Imperial College London

Counting the dead

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Declaration of Authorship

I, Theo Rashid, hereby declare that the work in this thesis is my own original research, and that I have appropriately cited any work within that is not my own.

"*Nobody is going to read your thesis.*"

Kyle Foreman

Abstract

People died in England and we modelled the death rates. This took longer than expected.

Acknowledgements

Thanks be to James Bennett.

Majid Ezzati, Seth Flaxman. Eric Johsnon Kyle Foreman, Robbie Parks. Barbara Metzler, Emily Muller. Ricky Nathvani, Honor Bixby, Sierra Clark, Victor Lhoste. Sam Acors Solange. Parents, Ros Geoff Hardern.

Table of contents

List of Figures

List of Tables

List of Abbreviations

CrI	**Cr**edible **i**nterval
CAR	**C**onditional **a**uto**r**egressive
CVD	**C**ardio**v**ascular **D**isease
GBD	**G**lobal **B**urden of **D**isease
ICAR	**I**ntrinsic **C**onditional **a**uto**r**egressive
IMD	**I**ndex of **M**ultiple **D**eprivation
LSOA	**L**ower Layer **S**uper **O**utput **A**rea
MCMC	**M**arkov **c**hain **M**onte **C**arlo
MSOA	**M**iddle Layer **S**uper **O**utput **A**rea
NCD	**N**on-**c**ommunicable **D**isease
NUTS	**N**o **U**-**t**urn **S**ampler
SAHSU	**S**mall **A**rea **H**ealth **S**tatistics **U**nit

Chapter 1

Overview

1.1 Welcome and Thank You

Welcome to this LaTeX Thesis Template, using the LaTeX typesetting system and Quarto and based on the LaTeX thesis template MastersDoctoralThesis version 2.0 downloaded from LaTeXTemplates. This LaTeX document class was authored by Vel (vel@latextemplates.com) and Johannes Böttcher based on a style file by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science.

1.2 A Short Math Guide for LaTeX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for LaTeX". It can be found online at AMS under the "Additional Documentation" section towards the bottom of the page.

1.2.1 Common LaTeX Math Symbols

There are a multitude of mathematical symbols available for LaTeX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page.

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the LaTeX command for the symbol you need.

1.3 About this Template

This LaTeX Thesis Template is originally based and created around a LaTeX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/.

Steve's `ecsthesis.cls` was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: http://www.sunilpatel.co.uk/thesis-template.

Sunil's template was made available through LaTeXTemplates where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil's template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by Vel (vel@latextemplates.com) and Johannes Böttcher.

1.4 What this Template Includes

1.4.1 Folders

- Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate qmd file. An example and template are included in the directory.

- Chapters – this is the folder where you put the thesis chapters. Each chapter should go in its own separate qmd file.

- Figures – this folder contains static figures for the thesis, i.e. figures that are not generated by code in the chapters.

1.4.2 Files

- example.bib – this is file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Zotero is popular and integrates with RStudio IDE if you use that.
- MastersDoctoralThesis.cls – this is the class file that tells LaTeX how to format the thesis.
- pdf in docs folder – this is your typeset thesis.
- Frontmater folder – this has the files for the various front matter elements.

1.5 Filling in Your Information

Most of the personal information is found on in the `_quarto.yml` file.

- author – you; optionally add url
- supervisor – your supervisor; optionally add url.
- university – your university
- department – your department
- faculty – faculty name
- group – research group name (optional)
- abstract

1.6 The `tex\before-body.tex` File Explained

The `tex\before-body.tex` file contains the structure of the thesis and is a mix of Pandoc template and LaTeX code. The bits that look like `$book.university$` say are Pandoc and are referencing variables in the `_quarto.yml` file. Knowing that, you should be able to figure out what is happening.

There are plenty of written comments that explain what pages, sections and formatting the LaTeX code is creating. Each major document element is divided into

commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of LaTeX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Many of the sections have `$if(...)$` so that the section is only included if you included information for that in `_quarto.yml`.

In the `_quarto.yml`, `pdf: toc: false` is used so that Quarto/Pandoc doesn't add a table of contents. This template puts the table of contents before the abbreviations and symbols pages and Quarto/Pandoc doesn't let us control where it puts the table of contents. So we have to add the TOC manually for pdf and pass in `toc: false`.

The list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is **not** done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

1.7 Adding Your Chapters and Appendices

Add your chapters and appendices to `_quarto.yml`. Note that the spacing is important as is the leading `-`.

1.8 Bibliography and Citations

Citations will be added and formatted automatically for you.

Practice reference (Rashid et al., 2021) Lorem ipsum dolor sit amet (Bennett et al., 2015, 2018; Yu et al., 2021)

If you use the RStudio IDE, then you can link Zotero to RStudio and Quarto will find your citations for you when you enter `@`. This is in the visual editor mode. Make sure to search for videos on how to do this as using Zotero libraries will make your citation and bibliography management much much easier.

In the text use `@smith2000` to produce Smith (2000) add use `[@smith2000, @jones1999]` to produce (Smith 2000; Jones 1999). See the natbib cheatsheet for how to do other types of formatting for your in text citations. The bibliography style (`classoption: "authoryear"`) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online.

1.8.0.1 A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. "international" characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. One solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in `tex/in-header.tex`: `backend=bibtex` and changing it to `backend=biber`. Google a bit to find information on this.

1.9 Thesis Features and Conventions {sec-ThesisConventions}

To get the best out of this template, there are a few conventions that you may want to follow.

1.9.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as adding `"oneside"` to `classoptions:` in the `_quarto.yml` file. The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the class options. The spacing can be changed similarly by replacing the `"singlespacing"` with `"onehalfspacing"` or `"doublespacing"` in the class options.

1.9.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be by editting `geometry:` in `_quarto.yml` in the pdf format section.

1.10 Tables

When you render your Quarto thesis to PDF, it will process LaTeX table code just fine. However, if you are doing that, I am guessing you would be writing your thesis in LaTeX not Quarto. So I will not discuss LaTeX tables. Instead here is how you create tables using R. Python and Julia users, you'll have your own table packages but the idea will be similar.

See the Quarto manual for full examples and instructions.

1.11 Figures

Again we write in Quarto (markdown) not LaTeX for our figures. You can write in LaTeX if you really want but it would only be interpreted for the PDF output.

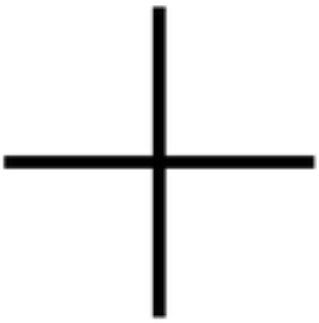

FIGURE 1.1: icon

The `#|` is what sets up our cross-references and you can then reference the table as `@fig-icon`.

This is Figure 1.1.

See the Quarto manual for full examples and instructions.

1.11.1 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, LaTeX will make it look beautiful, for HTML or PDF output.

The Not So Short Introduction to LaTeX should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, A Short Math Guide to LaTeX.

1.12 In Closing

Good luck and have lots of fun!

This guide was written originally by

Sunil Patel: http://www.sunilpatel.co.uk}{www.sunilpatel.co.uk

and Vel: http://www.LaTeXTemplates.com

and heavily shortened and adapted for Quarto by Eli Holmes.

Chapter 2

Background

2.1 Small area health statistics (unit)

In 1983, a documentary on the fallout produced from a fire at the Sellafield nuclear site in Cumbria claimed that there was a ten-fold increase in cases of childhood leukaemia in the surrounding community. This anomaly had gone undetected by public health authorities, raising concern that routinely collected data were not able to identify local clusters of disease. The subsequent enquiry confirmed the excess, and recommended that a research unit was set up to monitor small area statistics and respond quickly to *ad hoc* queries on local health hazards. The Small Area Health Statistics Unit (SAHSU) was established in 1987 (Elliott et al., 1992).

Beyond producing substantive research studies on environment and health, a core aim of SAHSU is to develop small area statistical methodology (Wakefield & Elliott, 1999) for:

- *Point source type studies.* Is there an increased risk close to an environmental hazard?
- *Geographic correlation studies.* Is there a correlation between disease risk and environmental variables?
- *Clustering.* Does a disease to produce non-random spatial patterns of incidence? If the aetiology is unknown, this could suggest the disease is infectious.
- *Disease mapping.* Summarising the spatial variation in risk.

In a pilot study for SAHSU, Elliott et al. (1992) investigated the mortality from mesothelioma and asbestosis near the Plymouth docks. Death registrations with postcode information were held by SAHSU. Both diseases are related to industrial exposure and asbestos, so concentric circular bands were drawn around the Plymouth dockyards as a way to approximate the exposure from a point source of environmental pollution. There was a clear increase in risk within $3km$ of the docks. A similar distance-based approach was adopted to look at excess respiratory disease mortality near two factories in Barking and Havering (Aylin et al., 1999), kidney disease mortality near chemical plants in Runcorn (Hodgson et al., 2004) In response to public concern over exposure to toxic chemicals in landfill, SAHSU conducted the most extensive study ever into health effects of landfill sites. Postocdes within a $2km$ buffer of a landfill site were classified as exposed. Compared to those living beyond $2km$, SAHSU found a small unexplained excess of congenital anomalies (Elliott, Briggs, et al., 2001), no increase in rates of cancer (Jarup, Briggs, et al., 2002), and no excess risk of Down syndrome (Jarup et al., 2007).

Distance from source is, however, only a basic model for the exposure, which can often exhibit more complex, directional spatial patterns. A number of SAHSU studies have employed physics-informed models to create an exposure surface, and assess the geographic correlations between this surface and the health outcome, notably for a plume of mercury pollution (Hodgson et al., 2007), exposure to mobile phone base station during pregnancy (Elliott et al., 2010), noise from aircrafts near Heathrow (Hansell et al., 2013), road traffic noise in London (Halonen et al., 2015), and PM10 from incinerators during pregnancy (Parkes et al., 2020). SAHSU published an environment and health atlas for England and Wales, showing the geographic patters of 14 health conditions at census ward level over an aggregated 25 year period alongside five environmental exposure surfaces (Hansell, Anna L. et al., 2014).

2.1.1 Disease mapping at SAHSU

Many of the studies at SAHSU focus on rare diseases at small areas. The data for the number of cases, or number of deaths, in a region are likely to small numbers. This sparseness issue is even more pertinant when the population is also statified by

age group. Rates calculated from observed data present apparent variability between spatial units, which is larger than the true differences in the risk. There is a need for statistical smoothing techniques to obtain robust estimates of rates by sharing information between strata. Aylin et al. (1999) mapped diseases for wards in Kensington, Chelsea and Westminster using a simple model that smoothed rates towards the mean of the risks across the region. SAHSU thereafter published a plethora of studies for disease mapping models with explicit spatial dependence, which are designed to give more weight to nearby areas than those further away.

There are three main categories for modelling spatial effects. First, we can treat space a continous surface, such as Gaussian processes or splines. Second, we can use areal models, which make use of spatial neighbourhood structure of the units. Thirdly, we can explicitly build effects based on a nested hierarchy of geographical units, for example between state, county and census tract in the US.

In the context of disease mapping, events are usually aggregated to areas rather than assigned specific geographical coordinates. Wakefield & Elliott (1999) model aggregated counts as realisations of a Poisson process, in which the expected number of cases is calculated by integrating a continuous surface that generates the cases integrated over the area. The surface was some function of spatially-referenced covariates. Kelsall & Wakefield (2002) describe an alterative model, where the log-transformed risk surface is modelled by a Gaussian process, whose correlation function depends on distance.

Best et al. (2005) provide a review of the use of hierarchical models with spatial dependence for disease mapping. In particular, the authors focus on Bayesian estimation, and different classes of spatial prior distributions.

The first prior proposed for spatial effects $\mathbf{S} = S_1, ..., S_n$ is the multivariate normal

$$\mathbf{S} \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}), \tag{2.1}$$

where $\boldsymbol{\mu}$ is the mean effect vector, $\boldsymbol{\Sigma} = \sigma^2\boldsymbol{\Omega}$ and $\boldsymbol{\Omega}$ is a symmetric, positive semi-definite matrix defining the correlation between spatial units. A common choice

when specifying the structure of the correlation matrix is to assume a function that decays with the distance between the centroids of the areas, so that places nearby in space share similar disease profiles. Note, this is mathematically equivalent to the practical implementation of a Gaussian process, whcih uses a finite set of points. An example in Elliott, Wakefield, et al. (2001) chooses the exponential decay function to map cancer risk in northwest England.

A more popular prior is the conditional autoregressive (CAR) prior, also known as a Gaussian Markov random field. These form a joint distribution as in Equation 2.1, but the covariance is usually defined instead in terms of the preicision matrix

$$\mathbf{P} = \mathbf{\Sigma}^{-1} = \tau(\mathbf{D} - \rho\mathbf{A}),$$

where τ controls the overall precision of the effects, $\mathbf{A}$ is the spatial adjacency matrix formed by the small areas, $\mathbf{D}$ is a diagonal matrix with entries equal to the number of neighbours for each spatial unit, and the autocorrelation parameter ρ describes the amount of correlation. This can be seen as a tuning the degree of spatial dependence, where $\rho = 0$ implies independence between areas, and $\rho = 1$ full dependence. The case with $\rho = 1$ is called the intrinsic conditional autoregressive (ICAR) model. Besag et al. (1991) proposed the model (hereafter called BYM)

$$S_i = U_i + V_i, \tag{2.2}$$

where U_i follow an ICAR distribution, and V_i are independent and identically distributed random effects. The BYM distribution was employed to model spatial variation in the relative risk of testicular (Toledano et al., 2001) and prostate (Jarup, Best, et al., 2002) cancers for small areas in regions of England.

Further disease mapping studies at SAHSU using spatially structured effects have also extended the methdology to look at age patterns and trends over time of disease. Asaria et al. (2012) analysed cardiovasuclar disease death rates by fitting a spatial model for all wards in England separately for each age group and time period. Bennett et al. (2015) considered a model to jointly forecast all-cause mortality for districts

in England, age groups and years. The model used BYM spatial effects and random walk effects over age and time to capture non-linear relationships. It is also possible to borrow information across causes of death, as applied in Foreman et al. (2017) on forecasting cause-specific mortality for states in the US. Random walk effects were again used to non-linear temporal effects, a CAR prior was used for spatial effects, and a multivariate normal where the covariance matrix describes the correlation structure between the 15 cause groups. The model did not, however, share information between age groups. Although this is not directly a SAHSU study, the model was developed by a several people in the department.

In building models which consider the hierarchy of geographical units, these relationships are often incorporated into the model as a nested hierarchy of random effects. These models account for which spatial units lie within common administrative boundaries, but, by design, there is no knowledge of spatial distance included. This is often a desirable property of the model for certain geographies, like states in the US, which are administrative. Policy is decided at these geographies, so there is reason to believe these boundaries may have a greater effect on health outcomes than spatial structure. Although not used in previous SAHSU studies, Finucane et al. (2014) demonstrate how country-level blood pressure can be modelled as such, in this case exploiting the hierarchy global, subregion, region and country. Note, although these models group by geographical region, these models are not spatial as they do not contain any information on the position relative to other units.

2.1.2 Small area analyses of mortality (over space, but also time age)

Population issue, measuring between census, migration. Look at sahsu spatial epi book, Wakefield 1999. Births, deaths and migration for population between census years

Poeple who have calculated SMR. **Indirect** model vs direct model (calculate age specific and use life tables) of mortality

Over space:

Rotterdam Jonker 2012

Australia, Stephens 2013 NSW

South Korea

SALURBAL. Santiago Chile Bilal 2019

Over space and time: Entire country level United States LDL King county 2015, LDL 2016

United Kingdom Bennett 2015 (Bennett et al., 2015)

At the city level

Canada, Yu 2022 (Yu et al., 2021)

Specific small area to the UK: Rasulo, D., Bajekal, M., Yar, M., 2007. Inequalities in health expectancies in England and Wales–small area analysis from the 2001 Census. Health Stat Q 34 (35), 35.

Congdon

London wards DALY Congdon 2014

Practice reference (Rashid et al., 2021)

2.2 Mortality by specific causes of death

In the mid-twentieth century, a team in the US Public Health Service, led by Iwao Moriyama, began looking into the decomposition of mortality for the first half of the century into all diseases and injuries. Notably, Moriyama & Gover (1948) grouped vital registration data into primary causes, and found as the US saw overall downward trend in mortality, leading causes of death changed from communicable diseases, such as tuberculosis and diptheria, toward non-communicable, “chronic disease of older ages”, such as heart diseases and cancers. The success of the reduction – and in the case of typhoid fever, near-elimination – of infectious diseases was attributed to the strategy of the health officer in the early 1900s, who was preoccupied with

improving water and sanitation, and public health intervations such immunisation and quartantines.

By comparing vital registration data over several centuries, Abdel Omran observed this shift of mortality from communicable to non-communicable diseases (NCDs) in many countries (Omran, 1977, 1971). Specifically, although the pace and determinants of the transition varied between countries, Omran formalised three common successive stages of the shift in mortality:

1. *The Age of Pestilence and Famine.* Mortality is high and largely governed by malthusian "positive checks" – epidemics, famines, and wars.
2. *The Age of Receding Pandemics.* Mortality decreases as epidemics become less frequent.
3. *The Age of Degenerative and Man-made diseases.* Mortality declines further along with fertility, increasing the average age of population and NCDs take over as the leading causes of death.

He termed this the *Epidemiologic Transition theory.* Omran (1971) explained that England and Wales took the classic transition path followed by western societies, whereby socioeconomic factors such as improvements to living standards are crucial in causing easily preventable diseases to subside and shifting towards the third phase of the transition, and medical and other public health technology only help society much later in the final stage.

Around the same time as Omran, Samuel Preston collated cause-specific mortality data for a huge number of populations, spanning 48 nations and nearly a century (Preston, 1970; Preston & Nelson, 1974). This would enable international comparisons of groups of causes of death over different time periods, and a deeper understanding of the upward trends in life expectancy. In particular, by plotting cause-specific disease rates against overall mortality, Preston & Nelson (1974) saw that, over time, the contribution of infectious diseases to a particular *level* of mortality had become ever smaller. That is to say, as mortality declines, the contribution from infectious diseases also declines. Preston attributed this to an accerlating rate of medical progress guided by the "germ theory of disease", which public health and science were not able

to replicate for NCDs. Preston also traced the excess deaths in older males observed in western societies to cardiovascular diseases, cancer and bronchitis – a direct result of dramatic increases in cigarette smoking (Preston, 1970).

Since its first edition in 1990, the subject of international comparisons of the cause-specific composition of mortality has been the remit of the Global Burden of Disease (GBD) studies (Murray & Lopez, 1996). The studies aim to quantify and compare the burden of diseases, injuries, and risk factors, usually through cross-sectional methods but occasionally by examining trends and subnational populations (for example, Ezzati et al. (2008) and Dwyer-Lindgren et al. (2017)). An important innovation of the GBD study was the introduction of a hierarchical classification of groups of causes, with the broadest level divided into three groups: communicable, maternal, perinatal, and nutritional diseases (Group 1), NCDs (Group 2), and injuries (Group 3). Salomon & Murray (2002) made use of the wide-ranging dataset and grouping from the GBD to revisit the epidemiologic transition for the second half of the twentieth century, finding the majority of the change in cause structure occurs among children, with a shift from Group 1 to Groups 2 and 3, and in young adults, where the role of injuries is more dominant for men.

2.3 Health inequalities in the UK

While the UK is, by global standards, a wealthy nation with relatively high life expectancy, and the breadth of health inequalities are nowhere near the extremes seen in many other countries, the nation suffers still vast, preventible inequalities in mortality and morbidity. There are several ways to stratify the UK population and comapare inequalities between subgroups. Here, we focus on class, income, geography, and deprivation.

The notion of class is prominent in UK society, but health outcomes between classes are difficult to separate from other risk factors such as hazards in manual labour or smoking rates. The Whitehall study of 1967 followed 17,530 men working in the civil service and recorded their mortality over a 10-year period. Marmot et al. (1984) found, by classifying the civil servants into social class according to their

employment grade, there was a three-fold difference in mortality between the highest class, administrators, and men in the lowest class, mainly messengers and unskilled manual workers. They found, in general, a strong inverse association between grade and mortality – a term Marmot has coined a "social gradient". The men were working stable, sedentary jobs in the same office building in London, so the gradient could not be fully explained by smoking or industrial exposure alone. There authors concluded be other factors inherent to social class (defined here by employment), which explain the mortality differences. A second cohort of Whitehall employees from 1985 to 1988, this time including women as well as men, were screened and asked to answer questions on self-reported ill-health. Marmot et al. (1991) found the social gradient in health had persisted in the 20 years separating the studies. In 2008, Marmot was asked by the Secretary of State to conduct a review into the state of health inequalities in England and to use the evidence to design policy for reducing these inequalities. A key plot in the first Marmot Review, released in 2010, depicted the social gradient in mortality for regions in England by socio-economic classification of jobs [].

Income data is not a routinely collected statistic in the UK. Nevertheless, using a small survey of 7000 people on three measures of morbidity, Wilkinson (1992) showed health improved sharply from the lowest to the middle of the income range.

In 2015, the GBD Study released its first subational estimates of mortality, starting with the UK and Japan. Steel et al. (2018) assess these data, which divided the UK into 150 regions, finding mortality from all-causes varied twofold across the country, with the highest years of life lost in Blackpool and the lowest in Wokingham. In a study on forecasting subnational life expectancy in England and Wales, Bennett et al. (2015) estimated a 8.2 year range in life expectancy for men and 7.1 year range for women in 2012 between 375 districts. The lowest life expectancies were seen in urban northern England, and the highest in the south and London's affluent districts. Within London itself, male and female life expectancy showed 5-6 years of variation.

There have been substantial efforts in the UK to measure the deprivation of an area, with the standard deprivation indicator in England since the 2000s is the Index of Multiple Deprivation (IMD) – a composite indicator for each Lower-layer Super Output

Area (LSOA) covering income, unemployement, health, crime and environmental data sources (*English Indices of Deprivation 2019*, 2019). The Marmot Report presented life expectancy and disability-free life expectancy against IMD at the Middle-layer Super Output Area, whcih exhibit a strong social gradient (Marmot et al., 2010). The GBD study found the 15 most deprived UTLAs had consistently raised mortality, especially for all causes, lung cancer and chronic obstructive pulmonary disease. Deprived UTLAs in London, such as Tower Hamlets, Hackney, Barking and Dagenham did better than expected for that level of deprivation (Steel et al., 2018). Bennett et al. (2018) jointly estimated death rates by age, year and deprivation decile. They found since 2011, "the rise in female life expectancy has reversed in the two most deprived deciles, and has stalled in the third, fourth, and fifth most deprived deciles but has continued in better-off deciles." The second Marmot Review in 2020 also found female life expectancy declined in the most deprived decile between the periods 2010-12 and 2016-18 (Marmot et al., 2020). Digging further into these trends by region, the report found this trend was seen in all regions except London, the West Midlands and the North West, and that male life expectancy in the bottom decile also decreased in the North East, Yorkshire and the Humber and the East of England.

Since the turn of the millenium, there have been two periods of contrasting health policy in the UK. The early 2000s saw the implementation of the English health inequalities strategy under New Labour, with explicit goals of reducing geographical inequalities in life expectancy. The strategy saw a large increase in public spending targeting the social determinants of health, with policies on supporting families, tackling deprivation, and preventative healthcare. Barr et al. (2017) analysed the trends in life expectancy for different quantiles of deprivation and provided evidence that the strategy acheived its aim of reducing the gap in life expectancy between the 20% most-deprived areas and the rest of the English population.

Following the change in government in 2010, the strategy came to an end. The Conservative government implemented a series of widespread cuts to public services, collectively known as austerity. The study by Barr et al. (2017) saw that the trends in inequality reduction were reversing since 2012. These trends have been found at both ends of the life course: rising infant mortality associated with childhood poverty

(Taylor-Robinson et al., 2019), and falls in female life expectancy at 65 and 85 (Hiam et al., 2018). Although difficult to uncover causal relationships, Alexiou et al. (2021) found strong associations between cuts to local government and the change in life expectancy of the district in the study period 2013-17. As written in the *The New York Times*, "after eight years of budget cutting, Britain is looking less like the rest of Europe and more like the United States, with a shrinking welfare state and spreading poverty" (Goodman, 2018) – a comparison only compounded by the Brexit vote in 2018.

Policies of austerity were brought about as a response to the financial crash of 2008, which were global in scale, and many countries adopted similar fiscal strategies. In an international study comparing mortality trends in England and Wales to 22 comparator countries Leon et al. (2019) show, however, that although there was a general slowdown in improvement of life expectancy across many nations, the slowdown in the most recent period of the study, 2011-16, was more pronounced in England and Wales.

After a decade of cuts, the UK entered the 2020s facing the greatest public health challenge for a generation: the Covid-19 pandemic. Unsurprisingly, England and Wales suffering one of the highest excess deaths tolls relative to other industrialised countries (Kontis et al., 2020). At the current time of writing in 2023, the health service is yet to recover, with waiting lists for operations and waiting times for emergency care unhealthily high (Dorling, 2023). There is no suggestion that the picture of health and health inequalities in the UK should improve in the coming years.

Chapter 3

The model

Bayesian workflow

3.1 The data

Same dataset for each By age + sex, log scale Age specific and Life expectancy male and female over time Colour geom_tile plot PCA for age (Alexander) Death rate 2002-19 by district

3.1.1 Other data sources

Population data from ONS. Estimates, modelled for inter-censal years using births, deaths, migration The mid-2020 Small Area population estimates covered by this bulletin are fully consistent with population estimates for higher levels of geography including local authorities, regions and the national total for England and Wales. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bu
The description of the methodology in the following sections uses the example of creating rolled-forward mid-2020 Lower layer Super Output Area (LSOA) estimates. For example, we produced the mid-2020 LSOA estimates using the mid-2019 LSOA estimates as the population base. Middle layer Super Output Area (MSOA) estimates are created in a similar manner using derived MSOA quinary age-by-sex change ratios and are constrained to local authority mid-year estimates. Change ratios were calculated by quinary age group and sex for the patient register data. The change ratios are calculated by dividing for each dataset the mid-2020 count by

quinary age and sex by the mid-2019 count by quinary age and sex. For example, a mid-2020 count of 50 divided by a mid-2019 count of 40 gives a change ratio of 1.25. The ratios are then constrained to the mid-2020 MSOA estimates (less mid-2020 special population), which have been constrained to the local authority mid-2020 estimates less mid-2020 special population. The number of patients registered on GP lists in each OA at the mid-year point is used as a proxy for the true size of the population at the same point in time.

IMD data Focus on income, education, – not health Aggregate to different geographies map of IMD for London (LSOA), and IMD for England (MSOA) in 2019

3.2 Model

Why we model? Robust estimates Explanation of death rates, small numbers, zero population, variability Regression, statistical smoothing Same model

As complex a model as possible, capture as more variation "Full" model More parameters is harder to fit, fewer parameters makes inference easier Models are overspecified, like Bayesian neural networks (AGW paper)

3.3 Inference

Choice made to do sampling – gold standard Approximate inference state-of-the-art for spatial models, INLA, scales badly with the number of effects

Start with NIMBLE, group has experience with BUGS Gibbs sampling, finds conjugate relationships where they exist R interface but C++ backend, scales well to a large problem like this

Move to numpyro. Created CAR distribution, contributed to open source Sampling faster, more efficient NUTS Sampling on GPU, much faster Tried VI methods in numpyro, such as laplace approx, but failed to converge to sensible values

Chapter 4

Small: Life expectancy trends in England, LPH

4.1 Introduction

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4.1.1 Methods

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4.1.2 Results

4.1.3 Discussion

4.1.4 Conclusion

Chapter 5

Smaller: Life expectancy inequality in London

5.1 Introduction

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5.1.1 Methods

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5.1.2 Results

5.1.3 Discussion

5.1.4 Conclusion

Chapter 6

Cancers

6.1 Introduction

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6.1.1 Methods

Nunc posuere quam at lectus tristique eu ultrices augue venenatis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aliquam erat volutpat. Vivamus sodales tortor eget quam adipiscing in vulputate ante ullamcorper. Sed eros ante, lacinia et sollicitudin et, aliquam sit amet augue. In hac habitasse platea dictumst.

6.1.2 Results

6.1.3 Discussion

6.1.4 Conclusion

Chapter 7

Cause-specific

7.1 Introduction

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7.1.1 Methods

Nunc posuere quam at lectus tristique eu ultrices augue venenatis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aliquam erat volutpat. Vivamus sodales tortor eget quam adipiscing in vulputate ante ullamcorper. Sed eros ante, lacinia et sollicitudin et, aliquam sit amet augue. In hac habitasse platea dictumst.

7.1.2 Results

7.1.3 Discussion

7.1.4 Conclusion

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Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

Pass in `urlcolor:` in yaml. Or set these in the include-in-header file.

If you want to completely hide the links, you can use:

{`\hypersetup{allcolors=.}`}, or even better:

{`\hypersetup{hidelinks}`}.

If you want to have obvious links in the PDF but not the printed text, use:

{`\hypersetup{colorlinks=false}`}.