# Title page & Abstract

## Title

Visualising and quantifying ‘excess deaths’ in Scotland compared with the rest of the UK and the rest of Western Europe

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## Abstract

**Background**

Scotland is known to have higher mortality rates than the rest of Western Europe (rWE), due to higher mortality from cardiovascular disease and cancer amongst older adults and alcohol- and drug-related deaths, suicide and violence amongst younger adults (especially since the 1980s). The extent to which this is due to interactions between age, period and cohort (APC) effects is unknown.

**Methods**

We obtained sex, age and year specific all-cause mortality rates for available European countries from the Human Mortality Database and constructed Comparative Level Plots (CLP) to visualise differences in mortality rates in Scotland compared with nearby populations, and synthetic cohort simulations to quantify the effect of such differences on excess deaths by different ages.

**Results**

Scotland’s mortality was consistently higher than the rest of the UK (rUK) since 1950 for men and women across ages. Those born between 1950 and 1960 in the UK, including Scotland, were also relatively protected from the mortality disadvantages experienced by other birth cohorts over time, but were relatively high for Scottish birth cohorts born between 1930 and 1950. Mortality rates were substantially higher in Scotland than rUK and rWE amongst younger adults from the 1990s onwards in a pattern suggestive of an age-period interaction. Only Eastern Europe had higher mortality than Scotland at this time (and only for the birth cohorts born in the 1970s).

**Conclusion**

Mortality in Scotland is not ubiquitously worse than other countries. Worsening mortality amongst young adults in the last 30 years reversed the relative advantage evident for those born between 1950 and 1960. Compared with rWE, Scotland and rUK have followed similar trends but Scotland has started from a worse position and had worse period effects in the 1990s and 2000s.

## Keywords

Mortality, Scotland, Age Period Cohort, Europe, Lexis

# Key Messages:

* Scotland has relatively high mortality rates but it is unknown if age, period or cohort (APC) effects are responsible.
* We used Comparative Level Plots (CLPs) and synthetic cohort simulations to look at and quantify APC effects in comparison to the rest of the UK and Europe.
* Since 1950, mortality in Scotland has been relatively high but the 1950s birth cohort in Scotland and UK had lower mortality, and young adults during the 1990s and 2000s higher mortality, than other parts of Europe.

# Summary Box

**What is already known on this subject?**

Substantively, it is known that mortality rates at many ages are high in Scotland compared with similarly developed countries, and have been for many decades. Methodologically, it is known that summary statistics such as period life expectancies can hide information about age and year specific mortality risks, which may indicate the presence of particular types of mortality risk; it is also known that heat maps and related approaches can be used to visually represent large numbers of age-year-group specific mortality risks, and so can help to reveal whether age, period or cohort (APC) effects are responsible for Scotland’s poor overall mortality.

**What does this study add?**

By refining Comparative Level Plots (CLPs) and comparing thousands of mortality risks in Scotland against those in the rest of the UK and Europe, we know that since 1950, mortality in Scotland have been relatively high but the 1950s birth cohort in Scotland and UK had lower mortality, and young adults during the 1990s and 2000s higher mortality, than other parts of Europe.

## Word count

Main document: 3437

## Acronyms

CLP Comparative level plot

HMD Human Mortality Database

APC Age period cohort

# Main Manuscript

## Introduction

Successive generations living in Europe have tended to outlive the last,1 as mortality rates both in infancy and at later ages fell.2,3. In this marathon to greater longevity, Scotland is considered a laggard.4 By 2010, Scotland’s life expectancy ranked lowest amongst countries in both Western and Central Europe,2 with higher mortality, and mortality inequalities, due to cardiovascular disease, cancer and respiratory disease amongst older adults, and relative and absolute rises, in substance abuse-related deaths, suicide and violence, in younger adults from the 1980s onwards.5–7

Research has explored the role of four mortality phenomena – lagging life expectancy improvement, wide health inequalities, the rise of external causes of death, the causes of the excess mortality – to understand Scottish longevity trends.8 Our paper extends these ideas by considering the role of age, period and cohort (APC) effects in explaining the overall differences in life expectancy and excess mortality in Scotland compared with the rest of the UK (rUK) and the rest of Western Europe (rWE), and how Scotland’s excess mortality has changed from the period 1950 to 2010. Given Scotland is part of the UK, and so subject to similar social and economic conditions, and political and healthcare decisions and priorities, as much of the rest of the UK, it is also important to compare the UK as a whole with rWE, to better understand whether APC and related effects observed in Scotland are also seen elsewhere in the UK. At the core of this paper, therefore, are three pairs of comparison: Scotland compared with rUK, Scotland compared with rWE, and the UK compared with rWE.

These three pairs of comparison, nested a bit like Russian Dolls, are made in two different ways: firstly visually using a form of heatmap we call a Comparative Level Plot (CLP); and secondly numerically, by using the same age-specific mortality rate data to simulate the cumulative mortality rates in different years, for different birth cohorts, and by different ages, in each of the populations being compared.

## Methods

### Data

Individual death and population counts were extracted from the Human Mortality Database (HMD),9 by single year of age at death and calendar year, for the period 1950-2010 from birth to age 90, for Scotland, the rest of the UK, and for other European countries. Death counts and population counts for the whole of the UK were produced by aggregating values for the same sex, year, and age for England & Wales (HMD code GBRCENW), Scotland (GBR\_SCO) and Northern Ireland (GBR\_NIR). Western Europe, excluding the UK, comprised Austria (AUT), Belgium (BEL), Switzerland (CHE), East and West Germany (DEUTE and DEUTW), France (FRACNP), Republic of Ireland (IRL), Luxembourg (LUX) and the Netherlands (NLD). Data were available in the HMD for each of these countries for each year from 1950 to 2009, except for East and West Germany (first year 1956) and Luxembourg (first year 1960). Population and death counts for 2010 were not available for Austria, Ireland, Luxembourg and the Netherlands.

### Measures calculated

Mortality rates at each age were calculated by dividing the aggregated death counts by aggregated population counts. For the CLPs, these were converted into log mortality rates using base 10, meaning that the values indicate the ‘number of zeroes’ in the mortality risk (i.e. -3.0 means 1-in-1000, -2.0 means 1-in-100, and so on). What the CLPs show are differences in these log mortality rates between populations of the same age, sex and in the same year between the two populations being compared. This means that the mortality rate ratio for any value, v, on the surface can be calculated as 10v. So, for example, a value of 0.01 implies around a 2% increased risk (100.01 = 1.023 to 3 decimal places ), a value of 0.05 around a 12% increased risk (100.05 = 1.122 to 3 decimal places) , a value of 0.10 around a 26% increased risk, and a value of 0.20 around a 60% increased risk.

Mortality rates at different ages and in different populations, sexes, and years were also used to estimate lifetables for different populations, and so the cumulative proportion of an initial population expected to survive to each age in single years, assuming the mortality rates observed either in a particular year or for a particular birth cohort. All analyses were performed using the R programming environment.

### Comparative Level Plots and Lexis Surfaces

The heatmap presented here, which we call a CLP, has age across the vertical axis, year across the horizontal, and values – the differences in log10 mortality rates – for each of these age/year combinations. This particular arrangement of values is known as a Lexis surface,10 defined more formally as a Cartesian mapping of year, age, and a third variable onto orthogonal axes.11,12 Lexis surfaces provide a qualitative description of instability across (i) the magnitude of rates, (ii) how rates vary by age, (iii) temporal trends in rates, (iv) the interaction between age and time (i.e. cohort influences).11,13 They form a useful first step in understanding the importance of age-period-cohort influences and supplement more formal modelling approaches which are often troubled in separating out age, period and cohort effects12,14,15

A red-blue divergent colour scheme was used in the CLPs. For any two population mortality rates A and B, the shade shows the value d = log10(B) – log10(A), or equivalently d = log10(B/A), and is red if the value B is greater than the value A, and blue if A is greater than B. The shade indicates how big the differences are between B and A, with darker shades indicating greater differences and lighter indicating smaller differences. Neighbouring values on the Lexis surface were ‘smoothed’ slightly using a Gaussian filtering algorithm within the spatstat package in R to make patterns and trends in the data easier to identify. The effect of this smoothing can be assessed by looking at the unsmoothed data in webappendix XXX16,17The CLPs were produced using the Lattice and LatticeExtra packages.18 An isomorphic projection was used to make it easier to identify cohorts, as with this projection they run at exactly 45 degrees from the bottom left to top right in the figures. A total of 61 years, from 1950 to 2010, are covered, and because of the isometric projection the maximum age presented is 90 years of age rather than older ages, to avoid producing figures that are much taller than they are wide.

### Synthetic cohort simulations

The synthetic cohort simulations involve simulating a large number of cohorts of 100,000 people (50,000 males and 50,000 females) from birth to much older ages. Each year, some of this initial cohort ‘die’ according to the age-specific mortality rates calculated previously, and the different population sizes remaining in place A (rUK or rWE) and place B (Scotland or UK) by particular ages are compared, producing estimates of cumulative ‘excess mortality’ in place B compared with place A by particular ages. The lifetables used to produce these excess mortality estimates were calculated both for periods, equivalent to vertical slices through the CLP, and for birth cohorts, equivalent to diagonal slices running at 45 degrees through the CLP, based on aggregated death and population counts for full calendar years, for each period from 1950 to 2010, and for each birth year from 1930 to 1979. For brevity the excess mortality estimates for each year or birth year are averaged over decades before being presented. The code used to produce these analyses, and the complete synthetic lifetables produced, are available as webappendix XXX.

## Results

### Comparative level plots

Figure XXX shows a two row by three column series of CLPs. Each row is a different sex, and each column is a different comparison: the left column Scot-rUK, the middle column Scot-rWE, and the right column UK-rWE. In total figure XXX represents more than 33,000 separate mortality risk differences, so to help navigate and discuss the figure we recommend each of the areas A, B and C, as indicated in Figure YYY, in turn.

Area A highlights the period 1950 to 1955. Over this period the average colour in the Scot-rUK column is pink/red, suggesting Scots have had higher mortality risk at most ages in the latter half of the twentieth century. Area A is partitioned into A0, covering childhood, A1, covering early adulthood, and A2, covering later adulthood. We can see from this that the difference in log mortality tends to be highest in A1, early adulthood, especially for males. However for females the Scot-rWE comparison suggests the greatest disadvantage is in A2, i.e. later adulthood, which given the much higher baseline risk at later ages has a greater overall contribution to Scot/rWE life expectancy differences. Area A in the UK-rWE column suggests similar mortality risk in childhood (A0), lower risk in early adulthood (A1), and similar (males) or higher (females) risk in later adulthood (A2).

Area B highlights cohorts born in the 1950. The sub-area B0 highlights 0 to 3 year olds, and the Scot-rWE and UK-rWE columns both show particularly low comparative mortality – a dark blue horizontal streak – at early ages. For UK-rWE males this comparatively low mortality appears to follow the cohort as they age, even as they enter their sixties. For UK-rWE females, and for Scot-rWE males and females, the 1950s cohort still appears distinct from neighbouring cohorts, but with effects that diminish with age and, for Scotland, to be associated perhaps with ‘less worse’ rather than ‘better’ mortality risk compared with rWE.

Area C highlights young adults, born after the 1950s, from 1995 onwards. The UK-rWE column shows that from the mid-1990s UK young adult mortality risk changed from lower (blue) to higher (red) than rWE, meaning a comparative advantage which had existed for nearly two generations was lost in recent years. Relative risk increased similarly for UK-rWE males and females, but slightly earlier and more severely in Scot-rWE, especially for males. Of particular concern are males aged between 30 and 40 years from 2005 onwards, marked as C\* in figure YYY, which appears as a distinctly dark red section in the figure, especially for males in the Scot-rUK and Scot-rWE, suggesting this recent deterioration is UK-wide but particularly acute in Scotland.

### Synthetic population simulations

Mortality rates in Scotland were higher at all ages than in the rest of the UK in the 1950s, with the excess larger with increasing age. However, over the subsequent decades, the excess mortality rates among those aged under 10 years reduced rapidly and consistently such that by the 1980s the rates were lower in Scotland. For those aged <20 years the excess deaths declined to a low of 2.2 per 100,000 per year in the 1980s before subsequently increasing. A similar pattern was also seen for those aged <60 years where the excess declined from 1950 to 1980 before subsequently increasing again. When adults aged >60 years were included, there was decline in excess mortality in Scotland until the 1970s before it increased. Each Scottish birth cohort had higher mortality than the rest of the UK throughout their life course, although earlier birth cohorts had consistently greater excesses than the later cohorts.

Compared to the rest of Western Europe, the UK had lower mortality rates at all but the oldest ages in the 1950s, with substantially lower rates particularly evident amongst those aged <70 years. This relative advantage decreased over time, and decreased first at younger ages and then sequentially with increasingly older groups. The pattern is confirmed by the birth cohort analysis which shows that each cohort born from the 1940s onwards had a decreasingly small relative advantage over their life course. The exceptions to this pattern was a substantial excess mortality in the UK amongst those aged 70-80 years in the 1980s and a smaller relative advantage for the 1930s birth cohort in the UK than subsequent cohorts. The comparison between Scotland and the rest of Western Europe has some similarities to that of the UK. However, the relative advantages are generally lower, and disadvantages higher, throughout. The mortality rates for the Scottish birth cohort from the 1930s carries a particularly high risk throughout the life course in Scotland (in stark contrast to the rest of the UK) and the 1940s birth cohort is only a little better; and mortality rates amongst those aged >40 years are consistently higher throughout the time series in Scotland. The birth cohort in Scotland born in the 1950s enjoys relatively lower mortality rates through the life course compared to both the UK and the rest of Western Europe.

## Discussion

### Main results

Mortality in Scotland has consistently been worse than rUK amongst adults over time, but the relative mortality advantage over the rWE has now been lost. The birth cohorts born in Scotland during the 1930s and 1940s had particularly high mortality rates over their life course relative to rUK and after the age of 50 years relative to rWE, in stark contrast to the relatively low mortality rates for those born in the 1950s in Scotland.

Between the 1950s and the 1980s, the relative advantage in mortality rates enjoyed by Scotland and the UK compared to rWE declined, and this was due to faster improvements amongst younger adults in rWE and the ageing of the 1950s UK birth cohort. During the 1990s and 2000s the relative mortality rates amongst young adults became substantially worse, and particularly amongst men. These changes were more akin to an age-period interaction than either a birth cohort effect or a period effect because mortality rates were not higher for the birth cohort prior to this time, nor did the higher mortality affect all age groups.

The methods employed here have identified birth cohorts in Scotland and the UK with vastly different mortality experiences over their life course, and age-period interactions since the 1990s, which are not easily identified from mortality summary statistics such as life expectancy or age-standardised mortality rates; thereby highlighting their utility.

### Strengths and weaknesses

This is the first study to visualize age-year mortality data for Scotland in comparison to populations beyond the UK. These data ‘maps’ reduce the need to use summary statistics which can hide important APC effects,20 and are efficient and effective at presenting many separate values. The SCPs and CLPs used allow thousands of data points to be visualized at the same time, reducing the need to aggregate data into coarser age categories, cohorts, and periods.

Aggregating mortality rates within adults aged 45-54 years, for example, led to overstated conclusions being drawn in widely publicized work by Case & Deaton about trends in all-cause and distress-based mortality in the USA since the late 1990s.21 More recent research showed this 10 year age to be too broad, leading to an aggregation bias22 which the Lexis surface approaches used here would have avoided.

The source of data is robust and the risk of error or systematic bias is low (although, as with all mortality data, there are some potential difficulties in interpreting mortality rates during wartime with the exclusion of some deaths in conflict). The code used are made freely available to other researchers.

The simulations following particular birth cohorts through time use period-based Lexis squares, rather than being composed of Lexis triangles which allow true population and death counts for specific birth cohorts to be estimated more precisely. Further research could investigate the effect that using Lexis squares rather than Lexis triangles has on these estimates. However the cohort-based simulations are mainly intended as illustrations of the cumulative effects of mortality differences on excess deaths, rather than being the most precise possible estimates.

The data have been smoothed slightly using an image processing algorithm before being plotted, and the appearance of the CLP necessarily depends partly on the degree and type of smoothing applied. Further research could investigate the influence the type and level of smoothing using both the spatstat package used here, the alternative MortalitySmooth package, and other approaches detailed elsewhere.16,17,23

As Webappendix A describes, we could not obtain data for all countries in each European region, nor for the entire time period (in particular for Eastern Europe). Some national boundaries changed slightly over time. Finally, mortality data are a relatively insensitive measure of health status, particularly at younger ages, and quite large differences in mortality rates are obscured by the relatively large bands between contours and colours on the charts.

### Comparison with other studies

Analyses of demographic and epidemiological data focused on England & Wales, and the UK overall, have identified cohorts born between around 1925 and 1945, between the first and second diagonal in the CLPs, as having experienced greater mortality rate improvements than earlier or later cohorts24,25. Case & Deaton looked at 45-54 year olds in the USA from the late 1990s onwards, an age group which interestingly included part of the 1950s ‘protected cohort’ in the late 1990s, but subsequent cohorts, with comparatively higher mortality, by the late 2000s, further highlighting issues with neglecting cohort effects in looking at these trends and of assuming homogeneous mortality risks within the age group.21

This paper confirms the findings of others in terms of the emergence of cohorts with higher mortality in Scotland from the 1980s,2,6,26,27 the intermediate position of Scotland between Eastern and Western Europe,2,4 and the relatively low mortality in childhood in Scotland as in most other affluent world nations.5 The long-term impact (birth cohort effect) of the 1918 influenza epidemic has been noted in Europe28 and elsewhere,29,30 but the positive generational birth cohort effect associated with the ‘baby boomers’ (born 1950-1960) in Scotland is new. Mackenbach’s recent work exploring the convergence and then divergence in mortality experiences across Europe using summary statistics similarly identified the increased mortality amongst young adults in Eastern Europe and Scotland;31 the visual method employed here adds age-period interactions. Our paper uses a similar grouping of countries into sub-European population regions as Mackenbach’s, to account for the different socioeconomic and political trajectories of different regions within Europe. We consider both rUK and rWE to be meaningful and similar comparators to Scotland, but have also made comparisons with other country groupings, such as other Anglophone nations. Further research could identify, for instance, which country or group of countries Scotland’s population most closely resembles.

The relative rise in mortality in young adults in Scotland is known to be related to increases in alcohol- and drug-related deaths, suicide and violence, as well as wide inequalities across socio-economic groups, and at older ages due to higher rates of cardiovascular, cancer and respiratory mortality.4,32 The causes of these mortality patterns have been discussed at length elsewhere,8,26 and are due to be updated.

### Implications

Mortality trends in Scotland both followed and lagged those in the rest of the UK, which worsened compared with rWE. Understanding why this relative decline occurred is important for improving health in Scotland and the rest of the UK. These methods could also be applied to understanding different populations within the same country or region, such as more and less socioeconomically deprived populations, and for exploring differing trends in cause-specific mortalities.

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