van Raalte, Alyson; Max Planck Institute for Demographic Research, Survival and Longevity; Erasmus University Medical Centre, Public Health
Primary Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, BASIC SCIENCES

Life expectancy and disparity

James W Vaupel, Zhen Zhang, Alyson A van Raalte

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
James W Vaupel, Founding Director

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany
Zhen Zhang, Research Scientist

Max Planck Institute for Demographic Research, Konrad-Zuse Straße 1, 18057 Rostock, Germany and Department of Public Health, Erasmus MC, University Medical Centre Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands
Alyson A van Raalte, PhD student

Correspondence to: James W Vaupel jwv@demogr.mpg.de

Keywords: Premature death, lifespan variation, health progress, international comparisons of life expectancy, historical trends in mortality

Word Count - 2500 words

Deleted: 2280

ABSTRACT

- **objectives** – To determine the contribution of progress in averting premature deaths to the increase in life expectancy and the decline in lifespan variation.
- **design** - International comparison of national lifetable data from the Human Mortality Database
- **setting** – 40 developed countries and regions, 1840 to 2009
- **population** – Men and women of all ages
- **main outcome measure** – We use two summary measures of mortality: life expectancy and life disparity. Life disparity is a measure of how much lifespans differ among individuals. We define a death as premature if postponing it to a later age would decrease life disparity.
- **results** - In 89 of the 170 years from 1840 to 2009, the country with the highest male life expectancy had the lowest male life disparity. This was true in 86 years for female life expectancy and disparity. In all years, the top several life expectancy leaders were also the top life disparity leaders. Although only 38% of deaths were premature, fully 84% of the increase in life expectancy resulted from averting premature deaths. The reduction in life disparity resulted from reductions in early-life disparity, i.e., disparity caused by premature deaths; late-life disparity levels remained roughly constant.
- **conclusions** – The countries that have been the most successful in averting premature deaths have consistently been the life expectancy leaders. Greater longevity and greater equality of individuals' lifespans are not incompatible goals. Countries can achieve both by reducing premature deaths.

Article focus

- We examined the relationship between high life expectancy and low life disparity.
- We determined the relative importance of premature vs. late deaths in increasing life expectancy and reducing life disparity.
- We examined whether policies to increase life expectancy were compatible with those to reduce lifespan variation.

Key messages

- Most of the gains in life expectancy have come from reducing disparities in how long people live, by averting premature mortality.
- Progress in reducing death rates for people who live longer than average has had little effect on life disparity levels, and its contribution to life expectancy gains has been modest.
- The countries that have been most successful at reducing premature mortality enjoy the highest life expectancies and the greatest equality in individuals' lifespans.

Strengths and limitations

- We are the first to examine this issue using a large, comparable database of 40 developed countries from 1840 to 2009 containing 7056 lifetables.
- Our analysis was limited to countries with high enough quality data to be included in the database. Although this database contains high mortality lifetables from historic populations, it is unknown whether the patterns we observed would also be seen in contemporary emerging and developing countries.

Deleted: 6940

Introduction

The rise in life expectancy, from under 40 years in all areas of the world two centuries ago to over 80 years today in many developed countries, has fundamentally improved the human condition.[1 2] Equally significant and closely linked to the increase in life expectancy has been the reduction of differences among individuals in the age at death.[3-6] Even in the most egalitarian societies before the mid-19th century the fate of most newborns was to die young but a fortunate minority survived to old age. Death rates today in health leaders such as Japan, Spain and Sweden imply that three-quarters of babies will survive to celebrate their 75th birthdays.[2]

The negative correlation between high life expectancy and low lifespan variation has been investigated for several countries, including the United States,[4 6 7] England and Wales[7], Sweden[6] and Japan[6]. The correlation is strong but there are discrepancies. Some countries, notably the United States, have substantially greater lifespan dispersion than might be predicted from their high levels of life expectancy.[3-5]

Progress in reducing premature deaths reduces variation in lifespans, whereas progress in reducing deaths at older ages increases variation in lifespans. A recently-developed demographic formula permits ready determination of the ages at which deaths are premature.[8] We use this new formula and apply it to a large dataset on developed countries to gain a deeper understanding of the relationship between high life expectancy and low lifespan variation. We find that the countries that have been the most successful in reducing premature deaths, and consequently in reducing lifespan variation, have consistently been the life expectancy leaders.

Methods

Our calculations are based on all period lifetables of the Human Mortality Database (*HMD*), from 1840 to the most recent year available in the data set (7056 lifetables covering 170 years).[2] This is a freely available database with reliable, comparable data covering 40 countries and areas. (Table 1 in the Supplementary Appendix lists the countries or regions and years used in the analysis).

Deleted: .

We measure dispersion in age-at-death by the life disparity measure, $e^{\dagger}$ (technical description in the Supplementary Appendix).[8,9] Life disparity is defined as the average remaining life expectancy at the ages when death strikes; it is a measure of life years lost due to death. The more egalitarian the lifespan distribution is, the lower the life disparity. In the Swedish female life table for 2008 life expectancy reached 83 years; for those women who survived to age 83, remaining life expectancy was 7.5 additional years. Hence a death shortly after birth would contribute 83 years whereas a death at age 83 would contribute 7.5 years. The average of such values over the Swedish female population, weighted by the number of deaths at each age, gives a life disparity of 9. In 1840 life expectancy for Swedish women was only 46 and life disparity was 24. Over time, as deaths became concentrated at later ages, the average gap was reduced between the age at which a person died and the remaining lifespans of people who survived beyond this age.

Saving lives (i.e., averting deaths) at any age increases life expectancy. Lifespan disparity, on the other hand, narrows or widens depending on the balance between saving lives at 'early' ages, which compresses the distribution of lifespans, and saving lives at 'late' ages, which expands this distribution by increasing the average remaining life expectancy of survivors. Separating the two is a unique threshold age, $a^{\dagger}$, which is generally just below life expectancy. Henceforth, we refer to deaths occurring before the threshold age as 'premature deaths', while those occurring after this age are 'late deaths'. Thus 'premature' deaths according to our definition are defined relative to the mortality level of the population. This is in contrast to other definitions which use a fixed age, e.g. age 65: use of a fixed age is problematic over long periods of time. This new definition implies that deaths at surprisingly old ages can be premature deaths. In 2008 deaths up to age 82 were premature deaths for Swedish females (Table 1).

Deleted: sitting

Deleted: the

Deleted: upper

Deleted: limits that would seem arbitrary over the long sweep of time.

Deleted: T

The life disparity measure has the property that it can be additively decomposed at any age such that the components before and after this age sum to the total life disparity.[8] When it is decomposed at the threshold age, the components are defined as 'early-life disparity' and 'late-life disparity'.

While it is known that high life expectancy is associated with low lifespan variation, we wanted to establish whether life expectancy leaders had the most egalitarian lifespan distributions. For each sex, year, and for up to 40 countries depending on the year, we determined the male and female record high life expectancy and record low life disparity. We calculated how many fewer years of life expectancy and additional years of life disparity each country experienced compared with the record-holding country in that year.

We next investigated the relative importance of premature vs. late deaths in determining the relationship between high life expectancy and low life disparity. To do so, we calculated first the number of premature and late deaths as a proportion of all deaths, measured by 10-year averages across all countries and years. We then compared this to the respective contributions of averting premature and late deaths to increases in life expectancy,[8 9] using a 20-year moving average to smooth mortality trends over exceptional years of war, pandemics or famine (technical description in the Supplementary Appendix).

Finally, we ranked countries according to their life expectancy and life disparity for the latest year for which we had data.

Results

Populations with high life expectancy enjoy low life disparity. In 89 out of 170 years, holders of record life expectancy for males also enjoyed the lowest life disparity (fig 1). For females this happened 86 times (appendix fig 1 on bmjopen.bmj.com). More generally, the country with record life expectancy usually had an exceptionally low life disparity and visa versa. This is remarkable because life expectancy is a measure of the average length of life and life disparity is a measure of variation among individuals in the length of life. In principle the two measures could be unrelated to each other. The set of countries with the highest life expectancies could be completely different from the set of countries with the lowest life disparities, but it turns out that the two sets largely overlap.

The most successful countries increased life expectancy not because of a general decrease in mortality at all ages, but because of a decrease in premature mortality. Figure 2 shows that the reduction in life disparity—from around 25 years in 1840 to between 9 and 15 years at present—is overwhelmingly due to reductions in early-life disparity caused by tackling premature mortality. Although mortality rates at old ages have come down considerably (which might cause one to expect increases in late-life disparity), the shifting of the threshold age to higher ages has caused late-life disparity to stay roughly constant at around or just under five years.

For females since 1840, premature deaths have accounted for only 38 percent of all deaths, but fully 84 percent of the increase in life expectancy resulted from decreases in premature deaths (appendix fig 2 on bmj.com). During this time the threshold age rose considerably, rising from 47 for Swedish women in 1840 to 85 for Japanese women in 2009. Historically (and today in less developed countries) infants, children and younger adults suffered most premature deaths. In today's more developed countries, premature deaths have shifted primarily to older adults in their sixties and seventies. The rise in the threshold age is highly correlated with the rise in life expectancy: the correlation coefficient is 0.96 for males and 0.98 for females.

Table 1 displays the latest period life expectancy, threshold age and life disparity calculated for each country. In Russia life expectancy is extraordinarily low and life disparity is very high. In the United States, life expectancy is much longer than in Russia but short compared to other highly developed countries. Females in most Eastern European countries, and males in some of them, do better than the U.S. in life disparity and hence face more certainty in their lifetimes. In contrast Japanese females are remarkably successful. They hold the record for life expectancy, 86.4 years in the lifetable for 2009. Half of deaths occurred after age 88 and the most common age of death was 93: deaths up to age 85 were premature in the sense that averting such deaths would decrease life disparity.

Deleted: with countries of similar income per capita

Discussion

These findings make clear that the correlation between high life expectancy and low lifespan variation is due to progress in reducing premature mortality. The countries that have the highest life expectancy today are those who have been most successful at postponing the premature deaths that contribute to early-life disparity.

In addition to life disparity, several other measures of lifespan dispersion have been proposed.[3 4 6 10] We analyzed the extent to which our findings depend on our use of life disparity as our measure of lifespan variation. We calculated Pearson correlation coefficients between pairs of the more commonly used measures of lifespan variation, based on all male and female period life tables available from the Human Mortality Database (appendix table 1 on bmj.com). As shown in Table 2 of the Supplementary Material, these measures are highly correlated with each other. In particular, the correlation of life disparity with the other measures never falls below 0.966 for females and 0.940 for males. Hence life disparity can be viewed as a surrogate for the other measures. Although the various measures are highly correlated, they differ somewhat in their sensitivity to deaths at different ages in the lifespan distribution.[4 11] The use of an alternate measure of lifespan variation would result in some changes in the ranking of countries with similar life disparity levels, but the high correlation between measures implies that such changes would be minor.

Some researchers have examined whether lifespan variation above the adult modal age at death has changed with increased survivorship. These studies also tend to find a gradual decline in later life mortality variation.[10 12-14] Exploring the relationship between life disparity and compression around the modal age at death is a promising avenue for further research. More generally, whether expansion or compression of the lifespan distribution is observed over time can depend on the age range examined.[15-17] While being a life expectancy leader is associated with low life disparity when the entire lifetime is examined, this relationship might not hold for selected age ranges.

Reducing early life disparities helps people plan their less-uncertain lifetimes. A higher likelihood of surviving to old age makes savings more worthwhile, raises the value of individual and public investments in education and training, and increases the prevalence of long-term relationships. Hence, healthy longevity is a prime driver of a country's wealth and well-being.[18] While some degree of income inequality might create incentives to work harder, premature deaths bring little benefit and impose major costs.[19]

Moreover, equity in the capability to maintain good health is central to any larger concept of societal justice.[20] The tenet that everyone should be entitled to a long, healthy lifespan has gained support as mortality at younger ages has declined. Currently, rates of change for adult mortality vary more across countries than those for infants and children.[21] In Williams' concept of *fair innings*,[22] individuals dying early are "cheated" while those living beyond a "normal" lifespan are "living on borrowed time". Groups and areas with lower socioeconomic status account for a disproportionate share of lifespan variation:[3 4 7] this compounds the inequity of premature death.

If death rates continue to decline, most babies born in advanced nations today may live to enjoy their 100th birthday.[23] As we celebrate this progress in extending lives it is reasonable to question whether we ought to continue aiming for ever longer lives *on average* or to ensure that more individuals avoid premature death. Policymakers face a choice of where to target health care spending. Reducing life disparity would lead to health policies that prioritize early mortality and to social protection schemes designed to shield vulnerable individuals and groups. We are not the first to make this argument. Heath poignantly reasoned that if health care services were serious about reducing health inequality they should direct their attentions to reducing premature mortality—even if this meant reducing expensive medical treatments for the elderly.[24] The accompanying editorial in *BMJ* proclaimed that "premature deaths should be the priority for prevention".[25]

Russia, the U.S. and other laggards can learn much from research on the reasons why various countries (including Japan, France, Italy, Spain, Sweden and Switzerland) have been more successful in reducing premature deaths. The reasons involve health care, social policies, personal behavior (especially cigarette smoking and alcohol abuse), and the safety and salubriousness of the environment.[26-33] Genetic variation plays a modest role in determining variation in how long we live[34 35] and cannot account for the major declines in life disparity and increases in life expectancy or the large differences in life expectancy and disparity among countries.

Smits and Monden[5] recently showed that countries achieving some level of life expectancy earlier than others did so with higher levels of lifespan variation. This led them to conclude that "reducing inequality and gaining increases in life expectancy might be alternative goals that require different policy measures to be achieved". Our results differ because we examine differences between countries in lifespan variation for each year whereas they examine differences over time in lifespan variation within each country. These different set-ups can lead to different conclusions. In a study comparing the United States to England and Wales, reductions in circulatory diseases were causing most of the changes in lifespan variation over time (in each country) whereas differences in external mortality explained much of the difference in life disparity between countries at any given time.[7] As can be seen in Figure 3 the relationship between being pioneers in life expectancy and having high life disparity is weak, especially after 1960. We take issue with Smits and Monden's conclusion which our cross-sectional results do not support. Over the past 170 years, the country with the lowest life disparity most often had the highest life expectancy. Even today, the most egalitarian countries are all among the longest living.

The increase in life expectancy is given by the product of two factors—life disparity and the rate of progress in reducing age-specific death rates.[9] The lower life disparity is, the greater is the rate of progress needed to achieve an additional year of life expectancy. Consequently it might be thought that countries would aim for life expectancy increases by maintaining high levels of inequality in the lifespan distribution. The opposite is true (Figure 1). The reason is that the countries with long life expectancy have gained this victory by focusing on reductions in premature deaths—and reductions in premature deaths reduce life disparity. It is not a question of either long life or low disparity: countries can achieve both by averting premature deaths.

We thank A. Baudisch, J. R. Goldstein , E. Loichinger, J. Oeppen, V. M. Shkolnikov, K. W. Wachter and H. Wilkoszewski for helpful comments. We are grateful to V. Canudas-Romo, A. Leyland, and M. Murphy for reviewing the paper.

Contributors: JWV conceived the research idea and co-wrote the drafts, ZZ managed the data analysis and commented on the drafts, AvR contributed to data analysis and co-wrote the drafts.

Funding: We acknowledge support from the Max Planck Society and the U.S. National Institute on Aging (NIA P01-08761).

Competing interests: "All authors declare that the answer to the questions on your competing interest form are all No and therefore have nothing to declare"

Ethics approval was not required for this study.

References

1. Oeppen J, Vaupel JW. Broken Limits to Life Expectancy. *Science* 2002;296(5570):1029-1031.
2. Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org (data downloaded on 18/02/2011)
3. Edwards RD, Tuljapurkar S. Inequality in life spans and a new perspective on mortality convergence across industrialized countries. *Popul Dev Rev* 2005;31:645-74.
4. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-58.
5. Smits J, Monden C. Length of life inequality around the globe. *Soc SciMed* 2009;68:1114-236.
6. Wilmoth JR, Horiuchi S. Rectangularization Revisited: Variability of Age at Death within Human Populations. *Demography* 1999;36:475-95.
7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* 2011;48:211-239
8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.
9. Vaupel JW, Canudas Romo V. Decomposing Change in Life Expectancy: A Bouquet of Formulas in Honor of Nathan Keyfitz's 90th Birthday. *Demography* 2003;40:201-16.
10. Cheung SL, Robine JM, Tu EJ, Caselli G. Three dimensions of the survival curve: horizontalization, verticalization, and longevity extension. *Demography* 2005;42:243-58.
11. Anand S, Diderichsen F, Evans T, Shkolnikov V, Wirth M. Measuring Disparities in Health: Methods and Indicators. In: T. Evans MW, F. Diderichsen, A. Bhuiya, M. Wirth editor. *Challenging inequities in health: from ethics to action*. New York: Oxford University Press, 2001.
12. Thatcher AR, Cheung SLK, Horiuchi S, Robine J-M. The compression of deaths above the mode. *Demogr Res* 2010;22:505-538.
13. Cheung SL, Robine JM. Increase in common longevity and the compression of mortality: the case of Japan. *Popul Stud (Camb)* 2007;61:85-97.
14. Kannisto V. Mode and Dispersion of the Length of Life. *Population* 2001;13:159-171.
15. Robine J-M. Redefining the Stages of the Epidemiological Transition by a Study of the Dispersion of Life Spans: The Case of France. *Population* 2001;13:173-193.
16. Nusselder WJ, Mackenbach JP. Rectangularization of the survival curve in The Netherlands, 1950-1992. *Gerontologist* 1996;36(6):773-782.
17. Engelman M, Canudas-Romo V, Agree EM. The Implications of Increased Survivorship for Mortality Variation in Aging Populations. *Popul Dev Rev* 2010;36:511-539.
18. Bloom DE, Canning D. The Health and Wealth of Nations. *Science* 2000;287:1207-09.
19. Anand S. The concern for equity in health. *J Epidemiol Community Health* 2002;56:485-87.
20. Sen A. Why health equity? *Health Econ* 2002;11:659-66.
21. Rajaratnam JK, Marcus JR, Levin-Rector A, Chalupka AN, Wang H, Dwyer L, et al. Worldwide mortality in men and women aged 15-59 years from 1970 to 2010: a systematic analysis. *Lancet* 2010;375:1704-17.
22. Williams A. Intergenerational Equity: An Exploration of the Fair Innings Argument. *Health Econ* 1997;6:117-32.
23. Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. *Lancet* 2009;374:1196-1208.
24. Heath I. What do we want to die from? *BMJ* 2010;341:c3883.
25. Godlee F. Premature deaths should be the priority for prevention. *BMJ* 2010;341:c3946.
26. Doll R, Peto R, Boreham J, Sutherland I. Mortality in relation to smoking: 50 years' observations on male British doctors. *BMJ* 2004;328:1519.

Deleted: in press.¶

27. Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL. Selected major risk factors and global and regional burden of disease. *Lancet* 2002;360:1347-1360.
28. Kauhanen J, Kaplan GA, Goldberg DE, Salonen JT. Beer binging and mortality: results from the kuopio ischaemic heart disease risk factor study, a prospective population based study *BMJ* 1997;315:846.
29. Lundberg O, Yngwe MÅ, Stjärne MK, Elstad JI, Ferrarini T, Kangas O, et al. The role of welfare state principles and generosity in social policy programmes for public health: an international comparative study. *Lancet* 2008;372:1633-1640.
30. Marmot M, Friel S, Bell R, Houweling TAJ, Taylor S. Closing the gap in a generation: health equity through action on the social determinants of health. *Lancet* 2008;372:1661-1669.
31. Peto R, Boreham J, Lopez AD, Thun M, Heath C. Mortality from tobacco in developed countries: indirect estimation from national vital statistics. *Lancet* 1992;339:1268-1278.
32. Rehm J, Mathers C, Popova S, Thavorncharoensap M, Teerawattananon Y, Patra J. Global burden of disease and injury and economic cost attributable to alcohol use and alcohol-use disorders. *Lancet* 2009;373:2223-2233.
33. Whitehead M, Dahlgren G. Concepts and principles for tackling social inequities in health: Levelling up Part 1. *WHO, Copenhagen* 2007:1-45.
34. McGue M, Vaupel JW, Holm NV, Harvald B. Longevity is moderately heritable in a sample of Danish twins born 1870- 1880. *J Gerontol* 1993;48:237-44.
35. Herskind A, McGue M, Holm N, Sørensen T, Harvald B, Vaupel J. The heritability of human longevity: A population-based study of 2872 Danish twin pairs born 1870–1900. *Hum Genet* 1996;97:319-23.

Formatted: Danish

Tables and Figures

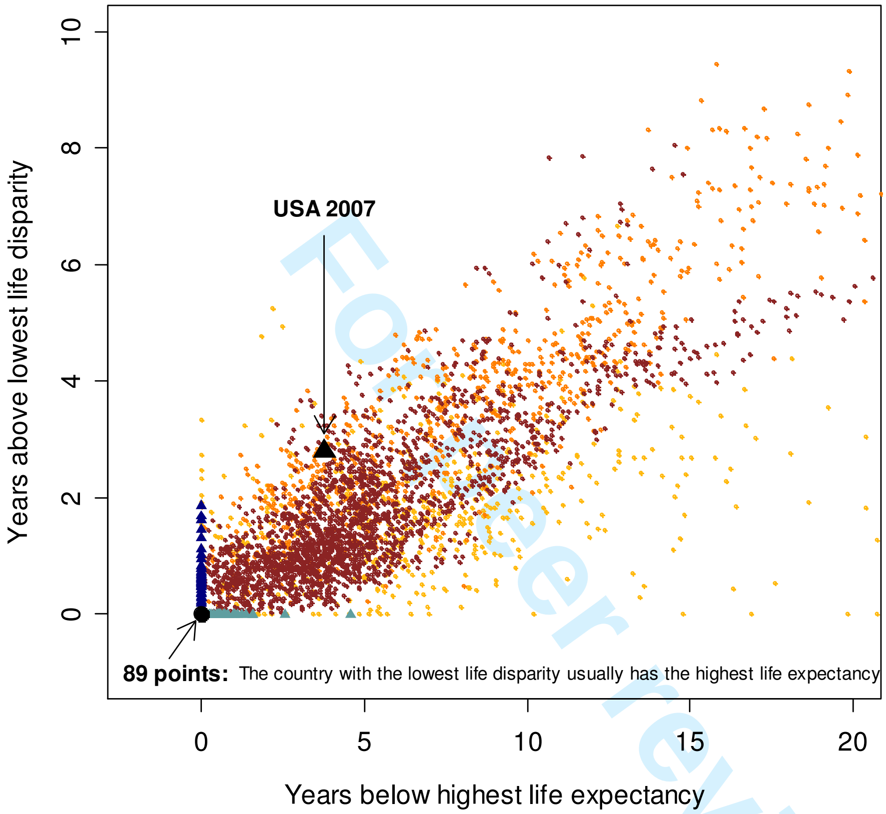

Fig 1: The association between life disparity in a specific year and life expectancy in that year for males in 40 countries and regions, 1840-2009 (Table 1 in the Supplementary Material). The correlation coefficient between them is 0.77 (95% confidence interval 0.76 to 0.78). The black triangle represents the United States in 2007: the U.S. had a male life expectancy 3.78 years lower than the international record in 2007 and a life disparity 2.8 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 89 holders of record life expectancy also enjoyed the lowest life disparity. The equivalent figure for females is presented as Fig 2 in the Supplementary Material.

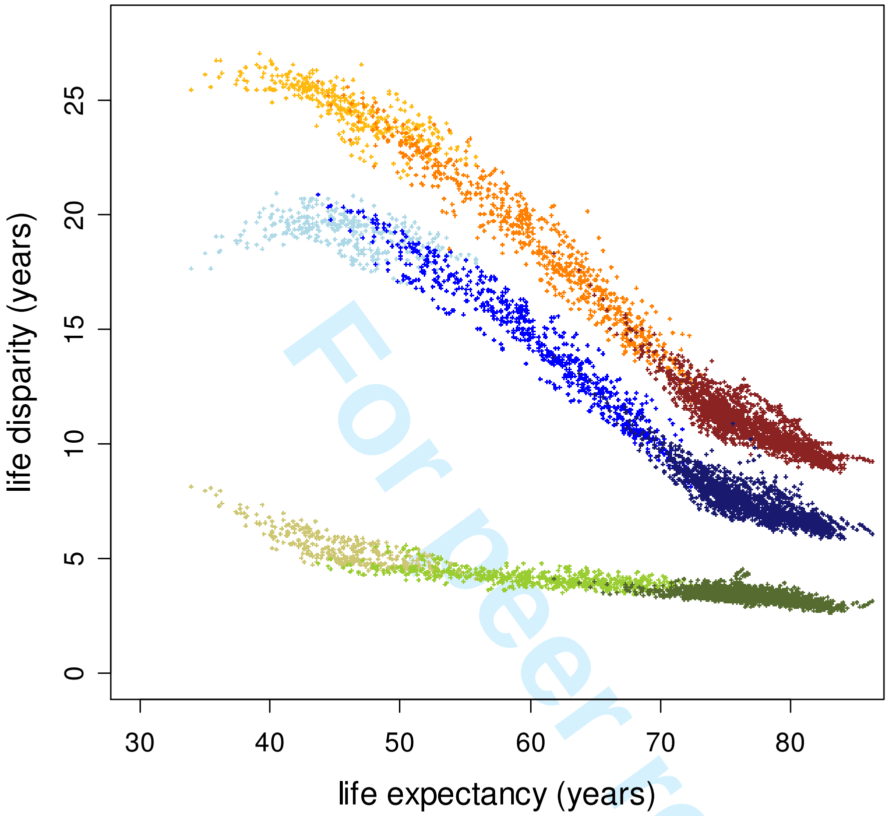

Fig 2: The relationship between total life disparity (red), early life disparity up to the threshold age (blue) and late life disparity after the threshold age (green). The darkest hues relate to data from 1950-2009, middle hues 1900-1949 and lightest hues 1840-1899. Total disparity is an additive function of early life disparity and late life disparity. Since 1840 the decrease in total life disparity has resulted from reductions in early life disparity. The correlation coefficient between early life disparity and total life disparity is 0.997 (0.997, 0.997). Late life disparity has remained remarkably constant at about 5 years across a wide range of life expectancies. Hence, according to this measure, there has been neither a marked compression nor expansion of mortality at advanced ages as life expectancy has increased. Data are for females from the 40 countries and regions of the Human Mortality Database (Table 1 in the Supplementary Material).

Deleted: The three curves can be fit by linear regression. The adjusted R^2 is .97 with slope -0.438 (95% confidence interval -0.440 to -0.435) for the red curve, 0.96 with slope -0.376 (-0.379, -0.373) for the blue curve, and 0.77 with slope -0.061 (-0.062, -0.060) for the green curve.

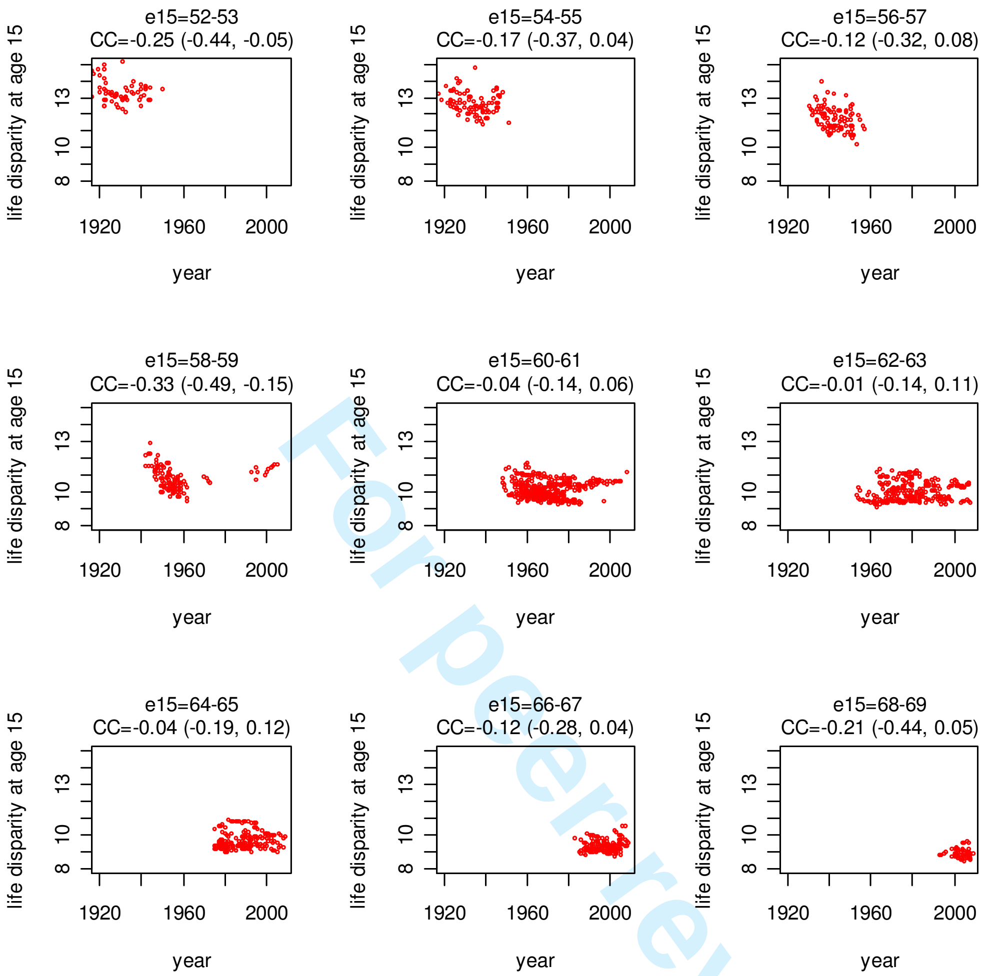

Fig 3: The relationship between remaining life expectancy at age 15 (e_{15}) and life disparity at age 15, according to the year in which e_{15} was first reached. Up until 1960 and for e_{15} from 54 to 59, the pioneers in first attaining a level of remaining life expectancy did so with higher levels of life disparity than the laggards. Since 1960 and at higher remaining life expectancies, the relationship between remaining life expectancy and life disparity at age 15 are not correlated. Ages 15 and over were examined to make the results comparable to those obtained by Smits and Monden.[5] Data are for females from the 40 countries and regions in the Human Mortality Database (Table 1 in the Supplementary Material).

Country or region	Females			Males		
	e_0	$e^\dagger$	$a^\dagger$	e_0	$e^\dagger$	$a^\dagger$
Japan	86.4 *(86.3, 86.4)*	9.2 *(9.1 ,9.2)*	85.3 *(85.3, 85.4)*	79.6 *(79.6, 79.6)*	10.6 *(10.6, 10.6)*	78.0 *(77.9, 78.0)*
France	84.4 *(84.3, 84.4)*	9.3 *(9.3, 9.4)*	83.8 *(83.7, 83.8)*	77.4 *(77.4, 77.5)*	11.4 *(11.3, 11.4)*	76.5 *(76.5, 76.6)*
Switzerland	84.1 *(83.9, 84.2)*	9.0 *(8.9, 9.1)*	83.2 *(83.1, 83.4)*	79.3 *(79.2, 79.5)*	10.2 *(10.1, 10.3)*	78.0 *(77.9, 78.3)*
Italy	84.1 *(84.0, 84.1)*	8.8 *(8.8, 8.9)*	82.9 *(82.8, 82.9)*	78.8 *(78.8, 78.9)*	10.2 *(10.1, 10.2)*	77.3 *(77.2, 77.3)*
Spain	84.1 *(84.0, 84.1)*	8.8 *(8.7, 8.8)*	82.9 *(82.9, 83.0)*	77.6 *(77.5, 77.6)*	11.1 *(11.0, 11.1)*	76.0 *(76.0, 76.1)*
Australia	83.7 *(83.7, 83.8)*	9.3 *(9.2, 9.3)*	82.9 *(82.8, 83.0)*	79.3 *(79.2, 79.4)*	10.6 *(10.5, 10.6)*	78.0 *(77.9, 78.1)*
Finland	83.1 *(83.0, 83.3)*	9.1 *(9.0, 9.2)*	82.4 *(82.2, 82.6)*	76.5 *(76.3, 76.7)*	11.2 *(11.1, 11.3)*	75.3 *(75.1, 75.5)*
Sweden	83.1 *(83.0, 83.2)*	8.9 *(8.8, 8.9)*	82.2 *(82.1, 82.3)*	79.1 *(79.0, 79.2)*	9.8 *(9.7, 9.8)*	77.9 *(77.7, 78.0)*
Austria	83.0 *(82.9, 83.0)*	8.9 *(8.8, 8.9)*	82.1 *(82.0, 82.2)*	77.6 *(77.5, 77.7)*	10.6 *(10.5, 10.7)*	76.6 *(76.4, 76.8)*
Norway	83.0 *(82.8 ,83.1)*	9.1 *(9.0, 9.2)*	81.9 *(81.7, 82.0)*	78.3 *(78.2, 78.5)*	10.0 *(9.9, 10.1)*	77.2 *(77.0, 77.4)*
Iceland	83.0 *(82.5, 83.7)*	8.7 *(8.3, 9.1)*	81.9 *(81.4, 82.6)*	79.7 *(79.0, 80.4)*	9.8 *(9.3, 10.3)*	78.2 *(77.1, 79.2)*
Canada	82.9 *(82.9 ,83.0)*	10.0 *(9.9, 10.0)*	81.9 *(81.8, 82.0)*	78.3 *(78.3, 78.4)*	11.0 *(10.9, 11.0)*	76.9 *(76.8, 77.0)*
Israel	82.9 *(82.7, 83.0)*	9.2 *(9.1, 9.3)*	81.1 *(81.0, 81.3)*	79.0 *(78.8, 79.2)*	10.9 *(10.7, 11.0)*	77.0 *(76.8, 77.2)*
England & Wales	82.5 *(82.4, 82.5)*	9.8 *(9.8, 9.8)*	81.1 *(81.1, 81.2)*	78.3 *(78.3, 78.4)*	10.9 *(10.9, 10.9)*	76.6 *(76.6, 76.7)*
West Germany	82.4 *(82.4, 82.5)*	8.9 *(8.9, 9.0)*	81.7 *(81.7, 81.8)*	77.5 *(77.5, 77.6)*	10.5 *(10.4, 10.5)*	76.1 *(76.0, 76.1)*
East Germany	82.4 *(82.2, 82.5)*	9.1 *(9.0, 9.1)*	81.2 *(81.1, 81.2)*	76.5 *(76.4, 76.6)*	11.0 *(10.9, 11.1)*	74.8 *(74.7, 74.9)*
Portugal	82.4 *(82.4 ,82.5)*	8.9 *(8.8, 8.9)*	81.5 *(81.4, 81.6)*	76.4 *(76.3, 76.5)*	11.0 *(10.9, 11.0)*	75.5 *(75.3, 75.6)*
Belgium	82.3 *(82.2, 82.4)*	9.5 *(9.4, 9.5)*	81.6 *(81.5, 81.7)*	76.9 *(76.8, 77.0)*	10.9 *(10.8, 10.9)*	75.7 *(75.5, 75.8)*
Netherlands	82.3 *(82.3, 82.4)*	9.6 *(9.5, 9.7)*	80.9 *(80.8, 81.0)*	78.3 *(78.2, 78.4)*	9.8 *(9.8,9.9)*	76.7 *(76.6, 76.8)*
Slovenia	82.2 *(82.0, 82.5)*	8.9 *(8.8, 9.1)*	81.0 *(80.7, 81.2)*	75.7 *(75.5, 76.0)*	11.0 *(10.8, 11.2)*	73.9 *(73.5, 74.2)*
Luxembourg	82.1 *(81.6, 82.6)*	9.2 *(8.9, 9.6)*	81.4 *(80.8, 82.0)*	76.6 *(76.1, 77.2)*	10.0 *(9.7, 10.4)*	76.0 *(75.2, 76.7)*
New Zealand non-Maori	82.1 *(81.9, 82.3)*	9.6 *(9.4, 9.7)*	81.2 *(81.0, 81.4)*	77.8 *(77.6, 78.0)*	10.4 *(10.3, 10.6)*	76.6 *(76.3, 76.8)*
Taiwan	82.0 *(81.9,82.1)*	10.1 *(10.0, 10.2)*	80.5 *(80.4, 80.6)*	75.9 *(75.8, 76.0)*	12.6 *(12.5, 12.7)*	73.7 *(73.6, 73.9)*
Ireland	81.9 *(81.7, 82.1)*	9.4 *(9.3, 9.6)*	80.3 *(80.1, 80.6)*	77.3 *(77.1, 77.4)*	10.2 *(10.1, 10.4)*	75.5 *(75.3, 75.8)*
Northern Ireland	81.3 *(81.0,81.6)*	9.9 *(9.7, 10.1)*	80.6 *(80.3, 80.9)*	77.2 *(76.9, 77.5)*	11.0 *(10.8, 11.3)*	76.1 *(75.7, 76.4)*
Denmark	80.9 *(80.8, 81.0)*	9.9 *(9.8, 10.0)*	79.4 *(79.2, 79.6)*	76.5 *(76.3, 76.6)*	10.7 *(10.6, 10.8)*	74.9 *(74.7, 75.1)*
USA	80.8 *(80.7, 80.8)*	11.1 *(11.0, 11.1)*	79.8 *(79.8, 79.8)*	75.6 *(75.6, 75.6)*	12.5 *(12.5, 12.5)*	74.5 *(74.4, 74.5)*
Chile	80.7 *(80.6, 80.8)*	10.7 *(10.6, 10.8)*	78.9 *(78.8, 79.0)*	75.0 *(74.9, 75.1)*	12.7 *(12.5, 12.8)*	72.3 *(72.0, 72.5)*
Scotland	80.4 *(80.3, 80.6)*	10.3 *(10.2, 10.4)*	78.9 *(78.7, 79.1)*	75.9 *(75.7, 76.0)*	11.6 *(11.5, 11.7)*	74.0 *(73.8, 74.2)*
Czech Republic	80.3 *(80.2, 80.4)*	9.3 *(9.2, 9.4)*	78.9 *(78.8, 79.0)*	74.0 *(73.9, 74.1)*	11.2 *(11.2, 11.3)*	71.7 *(71.6, 71.9)*
Estonia	80.0 *(79.7,80.3)*	9.9 *(9.6, 10.1)*	79.0 *(78.8, 79.3)*	69.7 *(69.4, 70.1)*	12.9 *(12.7, 13.2)*	66.3 *(65.8, 66.9)*
Poland	79.9 *(79.8, 80.0)*	10.0 *(9.9, 10.0)*	78.9 *(78.8, 79.0)*	71.5 *(71.4, 71.5)*	12.5 *(12.5, 12.6)*	68.7 *(68.6, 68.8)*
Slovakia	78.8 *(78.7, 79.0)*	9.8 *(9.6, 9.9)*	77.2 *(77.0, 77.3)*	70.8 *(70.6, 71.0)*	12.2 *(12.1, 12.3)*	67.8 *(67.6, 68.0)*

Lithuania	78.6 *(78.4,78.7)*	10.2 *(10.1, 10.4)*	78.0 *(77.8, 78.2)*	67.5 *(67.3, 67.7)*	13.6 *(13.4, 13.7)*	64.0 *(63.6,64.3)*
China[*]	*78.2*	*11.7*	*76.5*	*73.4*	*12.6*	*72.0*
Latvia	78.0 *(77.8,78.3)*	10.5 *(10.4, 10.7)*	77.5 *(77.2, 77.7)*	68.3 *(68.0, 68.5)*	13.2 *(13.0, 13.3)*	64.8 *(64.5, 65.1)*
Hungary	77.7 *(77.5, 77.8)*	10.7 *(10.7, 10.8)*	76.1 *(76.0, 76.2)*	69.2 *(69.0, 69.3)*	12.9 *(12.8, 13.0)*	65.0 *(64.8, 65.1)*
Bulgaria	77.3 *(77.1,77.4)*	10.1 *(10.0, 10.2)*	76.3 *(76.1, 76.4)*	70.0 *(69.9, 70.2)*	12.6 *(12.5, 12.7)*	67.3 *(67.2, 67.5)*
Belarus	76.1 *(76.0, 76.3)*	10.9 *(10.8, 11.0)*	74.7 *(74.6, 74.9)*	64.5 *(64.4, 64.7)*	13.7 *(13.6, 13.7)*	60.4 *(60.2, 60.6)*
Russia	74.2 *(74.1, 74.2)*	11.9 *(11.9, 11.9)*	73.4 *(73.4, 73.5)*	61.8 *(61.7, 61.8)*	15.0 *(15.0, 15.1)*	57.4 *(57.3, 57.4)*
Ukraine	73.8 *(73.7, 73.9)*	11.6 *(11.6, 11.7)*	72.9 *(72.8, 72.9)*	62.3 *(62.2, 62.4)*	14.7 *(14.7, 14.8)*	58.0 *(57.9, 58.0)*
India[*]	*63.8*	*18.2*	*72.8*	*61.8*	*18.2*	*69.7*
South Africa[*]	*52.6*	*20.7*	*60.6*	*50.0*	*19.8*	*56.8*

Data sources: [*] Data for 2006 from World Health Organization (WHO), not used in the analysis but shown here for comparative purposes. All other data are from the Human Mortality Database 2011; see Table 1 in the Supplementary Material for latest year available.

Table 1: Countries and regions of the Human Mortality Database[2] used in our analysis, ranked by female life expectancy for the latest year available. Life expectancy is denoted by e_0, the threshold age separating 'premature' from 'late' deaths by $a^{\dagger}$, and life disparity by $e^{\dagger}$, with 95% confidence intervals given in brackets (see supplementary material). Information for Eastern European countries is shown in red and for the United States in blue. The countries used in our analyses are in regular type face. The countries in italics are shown for comparison; data are less reliable for these countries.

Supplementary Material

Life Disparity

Life disparity, $e^{\dagger}$, is the life expectancy lost due to death, $e^{\dagger} = \int_0^{\omega} e(x,t) f(x,t) dx$, where $e(a,t) = \frac{\int_a^{\omega} l(x,t)dx}{l(a,t)}$ is remaining life expectancy at age a and time t, $l(a,t) = \exp(-\int_0^a \mu(x,t)dx)$ gives the probability of survival to age a and $\mu(a,t)$ denotes the age-specific hazard of death. The life table distribution of deaths is given by $f(a,t) = l(a,t)\mu(a,t)$. Maximum lifespan is denoted by ω.

Conceptually, this measure is similar to Greville's 1948 variant of the Potential Years of Life Lost (PYLL) measure,[S1] which weights the death counts from a given disease at each age by remaining life expectancy in order to assess the importance of major causes of death. In this way the age profile of disease mortality is taken into account, which can lead to different conclusions than assessments that compare diseases strictly on the basis of death counts or on their average effect on lifespan.

When all causes of death are taken into account, life disparity functions in much the same way. Saving lives at ages with both many remaining life years and a high number of death counts has the greatest impact on lifespan variation. This was first observed by Keyfitz,[S2,S3] who derived the formula for the elasticity of life expectancy to a proportional change in mortality (also known as the entropy of the life table, or Keyfitz' *H*), which he observed was related to variation in age-at-death. Life disparity equals the entropy of the life table multiplied by life expectancy.[S4-S6] It is only in recent years that the full potential of life disparity as a measure of lifespan variation has been realized.[S7,S8]

Methods to calculate the contribution of premature and late mortality to changes in life expectancy

Let $\rho(a,t)$ represent the rate of progress in reducing mortality:

$$\rho(a,t) = -\frac{\frac{\partial}{\partial t}\mu(a,t)}{\mu(a,t)}$$

Vaupel and Canudas Romo[S9] showed that the change in life expectancy at birth, $\dot{e}(0,t)$ could be decomposed as:

$$\dot{e}(0,t) = \int_0^{\omega} e(a,t)\rho(a,t)f(a,t)da$$

Meanwhile, Zhang and Vaupel[S8] proved that this relationship could be further decomposed by age components, for instance premature and late life mortality components separated by the threshold age:

$$\dot{e}(0,t) = \int_0^{a^{\dagger}(t)} e(a,t)\rho(a,t)f(a,t)da + \int_{a^{\dagger}(t)}^{\omega} e(a,t)\rho(a,t)f(a,t)da$$

We used these relationships to calculate the yearly contributions of averting premature and late deaths to increases in life expectancy, which we then smoothed using a 20-year moving average.

Methods to obtain confidence intervals

To be sure that random fluctuation was not substantially affecting our rankings of life expectancy, life disparity and the threshold age in Table 1, we estimated 95 % confidence intervals around our results. This was done by Monte Carlo simulation, assuming a binomial distribution of death counts. For each age interval the number of observations in each simulation round was based on the observed number of deaths, D_x, divided by the probability of dying, q_x. The simulated death counts, d_x^{sim}, divided by the observed population at risk, N_x, gave us simulated death probabilities q_x^{sim}. From these values we simulated 1000 life tables that we used to generate confidence intervals around our life-table-based estimates. Others have used similar methods to generate confidence intervals around life expectancy and healthy life expectancy for small populations.[S10-S13]

Country or region	Earliest year	Latest year
Australia	1921	2007
Austria	1947	2008
Belgium*	1841	2007
Bulgaria	1970	2009
Belarus	1970	2007
Canada	1921	2007
Switzerland	1876	2007
Chile	1992	2005
Czech Republic	1950	2009
West Germany	1956	2008
East Germany	1956	2008
Denmark	1840	2008
Spain	1908	2006
Estonia	1959	2009
Finland	1878	2009
France	1840	2007
England & Wales	1841	2009
North Ireland	1922	2009
Scotland	1855	2009
Hungry	1950	2006
Ireland	1950	2006
Iceland	1840	2008
Israel	1983	2008
Italy	1872	2007
Japan	1947	2009
Latvia	1970	2009
Luxembourg	1960	2007
Lithuania	1959	2009
Netherlands	1850	2008
Norway	1846	2008
New Zealand non-Maori	1901	2008
Poland	1958	2009
Portugal	1940	2009
Russia	1959	2008
Slovakia	1950	2009
Slovenia	1983	2009
Sweden	1840	2008
Taiwan	1970	2009
Ukraine	1970	2006
USA	1933	2007
Australia	1921	2007

Table S1: Countries and regions of the Human Mortality Database used in our analysis. We used data from the earliest year given in the table through the latest year. *No data was available for 1914-1918.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.993	1.000						
Standard deviation (σ)	0.985	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.972	0.964	0.961	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.966	0.936	0.919	0.916	1.000			
Gini coefficient (G)	0.983	0.961	0.946	0.937	0.997	1.000		
Inter-Quartile Range (*IQR*)	0.967	0.944	0.917	0.921	0.966	0.974	1.000	
Inter-individual difference (AID)	0.995	0.998	0.996	0.973	0.937	0.962	0.945	1.000

Table S2(a): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3528 female period life tables available from the Human Mortality Database, 1840-2009.

	$e^{\dagger}$	σ^2	σ	σ_{10}	$e^{\dagger}/e(0)$	G	IQR	AID
Life disparity ($e^{\dagger}$)	1.000							
Variance (σ^2)	0.986	1.000						
Standard deviation (σ)	0.979	0.996	1.000					
Standard deviation past age 10 (σ_{10})	0.940	0.909	0.908	1.000				
Entropy of life table ($e^{\dagger}/e(0)$)	0.958	0.913	0.898	0.879	1.000			
Gini coefficient (G)	0.979	0.946	0.933	0.898	0.996	1.000		
Inter-Quartile Range (*IQR*)	0.965	0.937	0.913	0.890	0.948	0.964	1.000	
Inter-individual difference (AID)	0.992	0.997	0.995	0.930	0.917	0.950	0.941	1.000

Table S2(b): Pearson correlation coefficients between pairs of measures of lifespan variation, based on all 3528 male period life tables available from the Human Mortality Database, 1840-2009.

Males								
Year	Record $e^{\dagger}$	Country	Average $e^{\dagger}$	Difference	Record e_0	Country	Average e_0	Difference
1840	23.8	Sweden	25.0	1.3	41.8	Sweden	40.4	1.4
1841	23.8	Sweden	25.1	1.3	43.0	Sweden	41.2	1.8
1842	24.5	Sweden	25.3	0.8	41.0	Denmark	40.3	0.7
1843	24.0	Sweden	25.0	1.0	42.6	Denmark	41.1	1.5
1844	24.2	Sweden	24.9	0.7	42.9	Denmark	41.6	1.4
1845	23.8	Sweden	24.9	1.1	43.5	Sweden	42.5	1.0
1846	24.3	Sweden	25.3	1.0	46.4	Norway	40.9	5.5
1847	24.1	Sweden	25.0	0.9	43.5	Norway	39.6	3.9
1848	23.4	Sweden	25.0	1.6	43.3	Norway	40.7	2.6
1849	23.9	Norway	25.0	1.1	46.3	Norway	39.5	6.8
1850	23.6	Norway	24.7	1.0	47.8	Norway	43.2	4.5
1851	23.7	Norway	24.8	1.1	48.0	Norway	42.7	5.3
1852	23.9	Norway	25.0	1.0	47.0	Norway	41.6	5.3
1853	24.0	Norway	24.8	0.8	46.5	Norway	40.6	5.9
1854	23.4	Norway	24.9	1.5	49.9	Norway	41.8	8.1
1855	23.1	Denmark	24.3	1.2	48.6	Norway	42.1	6.5
1856	23.6	Norway	24.8	1.2	48.8	Norway	43.2	5.7
1857	23.6	Norway	25.2	1.6	48.8	Norway	40.6	8.2
1858	23.6	Norway	25.3	1.7	50.0	Norway	41.5	8.5
1859	24.5	Norway	25.4	0.9	48.5	Norway	41.7	6.8
1860	23.5	Sweden	24.3	0.8	48.7	Norway	44.8	3.9
1861	23.5	Denmark	25.0	1.5	46.2	Denmark	43.5	2.8
1862	23.5	Denmark	25.2	1.8	46.7	Denmark	42.9	3.7
1863	23.8	Denmark	25.2	1.4	46.6	Denmark	43.2	3.4
1864	24.5	Norway	25.1	0.6	47.6	Norway	41.9	5.7
1865	24.3	Norway	25.2	0.9	49.0	Norway	42.0	7.0
1866	24.0	Norway	25.0	1.0	48.3	Norway	42.7	5.7
1867	23.5	Sweden	24.5	1.0	46.2	Norway	43.4	2.8
1868	24.4	Sweden	25.1	0.7	45.4	Norway	42.3	3.1
1869	24.2	Norway	24.9	0.7	47.5	Norway	42.5	5.0
1870	23.4	Norway	24.5	1.1	49.2	Norway	42.3	6.9
1871	23.1	Sweden	24.6	1.5	48.0	Norway	39.9	8.1
1872	23.6	Sweden	24.9	1.3	48.5	Norway	43.5	4.9
1873	23.6	Denmark	24.7	1.1	48.2	Norway	43.8	4.4
1874	23.9	Denmark	24.9	1.0	46.3	Norway	42.9	3.4
1875	24.3	Denmark	24.8	0.5	46.1	Norway	42.0	4.1
1876	24.3	Denmark	25.0	0.7	45.3	Norway	42.7	2.6
1877	24.2	Denmark	24.8	0.6	48.3	Norway	44.0	4.3
1878	24.2	Norway	25.0	0.7	50.4	Norway	43.3	7.1
1879	23.4	Norway	24.3	0.9	51.9	Norway	44.6	7.4
1880	23.6	Norway	24.9	1.3	50.5	Norway	42.6	7.9
1881	23.6	Denmark	24.5	1.0	49.0	Norway	43.6	5.5
1882	24.0	Switzerland	25.0	1.0	46.9	Sweden	43.5	3.4
1883	23.4	Switzerland	24.5	1.1	48.5	Norway	44.1	4.3
1884	23.6	Switzerland	24.7	1.1	49.5	Norway	44.1	5.4
1885	23.3	Denmark	24.4	1.1	49.8	Norway	44.6	5.2
1886	23.4	Switzerland	24.5	1.1	50.5	Norway	44.4	6.1
1887	23.2	Switzerland	24.2	1.0	50.6	Norway	45.6	5.0
1888	22.9	Sweden	24.1	1.2	51.0	Sweden	45.4	5.6
1889	23.0	Sweden	24.3	1.4	51.1	Sweden	45.3	5.8
1890	23.0	Switzerland	24.3	1.4	49.1	Sweden	44.2	4.8
1891	23.5	GBR_SCO	24.2	0.7	49.6	Sweden	44.1	5.5
1892	22.9	Switzerland	24.1	1.2	49.3	Sweden	44.2	5.1
1893	22.9	Switzerland	24.2	1.3	50.0	Sweden	44.8	5.2
1894	23.0	Switzerland	23.9	0.9	50.9	Sweden	46.4	4.5
1895	22.5	Sweden	23.7	1.3	52.8	Sweden	46.5	6.3
1896	22.3	Switzerland	23.5	1.2	52.2	Sweden	48.0	4.1
1897	22.3	Switzerland	23.3	1.1	52.8	Sweden	48.1	4.8
1898	22.3	Sweden	23.5	1.2	53.2	Sweden	47.9	5.3
1899	22.4	Switzerland	23.7	1.3	49.8	Norway	46.5	3.3
1900	22.1	Denmark	23.4	1.3	51.8	Norway	46.3	5.4
1901	22.5	Switzerland	23.5	1.1	52.7	Norway	47.5	5.2
1902	19.9	New Zealand*	22.5	2.6	56.6	New Zealand*	49.9	6.7
1903	20.3	New Zealand*	22.6	2.3	56.9	New Zealand*	50.1	6.8
1904	19.3	New Zealand*	22.4	3.1	58.9	New Zealand*	50.3	8.6
1905	18.4	New Zealand*	22.5	4.0	60.2	New Zealand*	49.9	10.3
1906	18.1	New Zealand*	22.3	4.2	60.0	New Zealand*	50.7	9.3
1907	19.9	New Zealand*	22.0	2.1	56.8	New Zealand*	50.7	6.1
1908	19.1	New Zealand*	22.2	3.2	59.4	New Zealand*	50.5	8.9
1909	18.9	New Zealand*	21.7	2.8	60.3	New Zealand*	51.8	8.5
1910	18.4	New Zealand*	21.6	3.2	59.9	New Zealand*	52.4	7.5
1911	17.9	New Zealand*	21.9	4.1	60.4	New Zealand*	51.3	9.1
1912	17.4	New Zealand*	21.1	3.7	61.6	New Zealand*	53.2	8.4
1913	18.0	New Zealand*	21.2	3.2	60.3	New Zealand*	53.1	7.2

1914	17.6	New Zealand*	21.1	3.5	60.6	New Zealand*	53.2	7.4
1915	17.9	New Zealand*	21.3	3.4	61.3	New Zealand*	51.3	10.0
1916	18.7	New Zealand*	21.4	2.7	60.0	New Zealand*	51.0	9.0
1917	17.6	New Zealand*	21.2	3.6	61.3	New Zealand*	50.6	10.6
1918	20.1	Finland	22.8	2.7	55.2	Denmark	44.1	11.0
1919	17.1	New Zealand*	21.6	4.4	61.7	New Zealand*	51.4	10.3
1920	18.0	New Zealand*	21.3	3.4	60.2	New Zealand*	53.2	7.0
1921	17.5	New Zealand*	20.2	2.8	62.4	New Zealand*	55.8	6.6
1922	16.7	New Zealand*	19.7	3.0	63.0	New Zealand*	56.1	6.9
1923	16.5	New Zealand*	19.5	2.9	62.5	New Zealand*	57.1	5.4
1924	16.5	New Zealand*	19.5	3.0	63.6	New Zealand*	56.8	6.8
1925	16.2	New Zealand*	19.2	3.1	63.9	New Zealand*	57.6	6.3
1926	16.0	New Zealand*	19.1	3.1	63.3	New Zealand*	57.8	5.5
1927	16.0	New Zealand*	19.2	3.1	64.1	New Zealand*	57.6	6.6
1928	16.3	New Zealand*	18.9	2.6	64.1	New Zealand*	58.3	5.8
1929	15.9	New Zealand*	19.0	3.1	63.7	New Zealand*	57.3	6.4
1930	15.7	New Zealand*	18.8	3.1	64.3	New Zealand*	58.8	5.5
1931	15.7	New Zealand*	18.3	2.6	64.9	New Zealand*	59.1	5.8
1932	15.0	New Zealand*	18.1	3.2	66.4	New Zealand*	59.7	6.6
1933	15.1	New Zealand*	18.0	2.9	66.2	New Zealand*	60.1	6.1
1934	14.9	New Zealand*	17.9	3.0	65.9	Netherlands	60.5	5.4
1935	15.0	New Zealand*	17.8	2.8	66.4	New Zealand*	60.3	6.2
1936	15.0	Netherlands	17.7	2.7	66.1	Netherlands	60.3	5.8
1937	14.7	Netherlands	17.6	2.9	66.2	Netherlands	60.5	5.7
1938	14.8	Netherlands	17.4	2.6	66.5	Netherlands	61.1	5.5
1939	14.2	Netherlands	16.9	2.7	66.9	Netherlands	61.4	5.5
1940	14.8	New Zealand*	17.9	3.1	66.1	New Zealand*	58.6	7.5
1941	14.7	New Zealand*	18.1	3.4	65.8	New Zealand*	58.2	7.5
1942	14.7	New Zealand*	17.9	3.2	67.6	Sweden	59.5	8.0
1943	14.9	New Zealand*	18.0	3.1	67.3	Sweden	59.7	7.6
1944	14.6	New Zealand*	18.2	3.7	66.3	Australia	58.7	7.6
1945	14.2	New Zealand*	17.8	3.6	67.2	Sweden	60.4	6.8
1946	13.8	Sweden	16.7	2.9	68.3	Sweden	62.8	5.5
1947	13.4	Sweden	16.5	3.0	68.3	Norway	62.7	5.6
1948	13.4	Sweden	16.2	2.8	69.7	Netherlands	63.6	6.1
1949	13.1	Sweden	15.8	2.6	70.0	Norway	63.8	6.2
1950	12.7	Sweden	15.5	2.8	70.3	Netherlands	64.3	6.0
1951	12.6	Sweden	15.2	2.5	70.8	Norway	64.6	6.2
1952	12.6	Sweden	14.9	2.3	71.0	Norway	65.4	5.6
1953	12.6	Sweden	14.6	2.0	71.2	Norway	65.7	5.5
1954	12.4	Sweden	14.4	2.0	71.3	Norway	66.3	5.0
1955	12.3	Sweden	14.4	2.0	71.5	Norway	66.5	5.0
1956	12.3	Netherlands	14.0	1.8	71.5	Iceland	66.5	5.0
1957	12.3	Sweden	14.1	1.9	71.7	Iceland	66.4	5.4
1958	12.0	Sweden	14.1	2.1	71.5	Sweden	67.0	4.5
1959	12.1	Sweden	14.1	2.0	71.6	Sweden	66.8	4.7
1960	12.0	Sweden	13.8	1.8	72.5	Iceland	67.1	5.4
1961	12.0	Sweden	13.9	1.9	71.6	Sweden	67.2	4.4
1962	11.9	Sweden	13.6	1.7	71.4	Iceland	67.2	4.2
1963	11.9	Sweden	13.6	1.7	71.5	Sweden	67.3	4.2
1964	12.0	Sweden	13.5	1.6	71.6	Sweden	67.7	3.9
1965	11.8	Sweden	13.3	1.6	71.7	Sweden	67.7	4.0
1966	11.8	Sweden	13.3	1.5	71.9	Sweden	67.8	4.1
1967	11.8	Sweden	13.3	1.5	71.9	Sweden	68.0	3.9
1968	11.8	Sweden	13.1	1.3	71.7	Sweden	67.9	3.9
1969	11.8	Sweden	13.1	1.3	71.7	Sweden	67.7	4.1
1970	11.9	Sweden	13.5	1.5	72.2	Sweden	67.6	4.6
1971	11.9	Sweden	13.4	1.5	72.0	Sweden	67.7	4.2
1972	11.9	Sweden	13.3	1.4	72.1	Iceland	68.1	4.1
1973	11.6	Sweden	13.2	1.6	72.2	Sweden	68.1	4.0
1974	11.6	Japan	13.2	1.6	72.2	Sweden	68.3	3.9
1975	11.5	Japan	13.2	1.6	72.2	Iceland	68.2	4.0
1976	11.4	Japan	13.0	1.6	73.7	Iceland	68.4	5.3
1977	11.4	Japan	13.1	1.6	73.2	Iceland	68.6	4.5
1978	11.4	Japan	13.0	1.6	73.7	Iceland	68.7	4.9
1979	11.4	Japan	13.0	1.6	74.0	Iceland	68.9	5.1
1980	11.2	Japan	12.8	1.6	73.4	Iceland	68.9	4.5
1981	11.1	Japan	12.8	1.6	73.8	Japan	69.1	4.7
1982	11.2	Japan	12.7	1.5	74.5	Iceland	69.5	5.1
1983	11.1	Sweden	12.6	1.5	74.2	Japan	69.6	4.7
1984	11.1	Japan	12.6	1.5	74.7	Iceland	69.8	4.9
1985	11.0	Japan	12.4	1.4	74.9	Japan	69.9	4.9
1986	11.0	Ireland	12.3	1.3	75.4	Iceland	70.4	5.0
1987	11.0	Japan	12.3	1.4	75.6	Japan	70.6	5.0
1988	10.8	Japan	12.3	1.5	75.6	Japan	70.7	4.9
1989	10.8	Iceland	12.4	1.5	76.1	Iceland	70.8	5.4
1990	10.8	Japan	12.3	1.6	75.9	Japan	70.8	5.2
1991	10.8	Japan	12.4	1.6	76.2	Japan	70.8	5.4
1992	10.7	Sweden	12.4	1.7	76.7	Iceland	70.9	5.8

1993	10.5	Sweden	12.3	1.8	77.0	Iceland	70.8	6.2
1994	10.6	Sweden	12.3	1.7	77.1	Iceland	71.0	6.1
1995	10.4	Sweden	12.3	1.9	76.4	Japan	71.1	5.3
1996	10.3	Sweden	12.1	1.8	77.0	Japan	71.5	5.5
1997	10.3	Sweden	12.1	1.8	77.2	Japan	71.9	5.3
1998	10.0	Iceland	12.0	2.0	77.7	Iceland	72.1	5.5
1999	10.1	Sweden	11.9	1.8	77.4	Iceland	72.3	5.1
2000	10.1	Sweden	11.9	1.8	77.9	Iceland	72.7	5.1
2001	10.1	Sweden	11.8	1.7	78.3	Iceland	73.2	5.1
2002	10.0	Sweden	11.8	1.8	78.5	Iceland	73.3	5.2
2003	9.6	Iceland	11.6	2.1	79.5	Iceland	73.6	5.9
2004	9.8	Iceland	11.7	1.8	78.9	Iceland	74.0	4.9
2005	9.7	Iceland	11.6	1.9	79.5	Iceland	74.1	5.3
2006	9.9	Sweden	11.6	1.7	79.4	Iceland	74.5	4.9
2007	9.7	Iceland	11.5	1.8	79.4	Iceland	74.5	4.9
2008	10.5	West Germany	11.6	1.1	79.3	Japan	74.7	4.6
Females								
Year	**Record $e^{\dagger}$**	**Country**	**Average $e^{\dagger}$**	**Difference**	**Record e_0**	**Country**	**Average e_0**	**Difference**
1840	23.6	Sweden	24.9	1.3	46.1	Sweden	43.2	2.9
1841	23.6	Sweden	25.1	1.5	47.2	Sweden	43.8	3.4
1842	24.3	Sweden	25.2	0.9	45.0	Sweden	43.0	2.0
1843	23.8	Sweden	25.0	1.2	45.1	Denmark	43.5	1.6
1844	23.7	Sweden	24.8	1.1	46.9	Sweden	44.4	2.5
1845	23.5	Sweden	24.9	1.4	48.5	Sweden	45.2	3.3
1846	24.4	Sweden	25.4	0.9	49.7	Norway	43.5	6.2
1847	24.5	Sweden	25.1	0.6	46.1	Norway	42.0	4.1
1848	23.1	Sweden	24.9	1.9	47.3	Sweden	43.6	3.7
1849	23.2	Norway	24.8	1.6	49.8	Norway	42.6	7.2
1850	23.2	Norway	24.6	1.3	51.3	Norway	46.3	5.0
1851	23.3	Norway	24.7	1.4	51.5	Norway	45.7	5.8
1852	23.9	Norway	25.0	1.2	49.9	Norway	44.4	5.6
1853	23.5	Norway	24.7	1.2	49.3	Norway	43.2	6.1
1854	22.8	Norway	24.7	1.9	53.3	Norway	44.7	8.6
1855	22.5	Norway	24.0	1.5	52.3	Norway	45.1	7.1
1856	23.3	Norway	24.7	1.4	51.9	Norway	45.9	6.0
1857	23.1	Norway	25.2	2.2	51.6	Norway	42.9	8.7
1858	23.0	Norway	25.2	2.2	53.1	Norway	43.7	9.4
1859	24.0	Norway	25.3	1.4	51.3	Norway	44.1	7.1
1860	23.2	Sweden	24.4	1.1	51.3	Norway	47.1	4.2
1861	23.6	Denmark	25.0	1.4	49.0	Denmark	45.8	3.2
1862	23.9	Denmark	25.4	1.5	48.5	Denmark	45.0	3.4
1863	24.0	Denmark	25.2	1.2	48.5	Denmark	45.5	3.0
1864	24.0	Norway	25.0	1.0	50.0	Norway	44.3	5.6
1865	24.0	Norway	25.3	1.3	51.9	Norway	44.6	7.3
1866	23.6	Norway	25.0	1.4	51.5	Norway	45.2	6.3
1867	23.2	Sweden	24.4	1.2	49.5	Norway	46.1	3.4
1868	24.6	Norway	25.2	0.6	48.9	Norway	45.0	4.0
1869	23.7	Norway	25.0	1.3	51.0	Norway	45.1	5.9
1870	23.0	Norway	24.5	1.5	52.6	Norway	45.4	7.1
1871	22.7	Sweden	24.7	2.0	51.4	Norway	43.0	8.4
1872	23.1	Sweden	24.8	1.7	51.9	Sweden	46.3	5.7
1873	23.7	Sweden	24.6	0.9	51.2	Norway	46.4	4.8
1874	23.9	Denmark	24.8	0.9	49.2	Norway	45.7	3.5
1875	24.2	Norway	24.8	0.6	49.2	Norway	44.6	4.5
1876	24.6	Engl. and Wales	25.1	0.5	48.3	Norway	45.4	2.9
1877	24.2	Engl. and Wales	24.8	0.6	51.2	Norway	46.8	4.4
1878	23.6	Norway	25.0	1.4	53.2	Norway	45.7	7.5
1879	22.9	Norway	24.3	1.3	54.4	Norway	47.1	7.3
1880	23.1	Norway	24.9	1.8	53.3	Norway	45.3	8.0
1881	23.6	Norway	24.6	1.0	51.9	Norway	46.2	5.6
1882	23.5	Switzerland	24.9	1.4	50.1	Sweden	46.2	3.9
1883	23.1	Switzerland	24.5	1.4	50.7	Norway	46.8	3.9
1884	23.2	Switzerland	24.7	1.4	52.0	Norway	46.7	5.3
1885	23.3	Switzerland	24.3	1.0	52.3	Norway	47.2	5.1
1886	23.2	Switzerland	24.5	1.3	52.9	Norway	47.0	5.9
1887	22.8	Switzerland	24.1	1.3	52.9	Sweden	48.2	4.7
1888	22.5	Switzerland	23.9	1.4	53.5	Sweden	48.1	5.4
1889	22.8	Sweden	24.3	1.5	53.4	Sweden	48.0	5.4
1890	22.6	Switzerland	24.2	1.6	51.8	Sweden	47.1	4.6
1891	23.1	Switzerland	24.0	0.9	52.5	Sweden	47.0	5.5
1892	22.2	Switzerland	23.8	1.6	51.8	Sweden	47.2	4.7
1893	22.4	Switzerland	24.1	1.7	53.3	Norway	47.7	5.6
1894	22.6	Switzerland	23.7	1.2	53.2	Sweden	49.3	3.9
1895	22.2	Sweden	23.4	1.2	55.4	Sweden	49.5	5.8
1896	21.8	Switzerland	23.2	1.5	55.9	Norway	51.1	4.8
1897	22.0	Switzerland	23.1	1.1	55.7	Norway	51.2	4.4
1898	21.9	Sweden	23.2	1.3	56.1	Sweden	51.0	5.0
1899	21.6	Switzerland	23.4	1.7	53.4	Norway	49.7	3.7

Formatted: Font: 8 pt

Formatted Table

1900	21.7	Denmark	23.1	1.3	55.2	Norway	49.6	5.6
1901	21.7	Switzerland	23.2	1.4	56.5	Norway	50.8	5.7
1902	19.8	New Zealand*	22.2	2.4	59.3	New Zealand*	52.9	6.4
1903	19.9	New Zealand*	22.3	2.4	59.5	New Zealand*	53.2	6.3
1904	18.7	New Zealand*	22.1	3.4	61.8	New Zealand*	53.2	8.6
1905	17.9	New Zealand*	22.2	4.3	62.4	New Zealand*	52.7	9.8
1906	18.1	New Zealand*	22.1	4.0	62.8	New Zealand*	53.4	9.3
1907	19.4	New Zealand*	21.7	2.3	58.9	New Zealand*	53.4	5.5
1908	18.2	New Zealand*	21.8	3.6	62.5	New Zealand*	53.3	9.2
1909	18.8	New Zealand*	21.3	2.6	63.3	New Zealand*	54.7	8.6
1910	17.8	New Zealand*	21.2	3.4	62.5	New Zealand*	55.3	7.2
1911	17.5	New Zealand*	21.6	4.1	63.3	New Zealand*	54.3	9.0
1912	16.3	New Zealand*	20.7	4.4	64.4	New Zealand*	56.2	8.3
1913	17.5	New Zealand*	20.7	3.2	63.1	New Zealand*	56.2	7.0
1914	17.0	New Zealand*	20.6	3.5	64.2	New Zealand*	56.5	7.7
1915	17.3	New Zealand*	20.6	3.3	64.6	New Zealand*	55.8	8.8
1916	17.4	New Zealand*	20.6	3.2	63.9	New Zealand*	56.1	7.8
1917	16.9	New Zealand*	20.5	3.6	64.2	New Zealand*	56.0	8.2
1918	19.3	New Zealand*	23.0	3.7	57.4	New Zealand*	50.3	7.1
1919	16.4	New Zealand*	20.9	4.5	64.9	New Zealand*	55.2	9.6
1920	17.8	New Zealand*	20.9	3.1	62.4	New Zealand*	56.3	6.1
1921	16.6	New Zealand*	19.6	2.9	65.5	New Zealand*	59.1	6.5
1922	15.9	New Zealand*	19.1	3.2	65.4	New Zealand*	59.2	6.2
1923	15.9	New Zealand*	18.8	3.0	64.9	New Zealand*	60.3	4.7
1924	15.8	New Zealand*	18.9	3.2	66.6	New Zealand*	60.0	6.5
1925	15.8	New Zealand*	18.7	2.9	66.4	New Zealand*	60.7	5.7
1926	15.6	New Zealand*	18.6	3.0	66.1	New Zealand*	60.9	5.2
1927	15.5	New Zealand*	18.5	3.0	66.9	New Zealand*	60.7	6.2
1928	15.5	New Zealand*	18.4	2.9	66.8	New Zealand*	61.3	5.6
1929	15.0	New Zealand*	18.3	3.3	67.0	New Zealand*	60.4	6.6
1930	15.1	New Zealand*	18.1	3.0	67.3	New Zealand*	62.3	5.1
1931	14.7	New Zealand*	17.6	2.9	67.8	New Zealand*	62.3	5.5
1932	14.6	New Zealand*	17.5	2.9	68.3	New Zealand*	62.8	5.5
1933	14.5	New Zealand*	17.2	2.7	69.1	New Zealand*	63.5	5.5
1934	14.2	New Zealand*	17.1	2.9	68.5	New Zealand*	63.9	4.7
1935	14.4	New Zealand*	17.0	2.6	69.2	New Zealand*	63.7	5.5
1936	14.4	Netherlands	16.8	2.4	68.5	New Zealand*	64.1	4.4
1937	13.9	Netherlands	16.6	2.7	68.6	New Zealand*	64.1	4.5
1938	14.1	Netherlands	16.4	2.2	69.0	Norway	65.0	4.0
1939	13.6	Netherlands	15.9	2.2	69.3	New Zealand*	65.5	3.8
1940	13.7	New Zealand*	16.4	2.7	69.7	New Zealand*	64.2	5.5
1941	14.0	New Zealand*	16.6	2.6	69.2	New Zealand*	64.2	5.0
1942	13.5	New Zealand*	16.4	2.9	70.4	Sweden	65.0	5.4
1943	13.6	New Zealand*	16.5	2.9	70.1	Sweden	65.1	5.0
1944	13.9	New Zealand*	16.6	2.7	70.0	New Zealand*	65.0	5.1
1945	13.4	New Zealand*	16.4	3.0	70.5	Norway	65.5	4.9
1946	12.9	Sweden	15.6	2.7	71.7	Iceland	67.2	4.6
1947	12.5	Sweden	15.4	2.9	71.7	Norway	67.1	4.6
1948	12.2	Sweden	15.2	3.0	72.9	Norway	67.7	5.2
1949	11.9	Sweden	14.7	2.8	73.2	Iceland	67.7	5.5
1950	11.6	Sweden	14.4	2.9	73.5	Iceland	68.6	5.0
1951	11.5	Sweden	14.0	2.5	74.3	Norway	68.9	5.4
1952	11.4	Sweden	13.7	2.4	74.9	Iceland	69.7	5.2
1953	11.3	Sweden	13.4	2.1	75.1	Norway	70.2	4.8
1954	11.1	Sweden	13.1	2.1	75.6	Iceland	71.0	4.6
1955	11.2	Sweden	13.0	1.8	75.9	Iceland	71.2	4.7
1956	10.9	Netherlands	12.8	1.8	75.5	Norway	71.3	4.3
1957	10.9	Sweden	12.7	1.9	75.5	Norway	71.3	4.2
1958	10.8	Sweden	12.7	1.9	76.0	Iceland	72.0	3.9
1959	10.7	Sweden	12.6	1.8	75.8	Norway	72.0	3.7
1960	10.7	Sweden	12.2	1.5	75.9	Norway	72.4	3.5
1961	10.6	Sweden	12.3	1.7	76.2	Iceland	72.7	3.5
1962	10.5	Sweden	12.1	1.6	76.1	Iceland	72.7	3.4
1963	10.4	Norway	12.0	1.6	76.0	Iceland	73.0	3.1
1964	10.6	Norway	12.0	1.3	76.4	Iceland	73.5	2.9
1965	10.5	Sweden	11.8	1.3	76.5	Norway	73.5	3.0
1966	10.4	Sweden	11.8	1.4	76.7	Norway	73.7	3.0
1967	10.4	Sweden	11.7	1.3	76.9	Norway	74.0	2.9
1968	10.4	Sweden	11.5	1.1	76.8	Norway	73.9	2.9
1969	10.4	Sweden	11.6	1.2	76.7	Norway	73.9	2.7
1970	10.0	Iceland	11.7	1.6	77.3	Norway	74.2	3.1
1971	10.3	Norway	11.6	1.3	77.4	Sweden	74.5	2.9
1972	10.2	Norway	11.5	1.3	77.5	Sweden	74.8	2.8
1973	10.1	Norway	11.4	1.3	77.7	Sweden	74.9	2.8
1974	10.1	Norway	11.4	1.3	77.9	Norway	75.2	2.7
1975	10.1	Norway	11.4	1.2	78.7	Iceland	75.3	3.4
1976	10.1	Japan	11.2	1.1	79.9	Iceland	75.5	4.4
1977	10.0	Japan	11.2	1.2	79.2	Iceland	75.8	3.4
1978	10.0	Japan	11.2	1.2	79.3	Iceland	76.0	3.3

Formatted: Font: 8 pt

1979	9.9	Norway	11.2	1.3	79.4	Iceland	76.2	3.2
1980	9.7	Japan	11.1	1.3	80.1	Iceland	76.1	4.0
1981	9.7	Japan	11.0	1.3	79.6	Iceland	76.4	3.2
1982	9.7	Japan	11.0	1.3	79.7	Japan	76.6	3.1
1983	9.6	Japan	10.9	1.3	80.4	Iceland	76.7	3.7
1984	9.6	Japan	10.9	1.3	80.3	Japan	76.9	3.3
1985	9.5	Japan	10.7	1.2	80.5	Japan	76.9	3.6
1986	9.5	Japan	10.7	1.2	81.0	Japan	77.3	3.7
1987	9.5	Japan	10.7	1.2	81.4	Japan	77.4	4.0
1988	9.3	Japan	10.6	1.3	81.3	Japan	77.6	3.8
1989	9.4	Japan	10.6	1.2	81.8	Japan	77.7	4.1
1990	9.3	Japan	10.6	1.4	81.9	Japan	77.8	4.1
1991	9.3	Japan	10.6	1.3	82.2	Japan	78.0	4.2
1992	9.4	Japan	10.6	1.3	82.3	Japan	78.2	4.1
1993	9.4	Japan	10.5	1.2	82.4	Japan	78.0	4.4
1994	9.3	Japan	10.6	1.3	82.9	Japan	78.3	4.6
1995	9.4	Japan	10.6	1.2	82.8	Japan	78.4	4.4
1996	9.3	Finland	10.4	1.1	83.5	Japan	78.6	4.9
1997	9.4	Spain	10.3	1.0	83.8	Japan	78.9	4.9
1998	9.2	Spain	10.3	1.1	84.0	Japan	79.1	4.8
1999	9.1	Spain	10.2	1.1	84.0	Japan	79.2	4.8
2000	9.2	Spain	10.2	1.0	84.6	Japan	79.5	5.1
2001	9.2	Spain	10.1	1.0	84.9	Japan	79.8	5.1
2002	9.0	Spain	10.1	1.0	85.2	Japan	79.9	5.3
2003	8.9	Spain	10.0	1.0	85.3	Japan	80.1	5.3
2004	9.0	Spain	10.0	1.0	85.6	Japan	80.6	5.0
2005	8.8	Spain	9.9	1.1	85.5	Japan	80.7	4.8
2006	8.9	Spain	9.8	1.0	85.8	Japan	80.9	4.8
2007*	8.9	Portugal	9.7	0.8	86.0	Japan	81.1	4.8
2008*	8.9	Austria	9.6	0.6	86.0	Japan	81.4	4.6

* The New Zealand population includes only the non-Maori population

Table S3: The record and average life disparity, $e^{\dagger}$ and life expectancy e_0 for each year, based on data from the Human Mortality Database (Table S1).

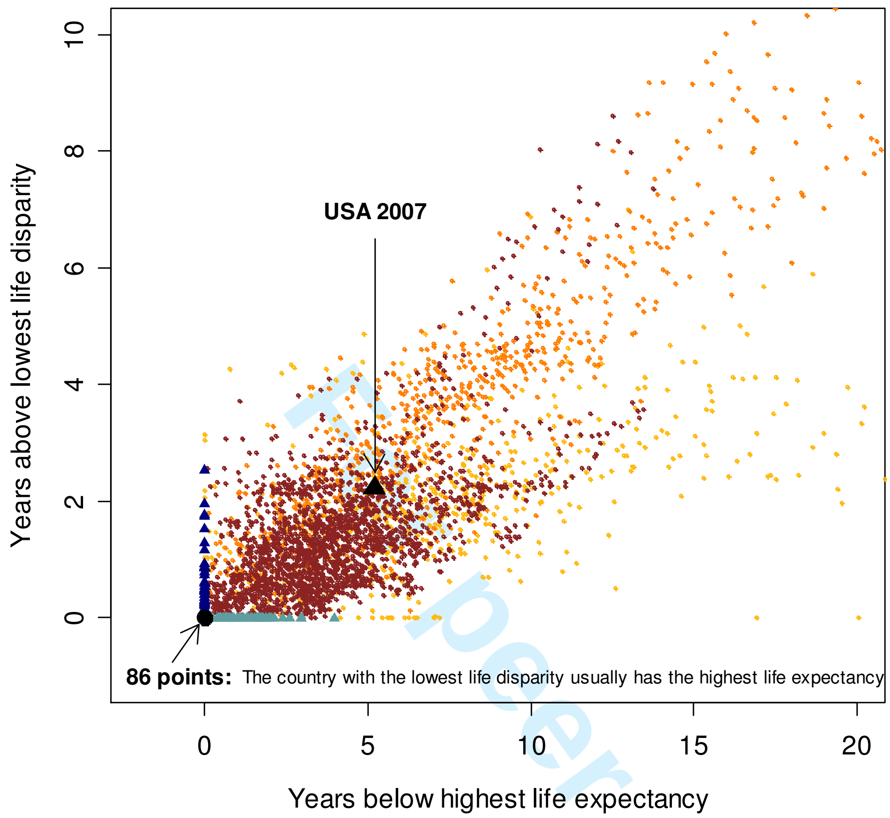

Fig. S1: The association between life disparity in a specific year and life expectancy for females in that year for the 40 countries and regions in the Human Mortality Database, 1840-2009 (Table S1). The correlation coefficient between them is 0.75 (95% confidence interval 0.73 to 0.76). The black triangle represents the United States in 2007: the U.S. had a female life expectancy 5.2 years lower than the international record in 2006 and a life disparity 2.2 years greater. The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year. The black point at (0,0) marks countries with the lowest life disparity and the highest life expectancy. During the 170 years from 1840 to 2009, 86 holders of record life expectancy also enjoyed the lowest life disparity.

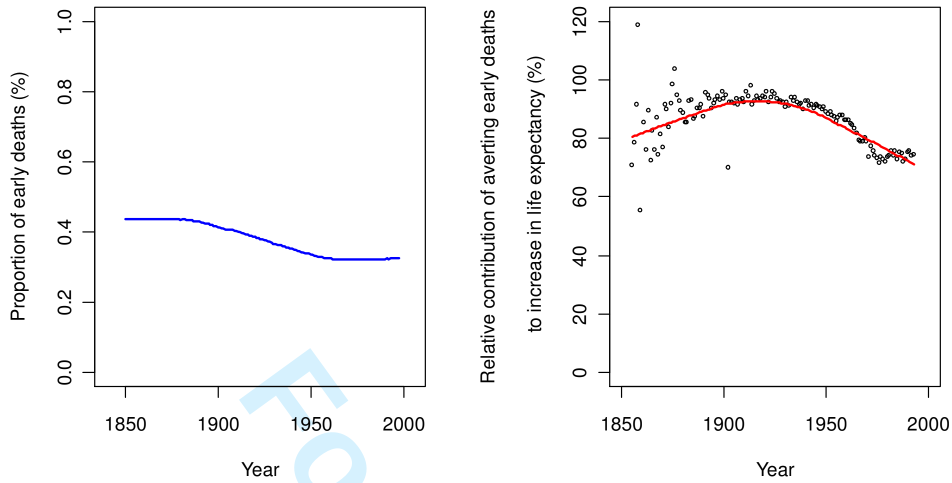

Figure S2: The left panel expresses early deaths as a proportion of all deaths, smoothed by 20-year averages. The right panel displays the 30-year moving average of the relative contribution of averting early deaths to the increase in life expectancy, with the red line marking the trend. The data pertain to females, 1840-2009, all 40 countries and regions of the HMD.

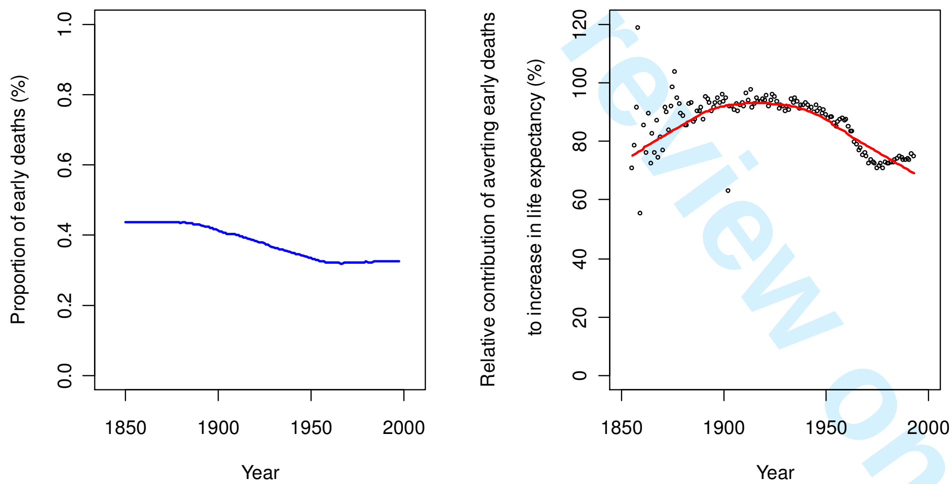

Figure S3: To show that the trends in Figure S2 above are not due to compositional change from new entrants into our dataset, we plotted the two relationships using only the eleven countries for which we had over 100 years of data (see Table S1).

The relationship between life expectancy and life disparity: comparing leaders and laggards

In Figure 3 we showed that reaching a level of life expectancy later was only sometimes associated with lower life disparity conditional upon survival to age 15. More often no clear relationship could be found.

Given the high correlation between life expectancy and life disparity, an interesting question is whether laggards in life expectancy at birth also have similar levels of life disparity to the leaders at the same level of life expectancy. The answer, seen in Figure S4, is yes. Thus while leaders are the first to reduce premature mortality, thereby reducing life disparity, laggards on average follow with similar reductions in life disparity alongside life expectancy increases.

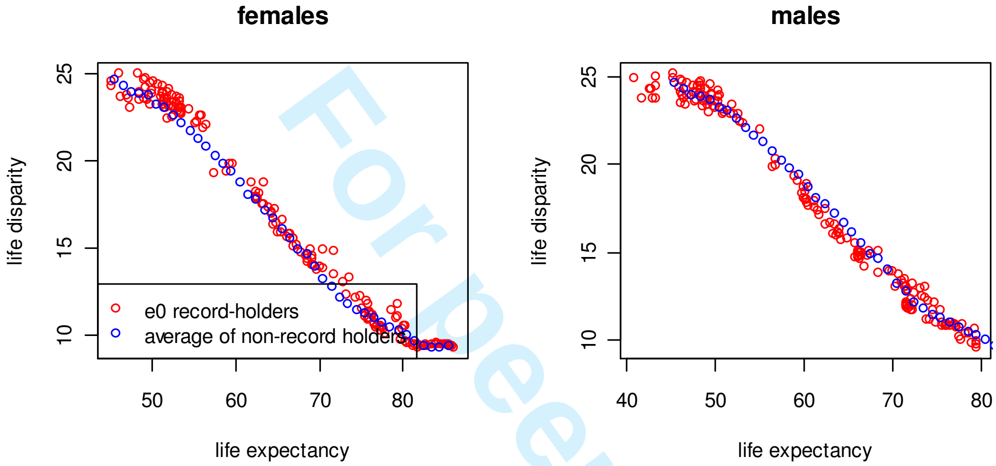

Figure S4: A comparison of the level of life disparity between (1) record-holders of life expectancy and (2) all other countries (averaged) once they had reached certain life expectancy levels (taken to be one year intervals).

Alternative calculations using the AID measure

Some concern might be raised about whether artefactual correlations are present in our findings since calculation of life disparity involves prior knowledge of life expectancy. We showed the high correlation between life disparity and other measures of lifespan variation in Table 2 of the supplementary material. Some of these other measures do not contain life expectancy in their formulation. To be sure that our results were robust to other measures, we ran our analysis with an alternative measure of lifespan variation, the absolute inter-individual difference (AID). While AID and life disparity are highly correlated, AID tends to be more sensitive to mortality change at younger ages than life disparity.[S7]

The AID is an alternative measure of lifespan variation that is related to the well-known Gini coefficient of inequality. There are many equivalent formulations to the AID, but the Kendall and Stuart definition is the most helpful for understanding the nature of the statistic, which essentially measures the average absolute distance in years between each pair of individuals' age at death (length of life) in the population.[S14] From the life table, it can be calculated as follows:

$$AID = \frac{1}{2}\int_0^{\omega}\int_0^{\omega}|x-y|f(x)f(y)dxdy \qquad (1)$$

where $|x-y|$ is the absolute value of the distance in years between age x and age y, and f(x) and f(y) are the probabilities of death at ages x and y respectively.

Using the AID measure, the country with the highest life expectancy also had the lowest AID 74 times for females (Figure S5), and 67 times for males (Figure S6) out of 170 years. Differences in this relationship between the two measures were mostly owing to differences in historical populations, especially during war, famine and epidemic years, when certain countries had qualitatively different age at death distributions from other countries.

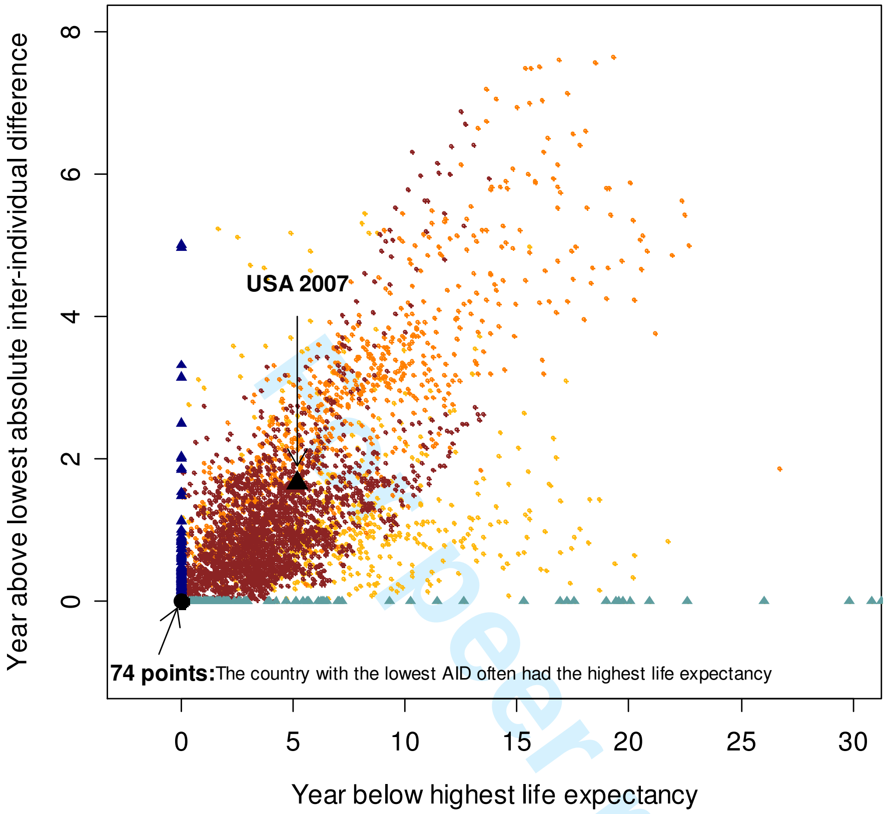

Figure S5: Alternative calculations using the AID measure, females. The correlation coefficient between them is 0.60 (0.58 to 0.62). The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year.

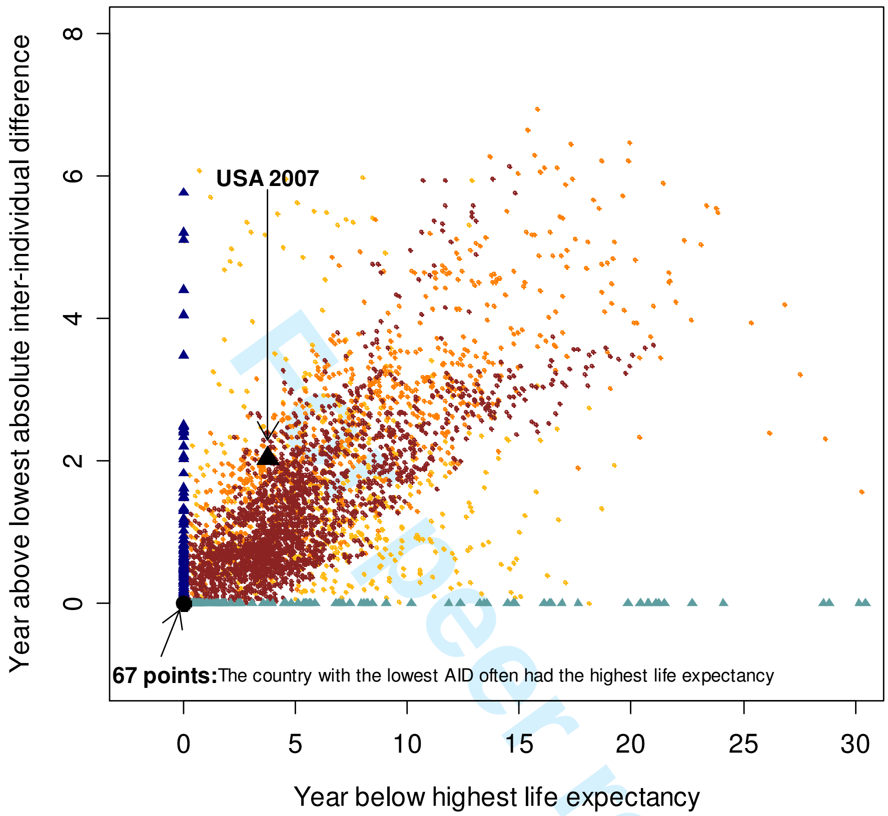

Figure S6: Alternative calculations using the AID measure, males. The correlation coefficient between them is 0.62 (0.60 to 0.64). The brown points denote years after 1950, the orange points 1900-1949 and the yellow points 1840-1900. The light blue triangles represent countries with the lowest life disparity but with a life expectancy below the international record in the specific year; the dark blue triangles indicate the life expectancy leaders in a given year, with life disparities greater than the most egalitarian country in that year.

Supplementary References:

S1. Greville TNE. Comments on Mary Dempsey's article on decline in Tuberculosis: the death rate fails to tell the entire story. *Am Rev Tuberc* 1948;57:417-19.

S2. Keyfitz N, Golini A. Mortality comparisons: the male-female ratio. *Genus* 1975;31:1-34.

S3. Keyfitz N. Applied mathematical demography. 1st ed. New York: Wiley; 1977.

S4. Mitra S. A Short Note on the Taeuber Paradox. *Demography* 1978;15:621-23.

S5. Goldman N, Lord G. A New Look at Entropy and the Life Table. *Demography* 1986;23:275-82.

S6. Vaupel JW. How Change in Age-Specific Mortality Affects Life Expectancy. *Popul Stud* 1986;40:147-57.

S7. Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the US and other developed countries: methods and empirical analysis. *Demography* 2011;48:211-239.

Deleted: in press.

S8. Zhang Z, Vaupel JW. The age separating early deaths from late deaths. *Demogr Res* 2009;20:721-30.

S9. Vaupel JW, Canudas Romo V. Decomposing Change in Life Expectancy: A Bouquet of Formulas in Honor of Nathan Keyfitz's 90th Birthday. *Demography* 2003;40:201-16.

S10. Veugelers PJ, Kim AL, Guernsey JR. Inequalities in health. Analytic approaches based on life expectancy and suitable for small area comparisons *J Epidemiol Community Health* 2000;54:375-380

S11. Salomon JA, Mathers CD, Murray CJ, Ferguson B. Methods for life expectancy and healthy life expectancy uncertainty analysis. *Global Programme on Evidence for Health Policy Working Paper No. 10, World Health Organization* 2001.

S12. Silcocks PBS, Jenner DA, Reza R. Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities *J Epidemiol Community Health* 2001;55:38-43.

S13. Eayres D, Williams ES. Evaluation of methodologies for small area life expectancy estimation *J Epidemiol Community Health* 2004;58:243-249

S14. Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function. Computation from discrete data, decomposition of differences and empirical examples. *Demogr Res* 2003;8:305-358.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

		Item No	Recommendation
✓	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
	Introduction		
✓	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
✓	Objectives	3	State specific objectives, including any prespecified hypotheses
	Methods		
✓	Study design	4	Present key elements of study design early in the paper
✓	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
✓	Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
✓	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
✓	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
✓	Bias	9	Describe any efforts to address potential sources of bias
✓	Study size	10	Explain how the study size was arrived at
✓	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
✓	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
			(*b*) Describe any methods used to examine subgroups and interactions
			(*c*) Explain how missing data were addressed
			(*d*) If applicable, describe analytical methods taking account of sampling strategy
			(*e*) Describe any sensitivity analyses
	Results		
✓	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
			(b) Give reasons for non-participation at each stage
			(c) Consider use of a flow diagram
✓	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
			(b) Indicate number of participants with missing data for each variable of interest
✓	Outcome data	15*	Report numbers of outcome events or summary measures
✓	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
			(*b*) Report category boundaries when continuous variables were categorized
			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
✓	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion			
☑	Key results	18	Summarise key results with reference to study objectives
☑	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
☑	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
☑	Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information			
☑	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.