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# Abstract

# Introduction

## Background

Mortality rates in Scotland, in common with most of the rest of Europe, have improved substantially since the 1850s. Although life expectancy has improved steadily since the end of World War II (WWII), they have improved more slowly in Scotland than in the rest of western and central Europe such that by 2010 it ranked lowest. Much of this more modest improvement can be attributed to higher mortality from cardiovascular disease, cancer and respiratory disease amongst older adults; and to substantial rises in absolute and relative terms from the 1980s onwards for alcohol- and drug-related deaths, suicide and violence amongst younger adults.

The recent rise in these (mostly external) causes of death amongst younger adults have also been responsible for a rapid and sustained rise in health inequalities within Scotland such that by the late 2000s Scotland had the greatest inequalities in western and central Europe (occupying a position somewhat in-between eastern European countries and the rest of western and central Europe). Although much of the higher mortality in Scotland compared to the rest of Great Britain (GB) can be explained by deprivation and socioeconomic status, Scotland also displays an ‘excess’ over and above that which can be explained in this way. This ‘excess mortality’ is particularly acute in west central Scotland and in Glasgow in particular (sometimes termed the ‘Scottish Effect’ and ‘Glasgow Effect’ respectively), with the causes of death and age groups most affected being very similar to those which are responsible for health inequalities.

The overall trends in age-standardised mortality rates and life expectancy in Scotland, as with elsewhere, can obscure patterns within populations which relate to age, period or cohort (APC) effects. Age effects are where mortality rates vary by age, and differences in age-specific mortality effects can be important in explaining differences between populations (for example, infant mortality rates have much more profound impacts on life expectancy than mortality rates at older ages ). Period effects are those which impact across age groups during a defined time period, although if there is an interaction between age and period effects (e.g. an exposure which impacts on a particular age stratum only) this can often be missed. Cohort effects are where an age stratum at a particular point in time carry with them a higher or lower mortality rate as they age compared to slightly older and younger cohorts.

The patterning of age, period and cohort effects (and particularly the interaction between them) can help pinpoint the exposures of most interest in explaining differences in mortality rates between populations and can help ascertain how long the impact of earlier exposures last (and for whom). For example, comparisons of Lexis surfaces (a visualisation technique which allows simultaneous comparison of mortality rates disaggregated by age, sex and period) between European populations have identified very marked negative period effects for young adults (i.e. a period-age interaction) associated with WWI and WWII for many countries (which can be explained by deaths due to armed conflict, civilian casualties and the acute impact of influenza (around 1919)), and also the identification of a negative birth cohort effect for those born around 1919 across several countries (with evidence of similar birth cohort effects for earlier generations). Within GB, this approach has helped to identify the emergence of a sustained age-period interaction effect (amongst younger adults) in Scotland compared with England & Wales during the 1980s and 1990s.

Within Scotland, the four mortality phenomena (lagging life expectancy improvement, wide health inequalities, the rise of particular ‘ external’ causes of death, and excess mortality over and above that explained by socioeconomic status) have been the subject of a wide-ranging programme of collaborative inter-disciplinary research which is beginning to tell a complex but important story about how and why these mortality phenomena have arisen. However, the role of APC effects remains underexplored given the potential for lagged impacts from historical exposures to provide part of the explanation.

Our paper aims to examine the extent to which the relatively high mortality experienced in Scotland can be explained by particular combinations of age, period and cohort effects.

## Types of Lexis surface visualisation

Lexis surfaces refer to plots which display data in a graph typically with age (individual years here) on the y-axis and time (years) on the x-axis whereby any cell/point of the graph represents the value for a given age in a given year. Given that the amount of data (the number of single ages in years multiplied by the number of single years) is more than can be effectively presented numerically, the values are instead plotted visually.

There are broadly two types of Lexis surface visualisation used here:

* **Shaded Contour Plots (SCPs)** : These use both shade/colour and contour lines to indicate variation in age specific log mortality rates over time. Colours represent values of the log mortality rates (logged due to large differences in mortality risk by age) and provide an aesthetically efficient means for quickly interpreting data (choice of colours varies by plot dependent on what works best). Contour lines indicate positions across the Lexis surface over which the log mortality rates are broadly equal, allowing a general comparison of similar mortality rates by age and year.
* **Comparative Level Plots (CLPs)** : These are Lexis surfaces of which compare the data taken from two Lexis surfaces, a 'specific' or 'index' surface, and a 'general' or 'reference' surface. A common example would be comparing the age and year specific mortality rates for two countries (or comparing one country to the values for a wider region of countries such as Europe) and plotting the differences in values between the countries. This approach allows a comparison of mortality patterns both by age, time and age-time (i.e. cohort) patterns. Within CLPs, red shades indicate that an age/year specific mortality rate in the index country is higher, i.e. worse, than the corresponding age/year specific value on the reference surface; conversely blue shades indicate lower, i.e. better, values compared with the reference surface. A contour line is added to some CLPS indicating where, along the surface, values 'cross over' from higher to lower or from lower to higher; i.e. at what ages, in which years, and for which cohorts, death rates in the index region change to being better or worse than in the reference region. Within some of the CLPs, thicker and more prominent contour lines are used to indicate areas within the surface with larger differences between index and reference regions' mortality rates. The shades correspond to differences in log mortality rates, using base 10.

Additionally, some figures present lattices, showing the Lexis surfaces for a number of countries and regions within a single image (i.e. multiple comparisons across the same range of ages and years), whereas other figures show just a pair of Lexis surfaces (males and females separately) for a single country, region, or comparison. The lattice figures show multiple surfaces using the same colour schemes and scales, making it easier to draw comparisons between the countries/regions included, whereas the simple paired images are each scaled according to the minimum and maximum values observed in that particular country/region.

## Range of surfaces

Where possible, the Lexis surfaces cover the age range from newborns to 90 years of age, and the year range from 1900 to 2010. This inevitably means that some countries' records are missing for some years, or did not even exist for some of these years (for example, Northern Ireland). This will inevitably lead to some discontinuities over the year axis (the horizontal axis) for reference regions, as different countries are included in the aggregation for different years. However this becomes less of a problem when the number of countries being aggregated is larger. It is important to be consistent in how we display the data as this will help comparing patterns between our analyses. Visual inspection of the reference surfaces, revealed by looking at their SCPs for indications of discontinuity with year, also qualitatively suggest this is not a substantively important issue.

# Figures

## SCP of Scotland

**Figure 1:** Shaded contour plot of male and female mortality rates in Scotland from 1900 to 2010.

The images are complex and contain a lot of information. To begin, we initially suggest following the contour lines labelled -1.0, which corresponds to a 0.100 risk (i.e. 10% risk of death) of dying in the next year, and -2.0 (a 0.010 risk or 1% risk of death). If the risk of dying in the following year did not vary over time then each of these lines would be horizontal, which is effectively the assumption made when period-based estimates of life expectancies are produced. But instead each of these lines has been gradually moving upwards, i.e. specific mortality risks that used to be associated with younger in adulthood are now associated with slightly older ages. For example, if we focus on the contour line marked -2.0 for females, we see that in 1920 this equivalent level of mortality risk (a 1% risk of death) was reached in the late forties; however, by 2000 this hurdle has shifted to the early sixties.

These continual reductions in specific mortality risks have been continuing for over 100 years, and there is some evidence they have been reducing faster since around 1950. These reflect broad trends of improved population health whereby life expectancy has improve dramatically thanks to improvements in the quality of life and medical innovations.

Trends and patterns in childhood, and in early adulthood, are dissimilar to those at older ages. Scotland, like other affluent world countries, has experienced large improvements (i.e. declines) in mortality rates, but unlike the trends in adulthood, which continued from 1900 onwards, the trends in specific mortality risk reduction during childhood are more discontinuous, with the greatest improvements occurring after WW2. There are marked differences between males and females, where this improvement has been more pronounced in females and has also extended further into early adulthood for females as well.

Within the male Lexis surface, the effects of both World Wars can be seen. For example, in the early 1940s, there is a clear change in the general improvements in mortality rates over time with contour lines rapidly changing. Through Figure 1, and by looking at the value labels of specific contours, which indicates a mortality peak of -2.0 (i.e. a 0.01 risk of dying in the next year, we can see that the effect of World War II was to raise the mortality risk for males in their early twenties to a level also associated, over the same period, with males in their mid 40s. This is despite the population and death count records used in the HMD being for the civilian rather than total (civilian plus military) populations. A similar but much smaller age-specific period effect occurred for females too, but the additional mortality rate for young adults was not large enough to generate an additional contour line. (If more contour lines, spaced less far apart, were presented then a similar, but less pronounced, pattern would appear in the female Lexis surface as well.) A similar drop, or increase in mortality risk, is also seen at the time of World War I.

## CLP of Scotland vs UK

**Figure 2:** Comparative level plot of Scotland compared with the UK overall.

In this figure, darker cell shading indicates a greater difference in risk parity between Scotland and the UK overall, with each additionally darker shade indicating either an increased (red) or decreased (blue) risk of mortality in Scotland compared with the UK of up to around 25%. This means that the lightest red shades indicate a mortality risk difference in the range 0 to 25%, and the next darkest red shades indicates a mortality risk difference of 26 to 58%, and so on. Because of the relatively low numbers of deaths observed in childhood and early adulthood since the 1960s, together with Scotland's relatively small population size, substantial variation in age-specific death rates in Scotland can be expected between individual neighbouring cells (individual age and year specific differences in log death rates) within the bottom right quadrants, resulting in a fairly 'noisy' or speckled pattern within these areas of the Lexis surfaces.

Despite relatively few observations of deaths in particular single ages and years, a number of trends and patterns are still discernible. Perhaps the most obvious of these is the large patch of dark blue cells in the male Lexis surface during World War I, suggesting that Scottish young Scottish males were much less likely to die of warfare during these years than equivalently aged males in the UK. (As Northern Ireland did not exist until after World War I, the UK prior to 1922 was England & Wales, and Scotland.)

The relatively lower specific mortality risks for males during WW1 contrasts with a elevated risk, compared with the UK as a whole, for young adult males (in their early twenties), during the latter half of WW2. The in base 10 log mortality rates was in excess of 0.5, as indicated by the additional contour line, suggesting that for around four years young male civilian Scots experienced a specific mortality rate around three times higher than males of the same age, and in the same year, in the UK as a whole. This may suggest that, amongst civilian jobs during WW2, young male Scots may have been engaged in some of the riskier work.

There is a patch of darker red cells associated with the mid to late 1940s, for Scottish females from late teenage years up to around the age of thirty as well, indicating that towards the end of and immediately following the Second World War, female mortality rates in this age group also fell behind that of the UK as a whole.

In general, the Lexis surfaces for both males and females are a light salmon/pink colour, indicating a mortality risk at almost all ages in Scotland that was similar to but very slightly higher than that of the UK as a whole. This indicates that Scotland has tended to closely follow age-specific mortality trends in the UK, but also to always lag slightly behind that of the UK overall. However, there are a number of exceptions to this general picture.

Turning first to the top left quadrants of the CLPs, there is some evidence that, historically, mortality rates amongst the elderly were slightly lower in Scotland compared with the UK overall, a pattern that persisted until the late 1920s. The patches of slightly blue cells in the male and female Lexis surfaces have a slightly triangular appearance, beginning from around the ages of 65 in the year 1900, and continuing to around 90 years old in around 1930. This pattern is suggestive of a very old protective cohort effect for Scots born in the 1840s.

A more recent pattern is also apparent, beginning in the 1960s and affecting children and young adults: although the number of deaths in childhood are low and have been reducing steadily, meaning the data at these ages are particularly noisy, there is still a strong indication that, for the last two generations, mortality rates for male and females children and young adults in Scotland have been slightly lower than in the rest of the UK. This effect is stronger for females than for males, but apparent for both sexes.

Above childhood ages, however, darker shades of red become apparent for both males and and females, though more so for males, beginning in the late teens and early twenties, and from the late 1980s/early 1990s onwards. This slightly darker red shade corresponds to a relative age-specific mortality risk in Scotland in the within the range 1.58 to 2.51 (58% to 251% i.e. 2 and a half times the comparator rate), indicating that age-specific mortality rates among young adults, and in particular young adult males, in Scotland have been around twice the equivalent rates in the UK as a whole. Like the blue patch in the top left quadrants of the Lexis surfaces, the patches of darker red shades have a slightly triangular appearance, hinting at a cohort effect, beginning in the late 1970s or early 1980s.

## Lattice CLP of Each UK Country against UK overall

**Figure 3:** Comparative level plot for England & Wales, Northern Ireland and Scotland compared to the UK as a whole.

Since Figure 3 already contains more than a single comparison between two regions, fewer breaks are used within the colour scheme of the level plots, with each difference in shade occurring at differences in 0.2, rather than 0.1, between corresponding log mortality values; this means that each shade indicates either an increase (red) or decrease (blue) in risk in the index country of around 58% compared with the UK as a whole.

The most interesting comparison here may be Northern Ireland, which with a population even smaller than Scotland's (around one third the size), produces an even 'noisier' image. However a number of features are still apparent. Like Scotland, there is some evidence that historically mortality rates among the elderly were lower than in the UK as a whole, with some suggestion of a male protective cohort effect, perhaps associated with males born around 1900, and persisting into the early 1980s. Like Scotland, there is also evidence that males were less exposed to the excess mortality effects of the First World War than in the UK as a whole, suggesting that excess male mortality rates due to this conflict were predominantly borne by the English & Welsh.

Despite Northern Ireland's small population, there is also clear evidence within the male CLP for Northern Ireland of excess mortality due to The Troubles, with clear patches of excess mortality associated with adults in the 20-40 year range, beginning in the early 1970s, abating slightly in the 1990s, but to some extent persisting to 2010. The darker vertical bands associated with 1971 and 1972 indicate these were particular bad years for young adult male mortality in Northern Ireland. The contrast between male and females in Northern Ireland since the 1970s is stark, with females born from this period experiencing, if anything, lower mortality rates than females of the same age in the UK as a whole. This pattern for females contrasts to Scotland, where the lower mortality rates extend further into adulthood than in Scotland.

## SCP of Western Europe overall

**Figure 4:** Shaded contour plot of Western Europe as a whole.

Figure 4 broadens the reference region, from the UK, to Western Europe. This means that the total population size is greatly increased, now including the populations of Austria, Belgium, Switzerland, Germany, France, Ireland, Luxembourg and the Netherlands, as well as the UK nations. With larger numbers of observations, the 'noisiness' of contiguous cells is reduced, and genuine trends and patterns become easier to see. However, there are some caveats to highlight as well: The reference may be less representative, less comparable, than when a single other country or smaller group of countries is used. Additionally, not all countries' data are available for the entire period. In particular, data from Germany are only available after the Second World War, introducing a discontinuity to the data as this country's (or these countries') records become included. As Germany was only re-unified in the late 1980s, mortality trends in East Germany, especially, may be unrepresentative of trends and patterns within Western Europe more generally.

Despite the above caveats, the SCPs show a number of long-term continuous patterns and trends in age-specific mortality rates in the region over time. As with the UK, following particular contour lines which cut through middle age and above can be a good place to start. In this case, we suggest following the contour lines labelled -2.0 and -1.0, corresponding to risks of dying in the next year of 1% and 10%, respectively. These contour lines have each been tending upwards since 1900, although the trends are somewhat more linear for females than for males. The differences between males and female exposure to additional mortality risks due to the two World Wars, and the relative impact of the first compared with the second world war, are also apparent from this figure (different compared to Scotland).

Also apparent are the rapid reductions in the mortality risks of early adulthood for both males and females after the Second World War, trends that are perhaps most apparent by looking at the contour lines labelled -2.6, corresponding to around a 0.3% risk of dying in the next year. These contours rose rapidly to older ages for both sexes: in 1930 this contour intersected males aged around 17 years old, and by the year 2000 it had moved to the early forties; similarly for females the contour intersected with the age of 16 years old in 1930, and around 48 years old in 2000. Figure 4 clearly shows that childhood mortality rates in Western Europe are now at historically unprecedented low levels. The degree of change in the contour line values during these ages over time does not appear to be slowing, suggesting that further reductions in childhood mortality may continue over the following decades.

## CLP of Scotland Compared with Western Europe

**Figure 5:** Comparative level plot of age- and sex-specific mortality rates for Scotland compared to Western Europe.

Figure 5 compares mortality rates in Scotland with the broader Western Europe region profiled in Figure 4. Figure 5 is similar to the comparison with the UK (Figure 2) but not identical. For example, the appearance of two vertical bands shows that mortality rates for both genders towards both the start (1940) and the end (1944-1945) of the Second World War are lower in Scotland at almost all ages than in Western Europe, with age/gender specific mortality rates in these years around half that in Western Europe for young adults. There is slight evidence, however, of a small cohort effect for Scots born towards the end of the First World War, however, suggesting around a 50% increased risk for Scots from this cohort compared with Western Europe overall. This may be because Scotland had a much lower rate of exposure to the direct mortality effects of the First World War, but also in other Western European countries it may have been that those afflicted with the 1918 influenza outbreak were less likely to have recovered, and so produced a cohort of affected but surviving children in the first place with higher risk of subsequent ill health (and associated mortality). There are also indications of additional detrimental cohort effects in Scotland beginning in the mid 1920s, and in 1939, possibly for similar reasons.

Following the Second World War, mortality rates in Scotland in childhood appear to have been similar to those in Western Europe overall, and in early adulthood to have been similar, but slightly lower, than in the reference region. However, following the 1980s this slight relative advantage compared in early adulthood appears to have disappeared, and instead become a relative disadvantage, especially for males, and in particular for males over thirty years old in the late 2000s. This is similar to the patterns observed when compared to the UK (Figure 2).

The main difference, however, between relative mortality risks in Scotland compared with Western Europe overall, has been a slight but persistent disadvantage from around the age of fifty years, a relative risk that appears to have been slightly greater for females than for males.

## SCP of Different European Regions

**Figure 6:** Shaded contour plots of mortality rates for Eastern, Northern, Southern and Western Europe.

Figure 6 shows SCPs for each of four mutually exclusive European regions, each comprising between three and 11 countries. Full definitions of the countries included in each of these regions is provided at the end of this document (Appendix A). The data for Eastern European countries do not go back as far as for some countries in other European regions.

Of the four European regions, Eastern Europe is perhaps the most distinct. Whereas the contours associated with mortality rates in older adulthood have trended upwards within Northern, Western and Southern Europe since the 1950s, contour lines over the equivalent sections of the Eastern European Lexis surfaces have tended to be relatively flat and horizontal for females in Eastern Europe, and to have declined slightly for males in Eastern Europe. For males in Eastern Europe, a number of these contours, in particular the -2.6 (0.0025 risk) and -2.4 (0.0040 risk) contour line associated with males in their twenties and thirties, dropped sharply in the late 1980s and early 1990s, whereas comparable contour lines in Western and Northern Europe, in particular the -2.8 (0.0016) contour line, appeared to move upwards at a slightly faster rate over the same years. For young adult Eastern European females similar but smaller effect is evident, in particular by following the contour labelled -3.2 (0.0006 risk), associated with females in their early to mid twenties, however similar effects are not evident at older ages.

All regions have shown very similar trends in reduced childhood mortality, with additional shades of blues and greens, opening up within the three to 18 years age range from the late 1940s onwards. For the three regions whose data series go back to 1900, there is evidence that childhood mortality rates had been continuing to reduce during the first half of the century, but accelerated in the second half of the Twentieth century.

## CLP of Scotland compared with different European Regions

**Figure 7:** Comparative level plot of mortality rates for Scotland compared to Eastern, Northern, Southern and Western Europe.

Figure 7 shows how mortality rate in Scotland compare with each of the European regions. Blues indicate lower mortality compared with the average within the region, and reds indicate higher mortality rates. Black contour lines separate positive and negative sections of the Lexis surfaces.

Compared to Eastern Europe, mortality rates in Scotland are lower at all ages, and have been since the mid 1980s. This comparative advantage appears to have been driven by differences in cohorts, with the upwards diagonal shapes of the black contours suggesting that, cohorts born after around 1920 for males, and from around 1930 for females, have had lower mortality risks at all ages in Scotland than in Eastern Europe. For males, this relative advantage appears to have increased with each decade until the 1950s, and became strongest once these cohorts reached adulthood, and in particular around the age of thirty years. For females, the relative differences are less pronounced, but still present over broadly the same range of ages and years.

Mortality rates in Scotland were lower compared to Southern and Western Europe during both world wars at all ages, and in particular compared to men of fighting age in the First World War. There is also a strong indication that, compared to Southern Europe in particular, and Western Europe to a lesser extent, childhood mortality rates in the first four years of life were also substantially lower in Scotland throughout much of the 1940s, and continuing into the late 1950s.

For both males and females, any historical comparative advantage in mortality risks for younger adults (20 to 40 years) disappeared in the late 1980s and early 1990s. By the 2000s, this comparative mortality advantage for younger adults had been replaced by a comparative disadvantage, which has been worsening since the late 1990s. This loss of a comparative mortality advantage within this age group means that mortality rates in Scotland now tend to be higher than those of each of the European regions at all ages.

As the differences shown by the CLPS are differences in log values, and absolute mortality rates in childhood and early adult tend to be low throughout Europe, absolute differences in life expectancies between European countries are to a much greater extent determined by proportionate mortality rate differences at older adult ages. Here Scotland has been at a consistent disadvantage compared to each of the regions throughout almost all of the Twentieth century. Though, the comparison with the UK average also showed, there is some evidence of a cohort-driven comparative advantage for elderly adults up until the 1920s, and a brief period-effect driven comparative advantage compared to Southern Europe and Western Europe towards the end of the Second World War, in other years mortality rates for people from around the age of 40 onwards have always tended to be higher in Scotland than elsewhere in Europe. Compared to Southern Europe, which has experienced the most rapid reductions in age-specific mortality risks within Europe in recent decades, the comparative disadvantage for females within the age range 50 to 80 have been particularly pronounced since the early 1980s, as indicated by a large cloud of darker shading in this region of the female, Southern Europe Lexis surface.

## Annual average differences in log age/sex specific mortality rates between other countries and Scotland from 1900

**Figure 8:** The average difference in all log age- and sex-specific mortality rates for Scotland by year compared to different regions of reference countries.

An overall difference in a life expectancy results from the accumulated differences in mortality risks at all ages. Although the differences in annual mortality risks may be small at any single age, over the life course they can amount to substantial differences due to the way these small disadvantages and advantages accumulate.

Figure 8 shows how, for each year from 1950 to 2010, the mean difference in age and sex specific log mortality rates in Scotland compares with 24 other countries in six different regions, including the rest of the UK as one region, and other Anglophone countries as another 'region' (Further details are provided in appendix X). This means that, unlike in the previous figures, the regions are not mutually exclusive. Differences above the zero line indicate that the average difference in log mortality rates is higher in Scotland than in the comparator country (and vice versa).

Beginning with 'Rest of UK', the figure shows that on average log mortality rates have been higher in Scotland than England & Wales, and slowly rising since the 1970s. Compared with Northern Ireland, the average log mortality rate in Scotland has tended to be higher, except for much of the 1970s, where higher log mortality rates among younger adult males in Ireland led to a negative difference in average levels.

Compared to other Anglophone nations out with the UK, the average log mortality rate in Scotland has tended to be higher than in Ireland, Canada, and Australia, and becoming steadily worse. Average log rates tended to be lower than in Ireland until the 1970s, but have since been higher and rising. The only exception to this trend is the USA, now has a slightly higher average log mortality rate than Scotland, and has done so since most of the 1980s.

Scotland's position compared to Southern European nations has also fallen, in particular since the late 1990s. This has seen Scotland's mortality advantage over countries like Spain and Portugal become reversed. Northern European nations have all tended to have lower average log mortality values, with the exception of Finland. Scotland's relative disadvantage has tended to be maintained compared with each of these nations, and in particular against Sweden.

Compared to Western Europe, there is some evidence of both catch-up and fall-back in Scotland's average log mortality rate differences, with a period of catch-up lasting late in to the 1960s, then fall back from the lat 1980s onwards. Only compared to Eastern Europe, which also appears to be the most heterogeneous region in terms of differences between countries, does Scotland now compare favourably using this measure.

This figure shows how, on average, log mortality rates for different ages and genders in Scotland have compared against log mortality rates at the same ages and genders in other countries, in the same year. It is effectively a summary of many vertical sections through a large number of CLPS compared with each of the 25 single countries being compared. However, as mortality rates are highest in infancy and in older adulthood, these are what matters most to overall difference in longevity. The following section therefore analyses differences in average mortality rates, rather than average log mortality rates.

## Annual average differences in age/sex specific mortality rates between other countries and Scotland from 1900, by year

**Figure 9:** The average difference in all age- and sex-specific mortality rates for Scotland by year compared to different regions of reference countries.

Figure 9, showing average differences in age and sex specific mortality rates, rather than log mortality rates as in Figure 8, is a clearer indication of how average relative advantages in Scotland compared with the comparator countries 'add up' to overall differences in longevity. Differences in infancy and mortality at older ages are therefore more important in determining the relative position of Scotland compared with these other countries in this plot.

Figure 9 presents evidence that Scotland's position relative to the Northern, Western and Southern European nations, UK and other anglophone countries, has been persistently worse throughout the period. Despite this, the average mortality rates of Scotland compared to these countries have converged over time, demonstrating some relative improvement in Scotland. Only compared to Eastern European countries does Scotland's comparative average age/sex specific mortality rate look favourable, representing the collapse of the Soviet Union. Within the regions, there has also been marked convergence and reduced heterogeneity of patterns for individual countries, apart from in Eastern Europe.

# Discussion

* In the long-term, the older 'affluent world' nations, i.e. European countries, and Anglophone countries in the North America and Australasia, have tended to follow similar trajectories in life expectancies, driving by similar trends in reduced mortality rates in infancy and older adulthood (mainly from retirement ages).
* The relationship between mortality risk and age tends to increase exponentially from early to mid adulthood, approximately the age of 35 years, and so to be able to compare specific mortality rates on a CLP it is useful to look to differences in log mortality rates rather than mortality rates directly. However, the greatest contributions to overall differences in life expectancy relate to differences in mortality risk in infancy and old age, so a country with an elevated mortality in early adulthood and reduced risk in old age will tend to have higher life expectancies than a country with reduced early adulthood risk and increase risk in old age. However, mortality rate differences at ages and in years where absolute mortality risks are low are still important to identify as they can point to broader societal and health differences between the two countries/regions being compared.
* Scotland has a long established reputation as a/the 'Sick Man of Europe' due to lagging behind these more general trends.
* Comparative level plots show how the age and year specific mortality rates, risks of dying in the next year, compare between an index country and a comparator country or region. We have compared these specific mortality rates in Scotland with a range of individual countries and regions, some of which can be thought of as more similar, and others more dissimilar, to Scotland in terms of a range of economic, social, linguistic, geographical, and cultural factors. (For example, other Western European countries, other countries in the UK, other Anglophone countries).
* For the UK, the CLPs of each of the constituent countries have also been presented as a lattice plot, although population and death counts for Wales are not available from England, and England & Wales comprises the bulk of the UK population, and so will by design be the main driver of overall specific death rates within the UK. Despite Northern Ireland having a small population compared with Scotland, and so a more 'noisy' CLP surface of values, we can discern patches of elevated mortality for young male adults during the peak of 'The Troubles'.
* Specific mortality rates in Scotland have tended to follow trends in the UK fairly closely, yet also be be consistently worse at almost all ages except childhood, where absolute specific mortality rates have tended to be low and decreasing. There is some evidence that the gap between specific log mortality rates in Scotland and the rest of the UK have increased for young adults since the mid 1990s.
* The main reason that Scotland has a relatively poor life expectancy compared with other European countries is that it has followed UK trends fairly closely, and the UK as a whole has changed from a subregion within Western Europe which had lower specific mortality rates in infancy, and up to middle age, from the 1950s to the early/mid 1980s, to higher specific mortality rates at almost all ages. Within Scotland, specific mortality rates for both genders in their thirties are particularly worse than for sex-age matched populations in Western Europe overall from the 2000s onwards.
* Specific mortality risks for persons above retirement age within the UK have tended to be worse than those for Western Europe as a whole, and in particular France, since WW2. However, there is evidence that historically the UK and Scottish health disadvantage at higher ages was not always the case, with elderly men and women up until around 1940 having slightly lower specific mortality risks in Scotland than Western Europe overall, and some evidence of a slightly lower specific mortality risk in Scotland for women aged over 80 years persisting from the 1960s to the 1980s.
* Overall, the specific mortality risk disadvantage in Scotland is slightly greater for females than males, a long-term pattern which has persisted since the 1940s, due to survival rates in late middle age (50s and later ages) falling proportionately further behind trends in Western Europe than for males.
* Specific mortality rate trends in Scotland compare favourably only with those in Eastern Europe. Male specific mortality rates in early adulthood (20-40 years) used to be better in Scotland than in Northern European (Scandinavian/Nordic) countries, though worse after the age of 40, but since the late 1990s even this comparative advantage has been lost. Population health in Southern European countries has improved rapidly in recent decades, and children born in the 1940s and 1950s, in particular, had substantially specific lower mortality risks than in Southern European countries. However, the relative specific mortality rate advantage of Scots born in these cohorts were lost as they reached middle age in the 1970s and 1980s, and in later years and at later ages became substantial disadvantages.
* Average trends in the differences in log specific mortality rates, which 'over weight' mortality differences in young adulthood and childhood, sees Scotland falling further behind both trends in other Anglophone countries like Ireland, Canada and Australia, as as well as consistently lagging being England & Wales. The rate of fall-back in Scotland compared with all countries in Southern Europe, and most non-Anglophone countries in Western Europe, has been greatest from the early/mid 1990s onwards.
* As the absolute specific risks of death (i.e. on identity rather than log scale) tend to be concentrated in the most elderly, as well as in infancy, and specific mortality risks for these groups have undergone long-term declines in most affluent world countries, in terms of average difference in mortality risk (rather than log mortality risk) between Scotland and many other countries, there is nevertheless evidence of Scotland's mortality risks converging with other Northern European countries. However, there are a number of countries with particularly low mortality risks at older ages - France and Switzerland in Western Europe, Spain and Italy in Southern Europe, and Australia and Canada among non-European anglophone nations - and as a result overall average mortality rate differences in Scotland are particularly poor in comparison to them.

## Principal findings

*Somewhat in order of importance rather than novelty*

*May be helpful to frame discussion in age, period and cohort effects.*

*In part duplicating what Jon? has already written.*

* Key results for Scotland's disadvantage

1. A persistent post war mortality disadvantage compared to most European regions, and for the whole period (Northern Europe) for women (35+) men (40+) *Age effect*
2. Late80s/Mid 90s mortality disadvantage for men and women and Scotland compared to all of Europe *age period specific effect?*
3. Not Novel finding but changes have been in the context of overall improvements in Europe with Scotland having slower improvements but note that since about 1990 Mortality rates for people in 20s have **increased**
4. A long term historical disadvantage relative to the UK
5. Somewhat speculatively there may be a cohort effect of disadvantage for cohorts born following WWI Relative to the UK (Both Genders) and Northern European women appear disadvantaged with respect to mortality.
6. Exception to Scottish disadvantage include older age groups at start of 20th Century, and mortality for girls (since 1960s) and Boys (since 1980s)likely to *age and period specific?*
7. I Might emphasis worse than Anglophone countries except US.

*Given potential space effects I am not sure I would place much emphasis on Eastern Europe as that is a different story*

## Comparison with other studies

* The Campbell paper - what this adds to that.
* Convergence and divergence in longevity - Mackenbach work?
* What is already known about at which ages, and in which years, Scotland fell behind European trends.
* Research on cause-specific mortality and excess morbidity in Scotland, and how this links to age-year-specific mortality risk patterns shown here.
* Global Burden of Disease estimates of amenable mortality in Scotland, and how this compares with England & Wales.

## Strengths and weaknesses

### Strengths

* Very large amounts of data presented. Less dependence on summary stats which risk hiding the locus of differences.
* Looking at a wide range of comparator regions, including nested comparisons: Scotland in UK; UK in Western Europe; Western Europe in Europe; Europe in Affluent World
* Deaths at different ages tend to be due to different causes, such as chronic non-communicable diseases like CVD in earlier old age, cancers at older old age, and deaths from external causes in early adulthood. Even without knowing cause specific mortality precisely the presentation of specific mortality rates at different single ages provides strong clues as to what health issues affect populations in one country more than in other countries/regions, and so suggests where further investigations into cause-specific differences should be focused. (For example, deaths from external causes in young adult populations seems to have been likely explanation in Northern Ireland due to the Troubles, and similar issues may affect USA today.)
* Visualisation enables presentation of vast amounts of information and may identify cohort effects where, regression based techniques would struggle or dubious assumptions.
* Use of Shaded Contour plots look at overall changes and comparative level plots changes relative changes. However hard to look at both at once.

### Weaknesses

* data limitations. Not all countries available in HMD. For example Greece is not in HMD and is important when thinking about 'Southern Europe' as a region.
* Cause specific mortality data are not available within the HMD, and would not be available/coded to the same level of consistency as all cause mortality (changing standards, coding schemes, quality of cause of death coding over time and between countries).
* In consistencies both between and within countries over how mortality rates were defined. For example, Some countries included military deaths during the WWII and others did not.
* Country boundaries and populations have changed over time.
* Scotland relatively small sample size so at some ages to results are noisy.
* Mortality is a relatively insensitive indicator during young adult and possibly mid-life. As such there may be Latent cohort effects in early and later life that do not emerge, but might be observable for more sensitive indicators for these ages such as smoking or alcohol consumption.

## Interpretation and implications

* Main contributions to overall difference in e0 are due to infant mortality trends and mortality trends at old age, because these are the ages at which mortality risks are highest in absolute terms.
* A massive set of potential comparisons between countries and regions - both a strength, research opportunity and limitation. It is important that these analyses are combined with a clear idea of what we want to explore and understand, as otherwise it is possible to get overwhelmed by the number of possible comparators that can be made.

## Unanswered questions and future research

* Broader questions about mortality rate convergence and divergence
* Whether to separate Germany data into separate East and West regions before reunification
* Approach can be applied to many different countries, regions composing countries, and regions within countries, in order to understand the main differences between populations. Lexis surface visualisations can help make sense of large amounts of complex data which are already being routinely collected.
* Future research could combine data visualisation approaches with more formal statistical modelling. In particular the 'nested' quality of the comparisons used here (Scot in UK, UK in Western Europe etc) suggests some kind of multi-level modelling approach could be appropriate, for quantifying how much of the mortality trends in Scotland are explained by it being part of the UK, and how much of the UK mortality trends are explained by it being part of Western Europe; could produce alternative models with different hierarchical specifications to explore whether Scotland follows trends of Western Europe (Super-region A) or non-European Anglophone nations (super-region B) more closely.
* The concept of the Lexis surface involves thinking about age and year 'as if' it were space. This suggests models developed for spatial data analysis could also be usefully applied to these data. For example, BYM models.
* There would be value in producing interactive apps/tools which allow researchers to generate their own SCPs and CLPs to produce the analyses of most interest to them.
* Technical questions about how to deal effectively with small cell counts, as the regions/places being compared get smaller. Approach in this paper is for level plot components of images to be presented 'as is' (cells show CMRs directly) but for the contours to be based on data which has been smoothed by passing to an image processing algorithm. How much 'smoothing' should be applied? i.e. choice of bandwidth/tuning parameters and other technical issues can affect what the visualisations appear to show.

# References

# Appendix

## Appendix A : Definition of Regions

* Western Europe:
  + Austria (AUT)
  + Belgium (BEL)
  + Switzerland (CHE)
  + Germany (DEUT)
  + France (FRATNP)
  + Northern Ireland (GBR\_NIR)
  + Scotland (GBR\_SCO)
  + England & Wales (GBRTENW)
  + Ireland (IRL)
  + Luxembourg (LUX)
  + Netherlands (NLD)
* Northern Europe
  + Denmark (DNK)
  + Sweden (SWE)
  + Finland (FIN)
  + Norway (NOR)
  + Iceland (ISL)
* Southern Europe
  + Spain (ESP)
  + Portugal (PRT)
  + Italy (ITA)
* Eastern Europe
  + Estonia (EST)
  + Lithuania (LTU)
  + Latvia (LVA)
  + Slovenia (SVN)
  + Slovakia (SVK)
  + Poland (POL)
  + Ukraine (UKR)
  + Belarus (BLR)