## Trends

In addition to this there are broad trends over time. This effectively means that the age effects are varying over time rather than fixed.

Two patterns which might have spatial components are the short-term spread of a pandemic, and the long-term spread of a broad range of public health provisions which led to increases in longevity over a period of decades.

There are thus five features which a statistical model needs to represent in order to be able to test the intuitions developed by visual inspection of the contour maps. These five features are: area ( spatial) effects; age effects; period effects ; cohort effects; and trends.

This paper describes what happens when we look at demographic data in a way which makes a range of complex patterns apparent. These demographic data, from the Human Mortality Database, have been recorded separately for males and females for thirty seven countries, including every European nation. For some nations, the data stretch back over a century. This depth and breadth of data, together with our knowledge about the spatial proximities of nations from each other, suggests that the visualisations can be used to help work towards a more formal analysis of the spatial influences that nations may have upon other nations. The method of visualisation, shaded contour plots, and the data being visualised are not new. However both the data and the software needed to analyse them are now more easily available than ever before. This opens up exciting new opportunities for further exploration of the data and generation of hypotheses about the influence of spatial and non-spatial factors to the patterns observed. By exploring a method of visual analysis which makes the identification of complex patterns easier, we hope to encourage the development of theoretically sophisticated statistical models which allow for the formal testing of hypotheses and projection of trends.

The generation and testing of hypotheses can be like a flywheel, with data required both for the confirmatory and disconfirmatory components of this journey. To aid the generation of hypotheses, effective and appropriate methods of visualisation can be of great benefit in making otherwise hidden patterns much easier to see. As people are prone to type 1 errors, however, the development of formal models which allow the testing of these hypotheses should then follow. The development of such models is important also for allowing the simulation and projection of the trends implied, including appropriately wide bounds of uncertainty.

Statistical summary measures can give the impression that things are the same when they are not. For this reason the use of graphical techniques is encouraged

Data visualisation can be helpful both as a prerequisite to formal statistical analysis, and as a corrective to over-reliance on summary measures which help identify patterns which summary statistics miss.

This paper represents a call for spatial statisticians to use our visualisations as a starting point for the development of formal spatio-temporal demographic models, which would allow the testing of a range of hypotheses implied by the visualisations, including the spatial influences they imply.

This paper will seek to do the following:

1. To introduce shaded contour maps to the viewer, and describe how these forms of visualisation can be used to identify complex patterns in mortality data
2. To highlight the spatial and temporal range of the data available. This range of data means that the contribution of spatial factors to the patterns observed can be explored.
3. To describe the features and hypotheses which formal statistical modelling of the data should be able to incorporate in order to be able to test and predict what is going on.

This paper will show how visualisation of demographic data can help to identify complex and important patterns. Identification of such patterns is a prerequisite for formal statistical modelling

Shaded contour plots of crude death rates across the age-year space, which we (re)introduced in a recent paper, allow complex patterns to be identified in these simple data.

The efforts of the demographers who set up the Human Mortality Database to curate data from many countries, and format and arrange these data in a consistent format, allowed for the consistent and automated production of shaded contour plots for all of the datasets the HMD makes available.

Having produced shaded contour maps for a large number of nations, and based on records which in some cases go back more than two centuries, there is untapped opportunity to look at these demographic maps in order to gain insights into broader spatiotemporal trends.

Basic demographic data have been recorded for hundreds of years in some European and pan-European nations. The accurate collection of such data has been encouraged in a large number of other nations though the creation of health demographic surveillance systems. These data allow a large number of subtle and complex trends to be identified. The fact that similarly unambiguous data have been recorded in a large number of countries which are more or less close together means that there is opportunity to use these records to make spatial inferences about the changing demographic and health structures of different nations, and factors which may have led to such causes.

The

is a project run by XX of XX and XXX of XX, freely available to researchers, in which the demographic records from a large number of countries have been compiled and presented in identical formats. This allows for the automation of analyses, as standard formats are used. In the case of our visualisations, this meant that the visualisations were developed for a larger number of nations. For the full dataset.

The resolution of the images is one year of age by one year of time.

### The Bathtub mortality model

Age effects are comprised of at least two components: mortality associated with infancy and early childhood, and also mortality resulting from ageing. The infant mortality represents a ‘hurdle’. All life afterwards is conditional on crossing this hurdle. The height of this hurdle has dropped to a fraction of its former value in many countries. The substantive implications of this his to typical lived experience are difficult to overstate. The size of the infant mortality drop is easiest to see by looking at the true values rather than log values. Using log values makes this harder to see.

The infant and child size of the bathtub has reduced substantially in almost all of the nations for which the records reach back sufficiently far.

For countries for which the records do not stretch back far enough, the spatial proximity of nations means that some degree of additional information could be called on to allow inference and imputation of what the trends would likely have been.

; especially vulnerable in the first year of live, an elevated risk then elevated risk then for the first few years of life. However, there have been great changes However, the mortality risk experienced in the

Historically, mortality rates within the first five years of life have been around one-in-three in England and Wales in the 1850s, and only underwent a dramatic reduction in the first half of the Twentieth Century. This dramatic drop-off in early years mortality has occurred throughout the developed world. The spatial influences and associations of these trends have not been formally investigate Figure: Reduction in Child mortality

# Age Effects

### Norway

Data for Norway go back a long time. Norway has a relatively hazardous natural environment. The coming of age effect for Norway is particularly pronounced in older years, but (on the unlogged scale) is much harder to detect in more recent years.

### Other maps – logged scale

Using maps of log-mortality rather than mortality make the coming of age effect clearer. Between about the ages of three and sixteen, people have very low mortality rates.

## Spatial components

### In some nations, civilian populations were more exposed to the effect cf military populations than in others

### Allied Effects & Axis Effects

### Gender effects

### Civilian vs military

For some nations, the data are presented separately for the total population compared with the civilian population. This allows some insight into how much military service was a factor in

### Centrality & Periphery

# Cohort Effects

## Later effects

This paper has discussed a recent rediscovered approach to the visualisation of spatial data. This approach makes it easier to identify age-period-cohort effects in the data than if it were presented in tabular form. This paper has emphasised how the data available allow spatial effects to be incorporated too, as many of the datasets are for nearby nations. This means that the data allow and even call for modelling of spatial aspects to the magnitude of the effects observed.

The appendix to our paper presented a variation of the shaded contour plot which was not featured in the main paper. In this variation, the horizontal axis represented year of birth, rather than year, and so a vertical line, going from bottom to top, follows the cohort of individuals born in that year. The effect of rearranging the data in this way is to turn the period effects, which in the standard shaded cohort plots presented here are disruptions along the north east diagonal, into vertical disruptions, and to turn period effects into diagonal disruptions moving in a north westerly direction. These variations were not the focus of this or the previous paper because they necessarily involve plotting triangles of empty space in the north east quadrant of the map – the mortality rates of sixty year olds in the cohort of individuals born last year is simply unavailable – and so are a less efficient use of the plotting area. However, they may be preferable for tasks such as gauging the size of the cohort effects described previously, and so are mentioned here for reference. [REF to appendix]

Neither looking at the historical real cohort or the cross-sectionally derived real cohort shows what is likely to be of most interest to researchers, namely, how will mortality vary as a function of age over the whole life course for specific cohorts comprising at least some members who are still alive?

The relationship between mortality risk and age can be determined either by following the mortality rates of a cohort of people as they age, or by looking cross-sectionally, and looking at the relationship between age and mortality rate in a given year.

There is also a protective effect associated with childhood. This can be seen for some very old data such as Norway, using real values. It can also be seen more clearly using more recent years using the log scale. Taking a cross section for a particular year, and using the log scales makes this risk easiest to see. Once someone has moved beyond childhood and entered early adulthood, there is evidence of a ‘hinge’ – a later age at which an ageing process starts to occur. It could be that this ageing hinge has has change over time. It is not known if this hinge is real or apparent. A model which assumes the ageing process is made up of few components may not be substantively worse at fitting than one which explicitly incorporates more parameters.

Although more subtle than the age effects in infancy and in older ages, many of the visualisations exhibit coming-of-age effects: i.e. once someone reaches young adulthood, then mortality rates rise.

There appears to be a different in the presence/degree of the coming of age effect between genders.

Given the age of the data in which this pattern was observed, it may be that this second hinge has shifted in the time since. This would be reflected in the distribution of contours on either the log or the standard scale. There may also be spatial as well as temporal factors at play, so that nations which are closer together may have coming-of-ageing hinges at similar values.

The need for more complex models to the Gompertz-Markham bathtub, and the influence of spatiotemporal effects, can be tested formally, through comparing the penalised model fit of the ‘bathtub’ model with models which explicitly account for coming-of-age and coming-of-ageing effects, which allow these effects to vary over time, and which allow for spatial influences between nations. Visual comparisons of the datasets through exploration of shaded contour plots can help researchers consider which hypotheses should be modelled and how they should be modelled.

Like the magnitude of the period effects which occurred around the same period, there is value in a more systematic comparison of the cohort effects originating from this period as well, as there is considerable variation in how large these demographic scars were. The

Cohort effects are positive or negative effects in mortality associated with being part of one particular cohort rather than other cohorts. A cohort effect which we will focus on is the 1918 cohort effect. Like period effects, cohort effects are easy to identify using shaded cohort plots.

There are also gender effects to explore. Gender is one way of helping to assess how differential exposure to events leads to different magnitudes of effects. For some of the data, results are also presented separately for civilian populations, allowing the additional effects of military service and mortality rates to be assessed.

The spatial influence on age effects are, unlike period and cohort effects, relatively subtle. The majority of the data available are from Europe. We can expect some level of sharing and copying of technologies, ideas and infrastructure. Countries which are closer to each other, either geographically or culturally, can be expected to be share and copy more from each other than those which are further apart. Formal modelling of how the health of nations have risen and fallen together is important and interesting.

Cohort effect are also apparent in the contour maps. The most important or salient cohort effect is associated with the wake of World War 1. This was a key feature discussed in Visualising Europe’s demographic scares. The effect is already known to demographers but the visualisations make it much clearer.

two variations to the Two variations were produced. In the standard variation, one of the axes is year and the other is year. In the alternative variation, year of birth rather than year is plotted. Within the birth year-age mortality surface, cohort effects are apparent as vertical disruptions, and period effects as disruptions running at a north westerly diagonal. By contrast, in the standard year-age mortality surface, cohort effects are vertical disruptions and cohort effects run at a north easterly diagonal. Within this paper, only the standard plots will be presented.

A task for statisticians, given this information, is to model the magnitudes of these effect and how they differ between countries. Given such forma modelling, the magnitudes of such effects for public health could also be estimated. For example the number of years of life lost to the pandemic in terms of additional mortality in the cohort can be estimated. The scar is even clearer in the log mortality pot. These plot mortality plots also show that a qualitatively similar cohort effect has emerged in the Wake of world War two. Given that this cohort is large in magnitude and entering retirement, a small cohort effect for this group may be more important than a larger effect of the now almost extinct WW2 cohort. For example, it may affect the size of the pensions deficit in many European countries, as this projections depend fundamentally on how long people are expected to live for.

1918 Effect

Thrifty Metabolism

(Painter et al.; Roseboom 2000; Roseboom et al. 2001; Elias et al. 2004)

## The benefits of formal modelling

Formal statistical models should be applied to the data to quantify the effects which the visualisations make apparent. The fact that some of the data are for the same time periods and nations which are near each other means the statistical model should incorporate spatial components into the analyses.

The benefits of formal modelling include: projection of trends into the future; projection of trends to years in which data are not available; estimation of counterfactuals in order to predict the magnitude of area-age-period cohort effects and trends. Good formal modelling is also needed to avoid being deceived, because people can see patterns when they are not really there.

## Bridge to main section

This paper will show particular visualisations in order to highlight age effects, period effects, cohort effects, and trends.

and to estimate the spatial factors which affected the results.

Our aim has been to show how such visualisations can help guide a general understanding of these effects,