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2. **Abstract.** [150-200 words]

This paper argues that an understanding of the human cost of the Troubles in Northern Ireland is vital in the context of Brexit. This human cost is manifest in all-cause mortality records for the country, which in this paper are explored visually using level plots. A model is developed which formalises a key intuition developed through exploring the data, in which excess deaths in young adult males are represented by a component with a peak intensity in 1972, which then gradually reduces over many years. We call this an initiation-decay model, and based on it estimate the Troubles to have cost nearly 3000 lives, close to estimates produced by meticulously aggregating conflict-related deaths, and calculate an intensity 'half-life' of nearly seven years. We argue by reference to the political and social history of Northern Ireland that the conditions may still be in place in Northern Ireland for a further wave of conflict to be initiated, and thus that Brexit negotiations need to be very cautious in its approach to the region and the land border separating it from the EU.

3. (Video Abstract)

4. 3-6 **keywords**.

Brexit; Northern Ireland; Mortality; Troubles; Data Visualisation

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6. **Disclosure statement**.

No potential conflict of interest was reported by the authors.

7. **Biographical note.** [up to 100 words]

Jon Minton is a researcher based in the School of Social & Political Sciences at the University of Glasgow. His primary research interest is in the applications of complex data visualisation approaches to exploring and understanding patterns in population data.

8. **Geolocation information.**

Scotland, UK

9. **Supplemental online material.**

The code used to produce the analyses presented here are available at the following location: https://github.com/JonMinton/Northern_Ireland_Troubles

A pre-print of this article and additional material is available from the following location: https://osf.io/3pj2f/files/

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The Shape of the Troubles: Visualising and quantifying conflict-attributable excess deaths after 1972 in young adult males in Northern Ireland

Introduction

Sectarian conflict often takes the form of tit-for-tat: they harm us, so we harm them (so they harm use, so we harm them…). Acts of violence in places in which sectarianism remains a predominant social force therefore tend to beget further violence. The most extreme forms of violent actions are killings, and in times, places and populations where sectarian tensions have tipped over into homicidal acts and reprisals, the effects of such conflict can be so intense as to become visible in the demographic records of the populations under the influence of such forces.

The aims of this paper are to first *illustrate*, then secondly to formally *represent*, the *shape* that the mortality effects of sectarianism in Northern Ireland had upon the demographic records of young adult men who lived and died in the country in the early 1970s and subsequent decades, a period commonly known as the Troubles. By *illustrating* this shape, I mean presenting mortality rates as a tiled surface of coloured values, each row a different age, and each column a different year. This arrangement is known as a Lexis surface, and by using different colours and shades to represent different mortality rates, a distinct visual feature – the demographic 'shape of the Troubles' – becomes clearly visible.

The 'shape of the Troubles' suggests that any additional mortality which resulted from the sectarian conflict has two properties. The first property is that it has a clear *time of onset (or 'impulse')*, with no visible mortality effect before this time, and a substantial effect afterwards. The second property is that, after onset, the intensity of the effect on mortality appears to *decay exponentially* with time. The second aim of this paper, to *formally represent* this shape, is therefore to build a statistical model of the complete mortality surface which includes these two key properties: the impulse, and the decay. By producing a statistical model of the complete mortality surface, in which the impulse-decay shape is included as a distinct component, a counterfactual surface of mortality risks can then be produced. This counterfactual mortality surface tries to answer the question: “What would have happened to mortality trends in Northern Ireland if the Troubles had not taken place?” By applying Northern Irish population counts to mortality rates in both modelled scenarios – the Troubles scenario and the no-Troubles scenario – an estimate of both the total number of lives lost to the conflict, and how the mortality burden varied over time and age, is therefore produced.

In the case of Northern Ireland, the number of deaths attributed to the Troubles has already been estimated carefully and directly, for example through studious collation of coroners’ records and newspaper reports. (See, e.g. (Smyth, 1998), (McDowell, 2008), (Curran, 2001)) These estimates cannot, of course, count any hypothetical deaths that may have been *averted* as a result of the Troubles, nor any that resulted *indirectly* from the Troubles. An example of an *averted* death could be if a young adult (most likely male) *would have* died of a vehicle-related fatality in an alternate Northern Ireland in which the Troubles did not occur, but due perhaps to the elevated police and military presence in the real Northern Ireland in the 1970s and 1980s, and consequent road speed restrictions and enforcement thereof, did not die of this cause, and so did not die in early adulthood. And an example of a death *indirectly* caused by the Troubles would be if an individual died of suicide or alcohol due to the emotional stress caused by living in this distinct sociocultural environment.

Given the near-philosophical nature of the above hypothetical scenarios of averted deaths and indirectly caused deaths, the counterfactual can never be truly known. What both the visualisations of mortality risks on Lexis surfaces, and the subsequent statistical model, aim to do is demonstrate what can be inferred about the human costs of violent sectarian conflicts from all-cause mortality records alone. All-cause mortality records (knowing whether someone has died) are invariably more readily available for populations than cause-specific mortality records (knowing why someone has died), and are less subject to economic and cultural variations in coding practice which can hinder meaningful comparison over large swathes of time and space. An example of temporal variation is the changes in ICD classification systems that periodically occur. [FURTHER DETAILS] An example of economic variation is the effect that limited public resource has on official record keeping and the construction of coroner reports. And an example of cultural variation could be the differential degree to which a coroner may be willing to designate an alcohol-related death or suicide *as alcohol-related or suicides* in a country with religious prohibitions on either consumption of alcohol or death by ('committing') suicide. By developing the Impulse-decay model and producing mortality estimates based on all-cause mortality records in the case of Northern Ireland, in which cause-specific estimates are available for comparison, the general utility and applicability of the model structure and broader model-development approach outlined here can be inferred for less economically developed populations which have also experienced sectarian conflict. Examples of possible applications are sadly numerous, and include Afghanistan and Pakistan/India in the 1980s; Algeria, Yugoslavia, and Rwanda in the 1990s; Iraq and Syria in the 2000s and 2010s; and Israel and its neighbours since 1948.

The impulse-decay model developed and introduced here can be applied to other populations whose mortality records exhibit the characteristic shape identified in young adult mortality surfaces for Northern Irish males, and will allow the human costs of sectarian conflicts to be compared in terms of two key model attributes: the initial intensity (impulse magnitude) of the conflict, and persistence of the conflict (decay rate) after initiation. The model presented here therefore links health and place with cognate concerns about conflict, peace and the causes and consequences of political actions to population health. An implication of the impulse component of the impulse-decay model, with a clear difference in mortality risk after compared with before initiation, is that the dynamics of peace in Northern Ireland are inherently unstable. It is as if there is a hidden threshold or 'tolerance' of sectarian tension, and once this threshold has been exceeded, inter-communal relations switch from a predominantly non-violent phase to a predominantly violent phase. Once this threshold has been exceeded, and the violent phase has initiated, its internal dynamics lead to an autocatalytic propagation of further violence, an echoed wave of additional mortality risk which can persist for many years or decades. This suggests there should be an imperative to adopt a precautionary stance when making political decisions involving Northern Ireland, as peace in the region may be more fragile than it currently appears. The issues relating to the United (sic) Kingdom's withdrawal from the European Union risk perturbing intercommunal relations in the region, in particular as they relate to power sharing arrangements within Northern Ireland, and to the Northern Irish border with the Republic of Ireland. These issues are discussed further in the discussion section.

Background and Intuition: Mortality in Northern Ireland compared with its Neighbours

Before providing a more formal description of the mortality model introduced above, it is useful to present some of those visualisations which led to the model being developed in the first place. As with much research, the origins of this paper are in a surprising but incidental finding in a previous paper [REF]. In this earlier paper, the substantive focus was on understanding the contribution that differences in age-specific mortality rates between Scottish and non-Scottish populations had to 'the Scottish Effect': i.e. to Scottish populations tending to have shorter life expectancies and higher standardised mortality ratios (SMRs) than most comparable populations. The aim was also to understand whether these difference in age-specific mortality rates had been persistent over time, or whether age-specific mortality rates had been converging or diverging compared with neighbouring populations.

In practice, visualising changing age-specific mortality rates, and changing differences between any two populations in age-specific mortality rates, meant arranging age-*year*-specific mortality as a series of coloured 'tiles', with the vertical position of the tiles determined by the age, the horizontal position by the year, and the colour/shade determined by the age-year specific mortality rate (or mortality rate difference) being referred to. These are Lexis surface (LS) visualisations, and in [REF] two types of LS visualisation were produced: shaded level plots (SLPs), showing the mortality surfaces for a single population group; and comparative level plots (CLPs), which show the degree of difference in age-year specific mortality rates on the log scale using colour and shade. For each CLP an index population B is compared with a comparator population A. Red cells indicate higher age-year mortality rates in B than A, and blue cells indicate higher age-year mortality rates in A than B. Further details are provided in [REF].

In the earlier paper the main index populations were either males or females in Scotland, and the comparator populations included England & Wales, the whole of the rest of the UK (rUK), or the rest of Western Europe (rWE). Comparing the mortality surfaces of Scottish populations with Northern Irish populations (not included in the final paper) revealed an unexpected and distinct pattern, with mortality hazards for young adult Scottish males suddenly 'falling below' those of equivalent males in Northern Ireland after the early 1970s. A moment's thought made it clear what this actually suggested was a sudden rise in Northern Irish mortality hazards, rather than a sudden fall in young adult Scottish males' mortality hazards. Reversing the index and comparator populations produces the CLP shown in the left-most column of Figure 1, in which red cells indicate higher mortality rates in Northern Ireland than in Scotland, and the intensity of the shade indicates the size of the difference in hazards between age-year matched populations. The second column compares mortality hazards between Northern Ireland and the rest of the UK (Scotland, and England & Wales combined); the third column compares mortality hazards between Northern Ireland and the rest of Western Europe (rWE), and the right-most column compares mortality hazards between Northern Ireland and Eastern Europe.

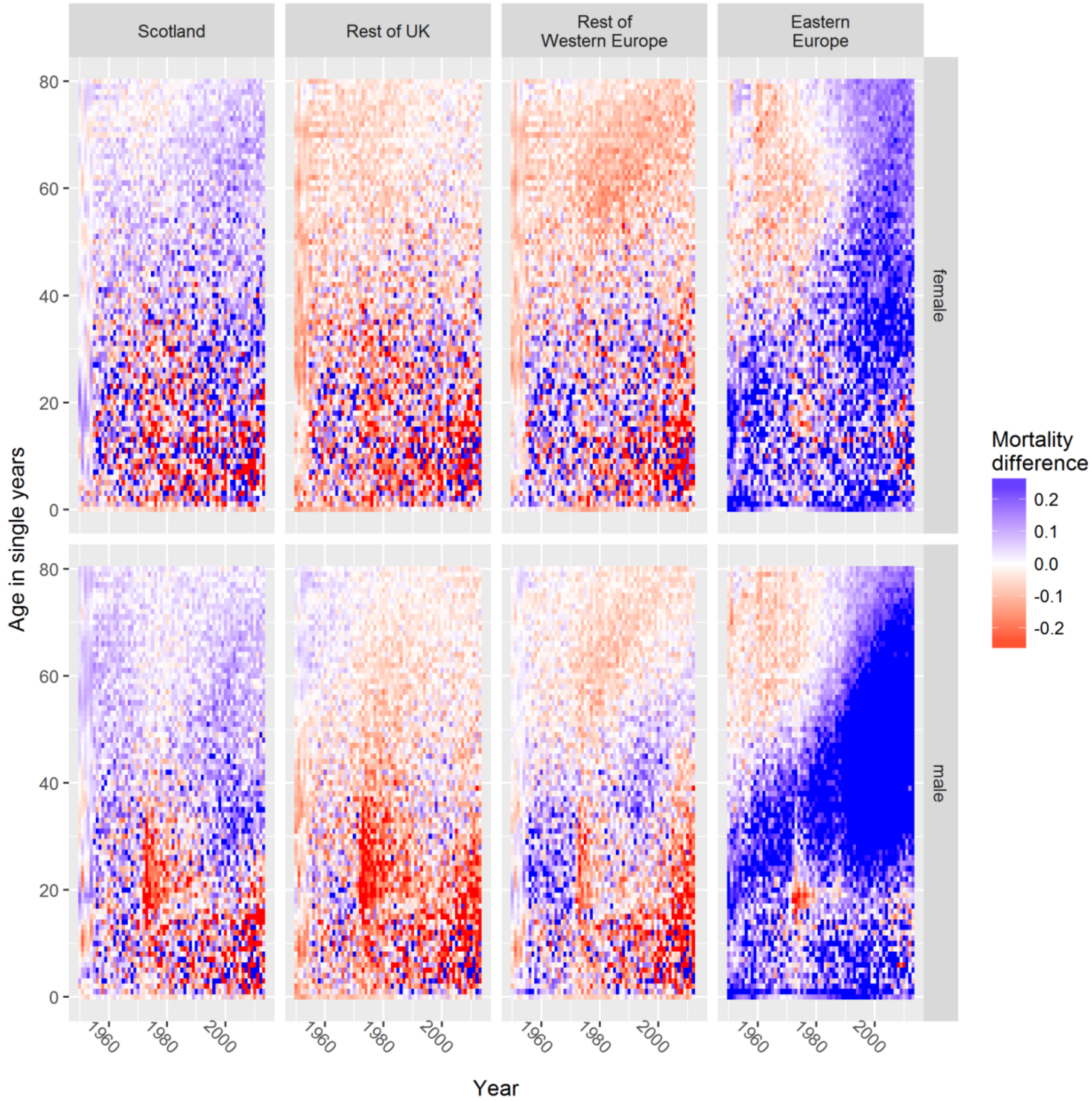


Figure 1 Comparative level plots (CLPs) for age-year specific mortality in Northern Ireland compared with other population groups. Differences shown are differences in log_{10} mortality rates, truncated within the range -0.30 to 0.30. Rest of UK comprises England & Wales (GBRTENW) and Scotland (GBR_SCO); Rest of Western Europe comprises Austria (AUT), Belgium (BEL), Switzerland (CHE), East Germany (DEUTE), West Germany (DEUTW), France (FRACNP), Scotland (GBR_SCO), England & Wales (GBRCENW), Ireland (IRL), Luxembourg (LUX) and Netherlands (NLD); Eastern Europe comprises Estonia (EST), Lithuania (LTU), Latvia (LVA), Slovenia (SVN), Slovakia (SVK), Poland (POL), Ukraine (UKR) and Belarus (BLR) Source: Human Mortality Database

Within Figure 1 a distinct asymmetric red vertical band is evident for male population comparisons, stretching between around ages 15 and 40, beginning in 1972. Mortality rates for young adult males (aged approximately 18 to 22 years) increased briefly above those seen in Eastern Europe (right column), even though mortality rates in Eastern Europe have tended to be much higher than those for those born after the establishment (and subsequent collapse) of the USSR; this is evident in the blue diagonal triangular features seen in these CLPs. A similar pattern is not observed for female populations. The rest of this paper proceeds incrementally from this initial observation, beginning with level plots and summary statistics of mortality rates and death counts observed in the age groups most affected, then proceeding to describe and fit the structural model developed in order to represent the characteristics of this feature.

Data and Methods

Data on all-cause mortality and population size, disaggregated by gender, age in single years and year, were extracted from the Human Mortality Database (HMD). (University of California, 2017) Mortality rates were calculated by dividing death counts by population exposure (adjusted population counts), with a continuity correction of 0.5 added to both numerator and denominator due to the use of the log scale and Northern Ireland's relatively small population size. All data management and analyses were performed using the R statistical programming environment. (R Core Team, 2016)

Initial visual exploration of data

In the first stage of the analysis, mortality rates by age and year are explored visually using Lexis surface level plots for a wide range of ages. (Jonathan Minton, 2014; Vaupel, Wang, Andreev, & Yashin, 1997) In the second stage of the analysis, equivalent level plots are produced for the age groups 15 to 45 years inclusive, as the bulk of the distinct mortality pattern appears to occur at this age. A simple plot of total numbers of deaths by year within this age groups is also produced, to illustrate the consequence of this pattern on mortality and gender differences.

Model development strategy and specification

In the third stage of the analysis, a model is developed to reproduce the main features of the level plot, with the Impulse-decay function modelled separately from underlying mortality trends. The considerations and approach used to develop this model specification are discussed further below.

Considerations in representing background rates of mortality improvement

In addition to the distinct Impulse-decay feature which is the focus of this paper ('the Shape of the Troubles'), it is also important to adequately represent longer-term trends in age-specific mortality rates. One of the most population actuarial models, the Lee-Carter model, assumes that all ages experience the same constant 'drift' towards lower log mortality over time. [REFs: Lee-Carter; Girosi & King] The intuition of this model assumption is as follows: imagine the Lexis surface of log mortality rates were drawn as a contour plot, as with a spatial map showing variation in height above sea level as a function of latitude and longitude. Each specific contour line in a Lexis surface of log-mortality rates therefore represents a fixed mortality hazards. The central assumption of the Lee-Carter model is that each of these contours 'drift' upwards from left to right at an angle somewhat shallower than 45 degrees (the angle indicating a single age cohort), and does so at all ages and for all periods of observations. For example, a given contour line, indicating a specific fixed mortality hazard, might be encountered at age 40 in 1950, age 45 in 1975, and age 50 in 2000; each mortality 'hurdle' is therefore put off to a slightly older age, and the overall result is a continuing improvement in life expectancies. The assumption that this rate of upwards drift in mortality hazards (in effect projecting forwards the Lexis surface along its first principal component) applies at all ages and is constant over time is a highly simplistic assumption, but often produces surprisingly good estimate of population life expectancy trends, because it tends to be a reasonable approximation of what has happened to mortality rate trends in older age (from about age 50 onwards), which is when most deaths occur.

In younger adulthood, and especially for male populations, the simplifying assumption of the Lee-Carter model appears less appropriate. The 'Shape of the Troubles' is a case in point, but mortality risks in young adulthood do tend to be more variable over in young adulthood than older ages due to risks of deaths from external causes, which claim a disproportionate share of lives in early adulthood, tending to be variable across time and place than deaths from many other causes. More complicated models for representing the way that mortality risks often increase sharply with the onset of adulthood in populations, especially males, have been developed, but these are difficult to fit and often do not also incorporate projections about changing age-specific mortality risks over time. [REFs]

Model specification and selection of mortality rate improvement phases

In order to try to represent how age-specific mortality risks are likely to have changed over time in the absence of the Troubles, the Lexis surfaces of log mortality rates in Northern Ireland were carefully explored within the 15-45 year age range for both indications of Lee-Carter style 'drift', and also discontinuities in the rate of 'drift' over time. Separate models were fit to represent changes in log mortality over time at each age in single years, but these models included a number of shared parameters. By looking at the extent to which mortality 'bands' of particular colours (the level plot analogue of contour lines in a contour plot) appeared to move upwards at different rates over time (See figure 5), it appears that underlying trends in mortality rate improvement fit within three distinct phases. These phases are: Phase one: 1922 to 1938, in which there was a moderate rate of drift; phase two: 1939 to 1955 inclusive, in which there was a rapid rate of drift (i.e. fastest improvement in mortality, despite including World War Two); and phase three: 1956 and later, in which there was a slow rate of drift. To represent these three distinct phases, the linear model specification allowed for separate intercept and slope terms for each phase, in addition to a parameter for representing the Troubles shape which will be discussed in more detail below. More formally, the model specification is as follows:

$$l_i(t) = \beta_{0,i}^{(P)} + \beta_{1,i}^{(P)} t^{(P)} + \beta_{2,i} T(t)$$

$$T(t) = (1-k)^{(t-1972)} \; IFF \; t \geq 1972; 0 \; otherwise$$

Where $l_i(t)$ indicates the log_{10} mortality rate for males of age i in year t, the superscript (P) indicates which of three distinct phases in mortality improvement to which year t belongs, and $t^{(P)}$ indicates the number of years since the start of the mortality improvement phase to which year t belongs. (Phase 3 was the 'reference period' in the regressions used.)

Operationalising and parameter tuning for the impulse-decay ('Troubles) function

In the above model, an impulse-decay ('Troubles') function, T(t), is introduced which aims to represent a particular form of mortality risk change that appears consistent with both domain knowledge of this history of the conflict, and also the particular pattern of change in age-specific mortality as shown in figure 1 and figure 2. This parameter operationalises the concept that the Troubles followed a single impulse-decay pattern over time, with events in the years prior to 1972 leading to a tipping point, an initiation in sectarian conflict that, once initiated, was then sustained through tit-for-tat violence, as might be expected in sectarian conflict in which violence from one side is likely to be met with reprisal attacks from the other side. Visually, this a change in underlying conflict intensity is shown in figure 2a below, in which there is first a sudden increase in intensity, followed by a slow decay in this intensity over time.

$T(t)$ is the function which models the mortality effect of the conflict, i.e. the Impulse-Decay or 'Troubles' function. It assumes that the additional mortality effect is greatest in the first year of the conflict, then decays exponentially with each subsequent year. The rate of decay in additional mortality is modelled using the parameter k, and can have any value from 0 to 1 inclusive. Numerical optimisation is used to select k such that the AIC (penalised model fit) is minimised.

Given k, the 'half life' of the conflict, i.e. number of years it takes for the additional log mortality risk to fall by half, can also be calculated using the formula $\lambda_{1/2} = \frac{\log(\frac{1}{2})}{\log(1-k)}$.

Use of Lexis surface visualisations for model diagnostic purposes

An innovative methodological innovation developed in this research is the use of CLP Lexis surface visualisations of *model residuals* (differences between observed and predicted age-year specific log mortality values). In these model residual level plots, red cells indicates that the model overestimates mortality rates, and blue indicates that the model underestimates mortality rates. The shade/intensity of these reds and blues indicates the magnitude of divergence between predicted and observed values, with darker shades indicating greater divergence.

The key intuition when looking at the residuals surface is that *better models will tend to look 'noisy',* with no clear patches of red and blue cells. A 'noisy' appearance suggests that the model is relatively effective in representing the underlying structure of the mortality surface, and that variations from the prediction surface are random. A surface with clear patches or regions of reds and blues indicate, instead, that the model does not yet adequately incorporate a key structural feature of the mortality surface, and so a new model specification, with additional terms to represent this feature, should be considered.

The use of Lexis surfaces to explore model residuals can therefore identify ways in which the model may be structurally inadequate, and should be seen as an important graphical diagnostic complement to standard summary measures of model fit such as adjusted R-squared and AIC.

Visualisation and estimating of effect of the Troubles on mortality

After having developed a final model specification by comparing a number of possible candidate models using standard model summary measures such as adjusted R-Square, AIC, and BIC, as well as by comparing residuals surfaces, and after 'tuning' the decay parameter k in T(t) using AIC, it is important to make the model predictions intelligible and substantively meaningful. This does not mean presenting a long series of statistical model coefficients and associated p values, but instead showing how the *surface* of age-years specific mortality rates produced by the selected model compare with the observed surface of values for the same range of ages and years. As the final model includes the Impulse-decay ('Troubles') function as a discrete term, a counterfactual prediction surface, in which the Troubles did not occur, can also be produced by setting the associated parameter value ($T(t)$) to zero for all ages and years.

By applying observed age-year specific population counts to both the standard ('with Troubles') and counterfactual ('without Troubles') model prediction surfaces, an estimate of the number of additional lives lost as a result of the Trouble can then be produced. More formally, the numbers of deaths at each age and in each year are estimated by applying the model's predicted mortality risks to the populations exposed to these risks, i.e. $D_i^A(t) = 10^{l_i^A(t)} p_i(t)$, where $D_i^A(t)$ is the number of deaths at age i and in year t under the active conflict scenario A, and $p_i(t)$ indicates the size of the population at this age and in this year exposed to the mortality risk.

A counterfactual surface of risks $D_i^C(t)$ is modelled by setting $T(t)$ to 0 in all years. The total number of conflict-attributable deaths estimated by the model in this age range is then the sum of differences in deaths estimated under both scenarios, i.e. $\sum_{i=15}^{45} \sum_{t=1922}^{2013} [D_i^A(t) - D_i^C(t)]$.

Finally, in the fifth phase of the analysis, the numbers of deaths at each age and in each year are estimated by applying the model's predicted mortality risks to the populations exposed to these risks, i.e. $D_i^A(t) = 10^{l_i^A(t)} p_i(t)$, where $D_i^A(t)$ is the number of deaths at age i and in year t under the active conflict scenario A, and $p_i(t)$ indicates the size of the population at this age and in this year exposed to the mortality risk. A counterfactual surface of risks $D_i^C(t)$ is modelled by setting $T(t)$ to 0 in all years. The total number of conflict-attributable deaths estimated by the model in this age range is then the sum of differences in deaths estimated under both scenarios, i.e. $\sum_{i=15}^{45} \sum_{t=1922}^{2013} [D_i^A(t) - D_i^C(t)]$.

Results

Visual exploration of patterns

Figure 2 shows the Lexis surfaces of $\log_{10}$ mortality rates for both genders and for each age between newborns and 90 years. Cells are coloured according to mortality rate. The legend on the right show which colours correspond to which mortality values. The values on this legend indicate the 'number of zeros' associated with the mortality risk, with ranges from 10^0 or 1.0 risk for light blue at the top, then to 10^{-1} (one in ten) for lighter green shades, 10^{-2} (one-in-100) for lighter reds, to 10^{-5} (one in a million) for the brown shade at the bottom of the scale.

Figure 3b provides a stylised 'pen portrait' of some of the main features seen in figure 1. As with in many other countries, there is a much sharper increase in mortality risk once males reach adulthood, not observed to the same extent in female. In more recent years this can be seen by noting that for males almost all purple cells are seen in childhood, with cells at older ages coloured light or dark orange. This broadly corresponds to somewhere between half an order of magnitude, to a full order of magnitude, increase in mortality risk after males reach adulthood compared with their risks in childhood. By contrast for females the difference in colour and shade in early adulthood is much less different to in childhood.

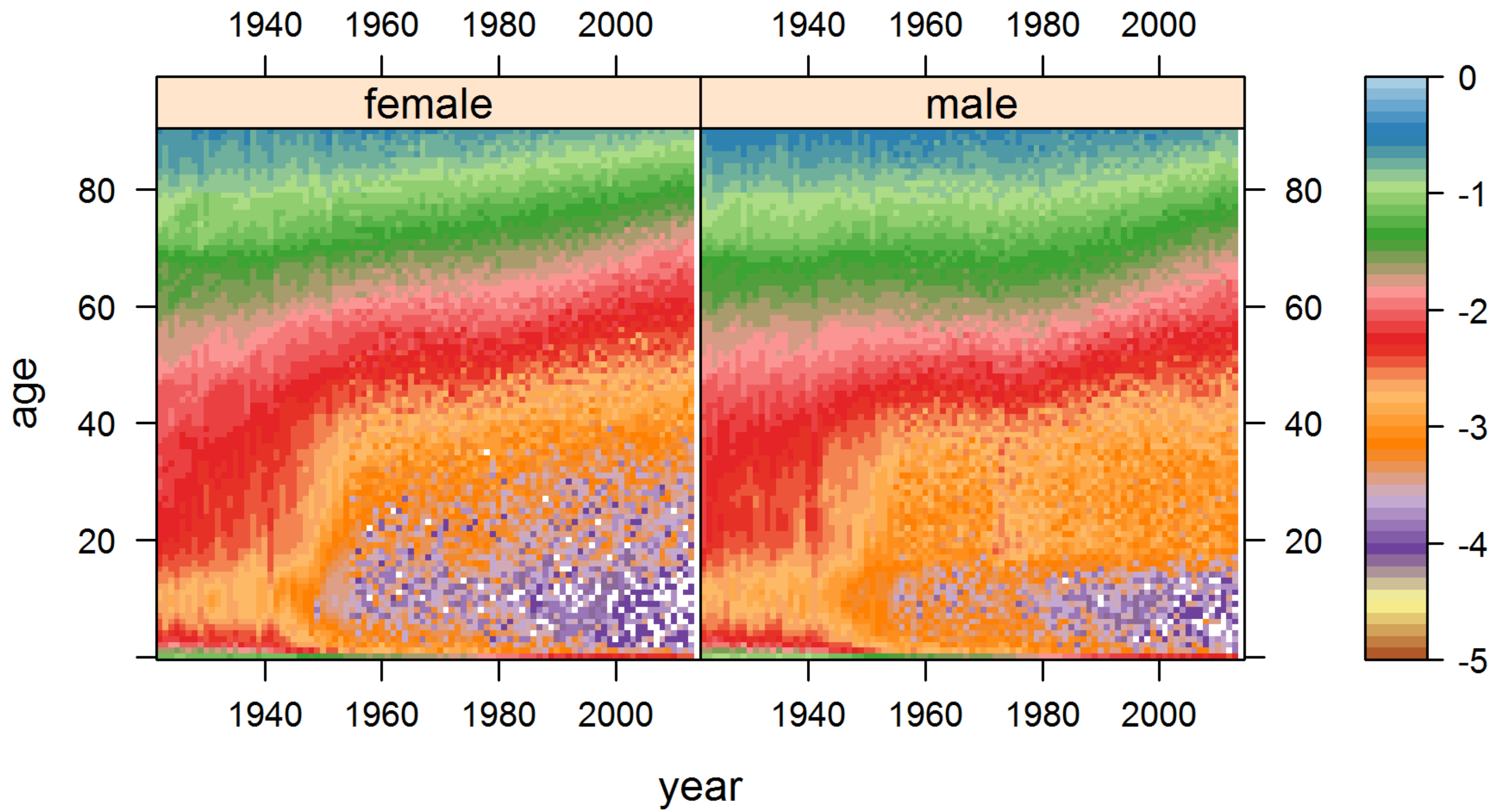
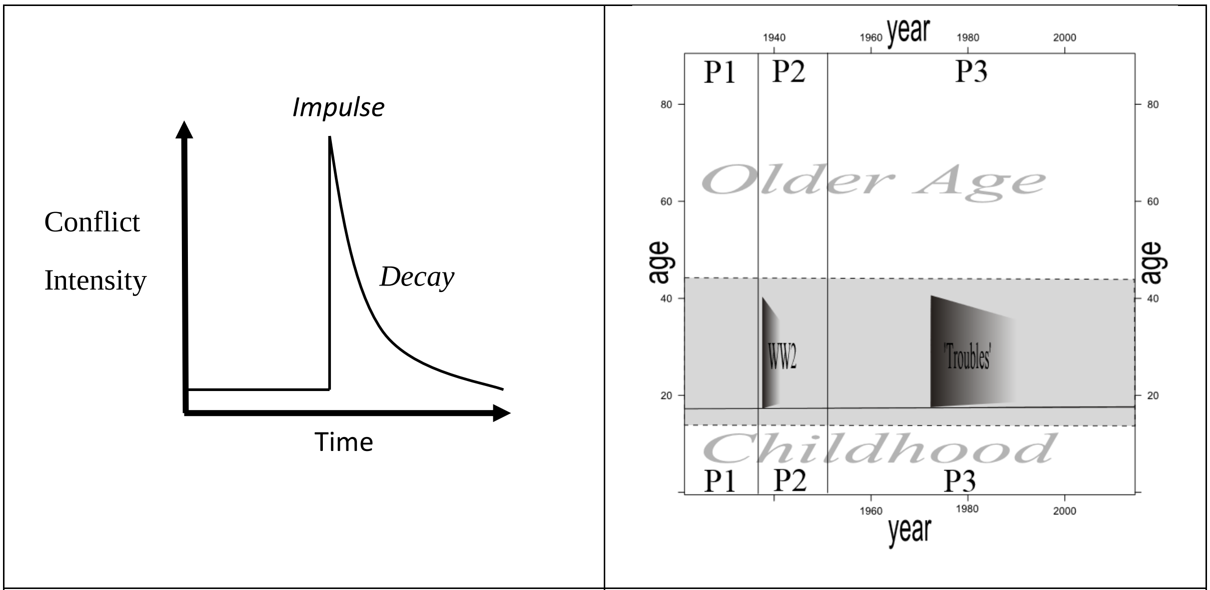


Figure 2: Levelplot of $\log_{10}$ mortality rates for males and females in Northern Ireland, 1922 to 2013. Cell colour indicates mortality risk. White cells indicate missing data. (Source: Human Mortality Database)



a) *Pen portrait of Parameter T(t)*	b) *'Pen Portrait' of key features in Figure 1.*

Figure 3: Stylised representations of a) impulse-decay component of conflict; b) Key visual features in the Lexis surfaces shown in Figures 1 and 2

Within Figure 3b, P1, P2 and P3 indicate 'Phase 1', 'Phase 2' and 'Phase 3', each demarcating periods of years in which there appeared to be systemic differences in the rate of change in mortality risk at different ages. The much more rapid falls in both female and male young adult mortality over Phase Two is evident in the Figure 2 level plot by noting that most of the cells in the age range 20 to 40 years are red before the late 1930s, whereas during this Phase they turn dark and light orange. This represents close to an order of magnitude fall in mortality risk at these ages over these years. This is despite the period including World War Two, indicated with a shaded polygon in Figure 3b.

The effect of the Troubles on mortality is evident by noting the faint vertical band of red cells which appears in the male level plot from around age 18 to 40 after the early 1970s. Before this red band appeared cells tended to be a darker orange shade (slightly under a 1-in-100 risk), and a slightly lighter orange/yellow shade after. No similar discontinuity at this age range after the early 1970s is evident for females. Figure 3 explores this pattern further, by plotting the number of deaths (not death rate) for males and females aged between 18 and 40 years. A grey band is added indicating the years 1971-1973. Male deaths increase in 1971 and 1972, peak in 1973, and then remain above those seen in earlier years for many years afterwards; no similar increase is seen for females. The Troubles had a longer term effect than WW2 on male mortality.

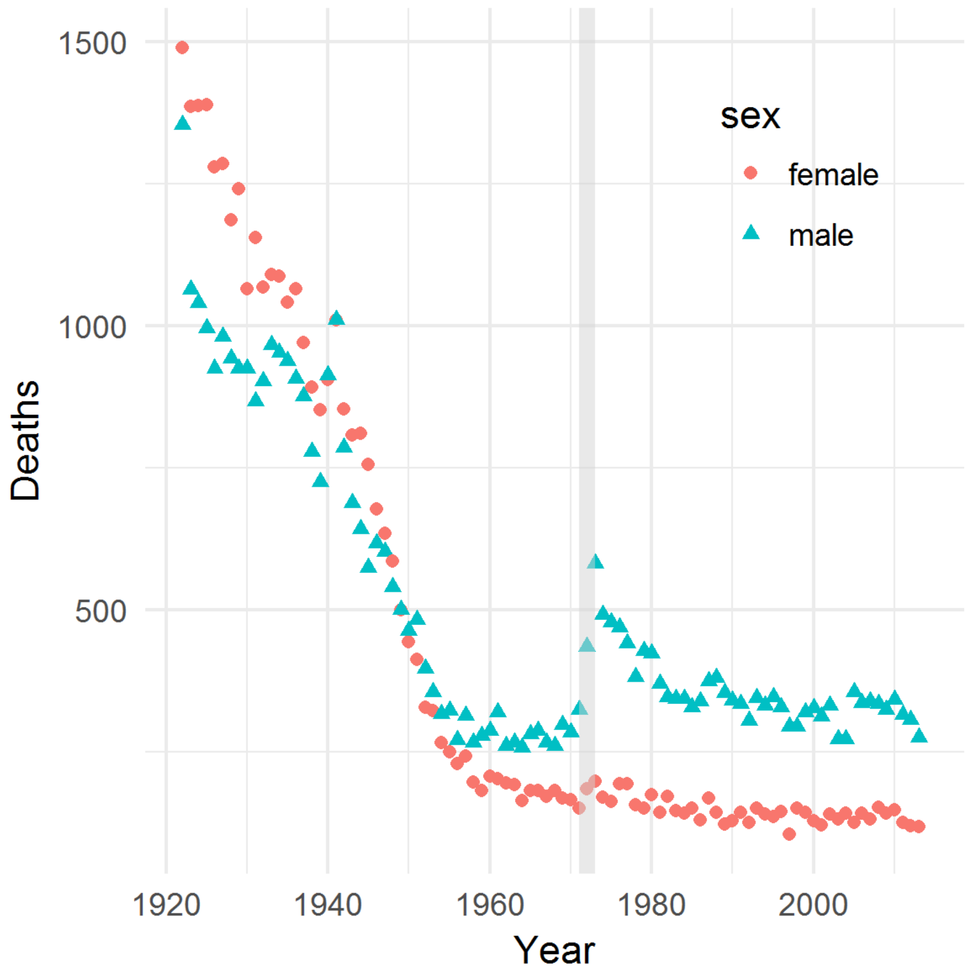


Figure 4: Deaths for males and females between the ages of 18 and 40 years in Northern Ireland. Grey band indicates the years 1971-1973

Within Figure 3b, the large horizontal grey band indicates the age range 15 to 45 years, within which further analyses will focus. Figure 5 shows level plots for males and females for this age range only, using a slightly different colour scheme and range of $\log_{10}$ mortality values to before. Within this plot the effect of the Troubles on male mortality is clearer, and appears as a band of light red, then dark red, cells after the early 1970s after orange and dark red cells in earlier years. Again, no similar pattern is seen for females. The disruption to earlier trends for males appears mainly to affect males once they have reached adulthood, and to be sharpest at younger adult ages, from around the ages of 18 to 21 years of age.

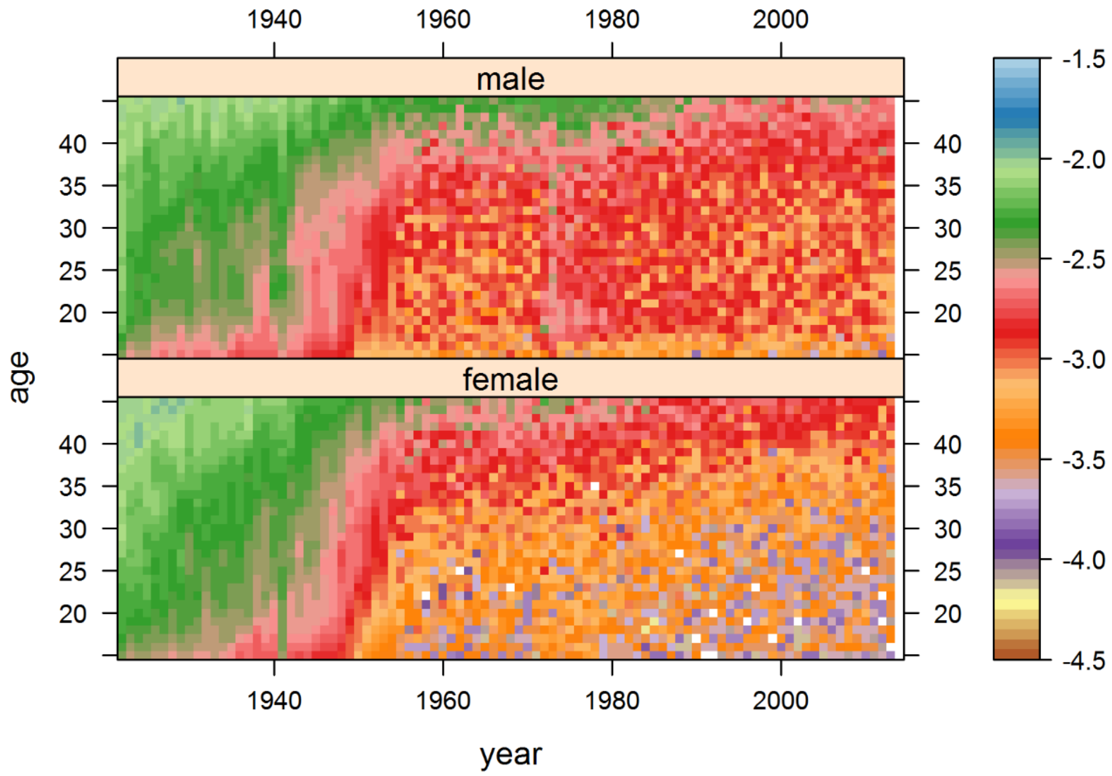


Figure 5: Level plot for log10 death rates for males and females between the ages of 15 and 45 years in Northern Ireland 1922-2013.

Modelling

Figure 6 comprises three rows, each presenting a $\log_{10}$ mortality surface for males over the age range 15 to 40 years and for all years. On the top row, labelled ‘predicted’, the model predicted surface, including the parameter for the Troubles, is presented; on the middle row, labelled ‘counterfactual’, the model prediction for a counterfactual scenario, in which the Troubles term is not applied, is presented; and in the bottom row, labelled ‘actual’, the actual $\log_{10}$ mortality values from the data are presented. We can see that the model is relatively effective at capturing the broad pattern and features of the actual surface, though is clearly and necessarily a somewhat stylised representation of the actual data surface.

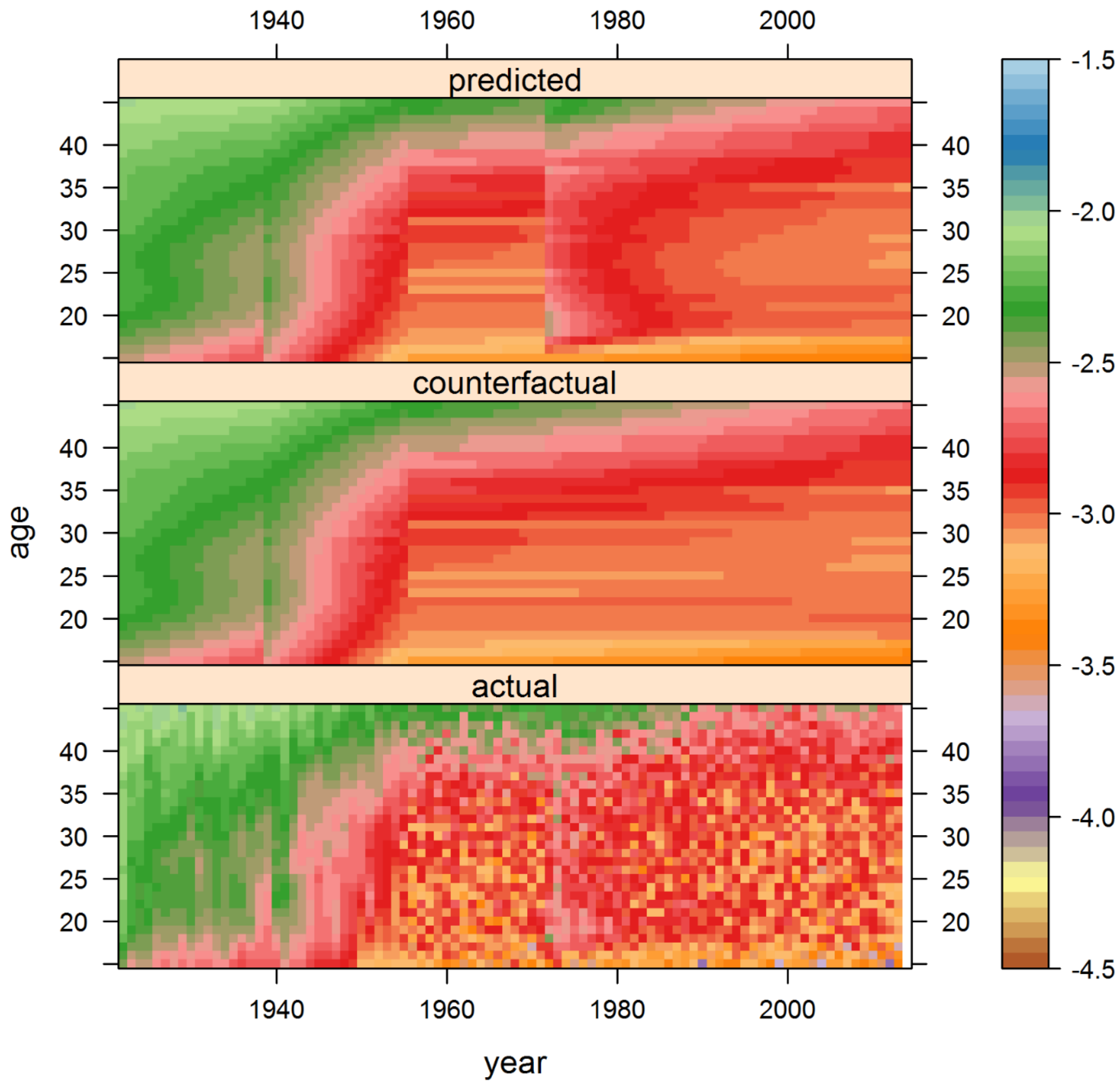


Figure 6: Level plots for modelled death rates (top row), modelled counterfactual death rates (middle row) and actual death rates for males aged 15-45 years in Northern Ireland, 1922-2013

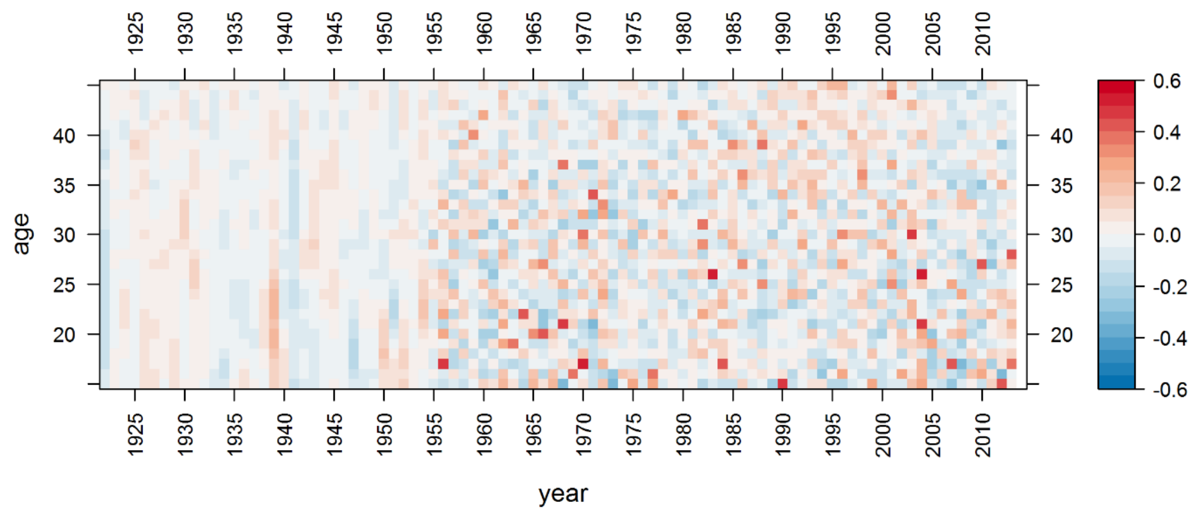


Figure 7: Level plots of residuals between modelled and actual log10 death rates by age and year for males 15 to 45 years in Northern Ireland, 1922-2013. Red indicates model overestimation, blue underestimation, and shade magnitude of error

Systemic bias in over-estimation or under-estimation of age-year specific mortality risks can be explored by looking at the surface of residuals between the predicted and actual surfaces, as shown in Figure 6: within this figure red cells indicate model over-estimation, blue cells under-estimation, and the shade of cells the magnitude of error. Systemic biases in these estimates appear as large 'patches' of cells with positive or negative residuals, as well as discontinuities in the data. There is a vertical band of red cells at younger ages in 1939; suggesting the model underestimates deaths in younger males during World War Two; this should not be surprising given the model does not include any terms to represent this event. Figure 8 shows the model fit as a function of the decay rate, k. The model has a best fit when k is 9.748%, suggesting a half-life of the Troubles of 6.76 years.

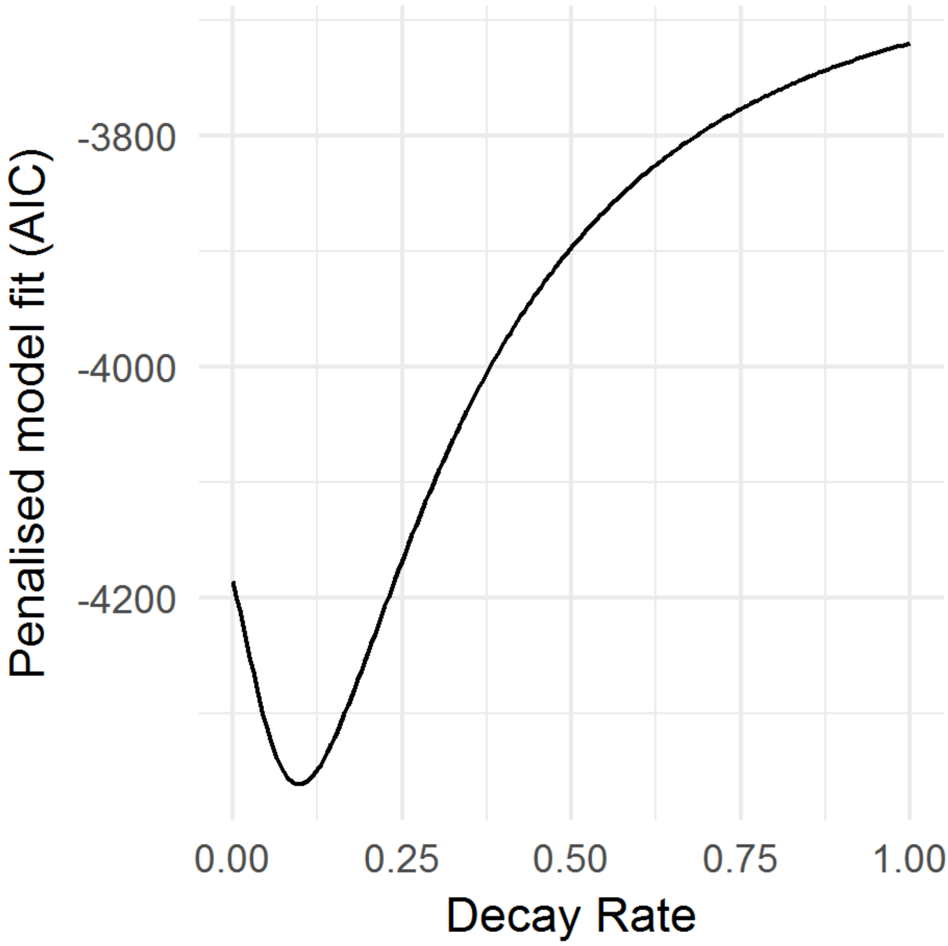


Figure 8: The relationship between decay parameter and model fit using AIC. (Lower AIC value = better)

Counterfactual estimation

Using the approach described in the methods section, the number of additional deaths attributed to the Troubles by the model can be estimated by applying mortality risks to population sizes under both the 'with-Troubles' and 'without-Troubles' scenarios. Figure 9 shows the estimated number of additional deaths at each age and year after 1972. These tend to be concentrated at the youngest adult ages, then reduce with age. This is further confirmed by extracting the coefficient associated with the Troubles for each age, as shown in Figure 9, which include the equivalent coefficients for females if using the same model specification.

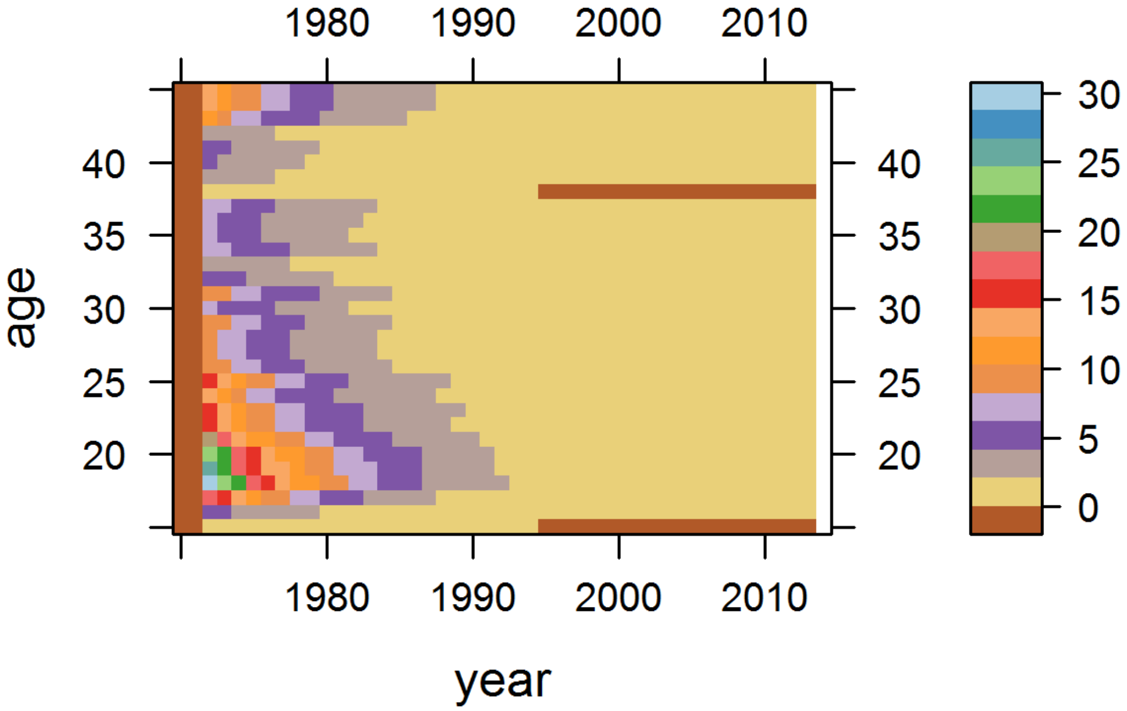


Figure 9: Model estimated 'excess deaths' due to the Troubles from 1970 onwards, in males in Northern Ireland aged 15-45 years. Colours indicate numbers of deaths by age and year; the legend is shown on the right.

For males the effect is positive at almost all ages, and is largest at age 18, then falls at most older ages; for females it tends to be negative, suggesting the model may be misspecified for females, and instead captures broader continual improvements in mortality risks over this time period. Table 1 shows the number of estimated additional male deaths by year and age group in five year intervals to the nearest whole number for each year from 1972 to 2013, with margins indicating the total number by year and age. This estimates nearly 2800 additional deaths by 2013, with over 1000 occurring in the first three years of the conflict from 1972 to 1975. Looking by age, over half of the estimated deaths (1470 out of 2776) are estimated to have occurred in boys and men aged between 15 and 25 years inclusive.

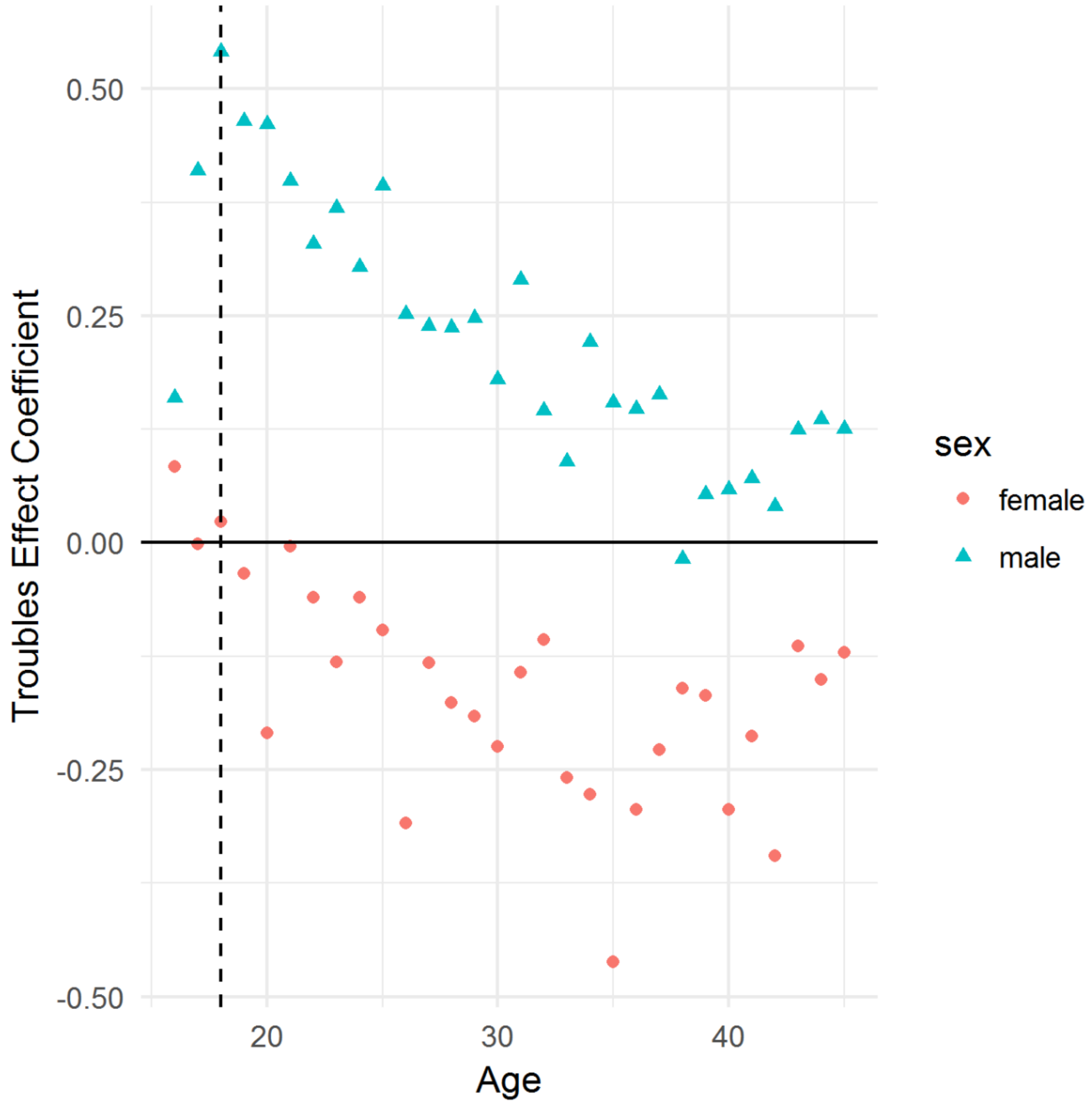


Figure 10: Coefficient of the ‘Troubles parameter’ by age in single years for males (blue triangle) and females (red circle).

	Age Group							
Year	[15,20]	(20,25]	(25,30]	(30,35]	(35,40]	(40,45]	**Total**	**Cumulative**
1972	101	78	43	32	22	46	322	322
1973	86	67	39	29	19	39	279	601
1974	73	58	34	26	17	34	243	844
1975	64	50	30	23	15	30	212	1056
1976	56	43	26	21	13	26	186	1242
1977	49	38	23	19	12	23	164	1407
1978	44	34	20	17	11	20	146	1552
1979	39	30	18	15	10	18	130	1682
1980	35	27	16	13	9	16	116	1798
1981	32	24	14	12	8	14	104	1902
1982	28	22	12	11	7	13	93	1995
1983	25	20	11	9	7	11	84	2079
1984	22	18	10	8	6	10	75	2154
1985	20	16	9	7	5	9	67	2221
1986	17	15	8	7	5	9	61	2282
1987	15	13	8	6	4	8	54	2336
1988	13	12	7	6	4	7	49	2385
1989	11	10	6	5	3	6	43	2428
1990	10	9	6	5	3	6	39	2466
1991	9	8	5	4	3	5	35	2501
1992	8	7	5	4	3	5	31	2532
1993	7	7	4	4	2	4	28	2560
1994	6	6	4	3	2	4	25	2585
1995	5	5	4	3	2	3	22	2607
1996	5	5	3	3	2	3	20	2627
1997	4	4	3	3	2	3	18	2645
1998	4	3	3	2	2	3	16	2661
1999	3	3	2	2	1	2	14	2675
2000	3	3	2	2	1	2	13	2688
2001	3	2	2	2	1	2	11	2700
2002	3	2	1	1	1	2	10	2710
2003	2	2	1	1	1	2	9	2719
2004	2	2	1	1	1	1	9	2728
2005	2	2	1	1	1	1	8	2736
2006	2	2	1	1	1	1	7	2743
2007	2	1	1	1	1	1	6	2749
2008	1	1	1	1	1	1	6	2755
2009	1	1	1	1	0	1	5	2760
2010	1	1	1	1	0	1	5	2765
2011	1	1	1	1	0	1	4	2769
2012	1	1	1	0	0	1	4	2773
2013	1	1	0	0	0	1	3	**2776**
Total	816	654	388	313	208	395	**2776**	

Table 1 Model estimates of numbers of Troubles-attributable deaths in males in Northern Ireland by year and age group

Discussion

Comparison of mortality estimates

(Smyth, 1998) estimated a total of 3598 deaths were attributed killings in the conflict between 1969 and 1998; this compares with 2661 estimated in our model between 1969 and 1998 in younger adult males in Northern Ireland only. Other total mortality estimates for the Troubles tend to be similar, with (McDowell, 2008) estimating slightly under 3700 deaths, and (Curran, 2001) estimating 3740 additional deaths between 1969 and 1999 (compared with our estimate of 2675 between 1972 and 1999). (Smyth, 1998) also found that a disproportionate share of deaths occurred in young adults, with a quarter occurring in people aged 18-23 years, and attributable deaths then falling at older ages. We found a qualitatively similar pattern of mortality burden by age, though with an even greater share in 18-23 age group, with 1053 deaths out of 2776, or 38% of all deaths, estimated.

My model, based only on all-cause mortality data, estimates around three quarters of the deaths that actually occurred, suggesting that the key modelling assumption - an initiation event leading to the sudden onset of a conflict whose intensity only slowly decays over many years – captures something of the essence of what occurred in Northern Ireland.

There may be a number of reasons why our estimates are below death counts directly attributed to political violence, in addition to my use of a more restrictive demographic group. Firstly, I did not explicitly model to include the particularly high spike of deaths in 1973. Secondly, adult males experience an increase mortality once they reach adulthood, and young adult male mortality displacement effects may occurred in Northern Ireland after the Troubles began. For example rates of homicide risk and suicide risk tend to be inversely correlated, and that both disproportionately affect younger adult males. (Curran, 2001; Durkheim, 1951; Lester, 2002) It may be that the high rates of 'bonding capital' within Northern Irish communities, though responsible for the maintenance of sectarian conflict, were also protective against some other forms of mortality risk, such as alcohol and drug-related deaths, that otherwise would have claimed more young adult males. (Leonard, 2004) In the counterfactual scenario, therefore, it may well have been that some of those who did not die of sectarian violence instead died of some of these other causes, and so the net deaths 'caused' by the conflict may be less than the number of people who died of conflict-related violence. Another specific example of this may be that fewer people died of vehicle-related deaths if, as expected, travel was more restricted during the peak of the Troubles due to increased police and military presence; exploration of aggregate trends in road traffic deaths may therefore be useful to quantify the size of any such effect on deaths in the affected age groups.

Thirdly, the Troubles are likely to have led to some net emigration of those most-affected groups, and the model may not have been sufficient in accounting for emigration as a 'competing risk'. Finally, not every death that occurred in a given year may have been attributed accurately to the year in which it occurred, especially if bodies were not found for many years if ever. Again, the effect of adjusting for these factors have not been explored, and further research is encouraged to do so.

One of the aims of this research was to estimate a counter-factual scenario in which the Troubles had not occurred; this was shown in the middle row of figure 6. This counterfactual was model dependent, and relied only on data from Northern Ireland. An alternative approach would be to aim to construct a 'counterfactual Northern Ireland' through an appropriately weighted average of mortality trend data from a range of other countries identified as otherwise similar to Northern Ireland for the period of comparison, an approach described as the Synthetic Control Method; (Abadie, Diamond, & Hainmueller, 2015) once again further research is welcome which uses this and other approaches to counterfactual estimation.

It has been suggested that the 1981 Irish Hunger Strike in the Maze prison, in which ten prisoners starved themselves to death, may have led to a renewed increase in violence; this could be tested by comparing the fit of a model specification assuming two distinct spikes in death risk, with the latter in 1981 or 1982, against the specification shown here, and again further research to explore this hypothesis is welcome. Finally, the role of cohort effects in mortality risk attributable to conflict has not been explored, and further research could do so.

Methodological considerations and implications

The incidental and accidental origins of this paper therefore highlight the value of the data visualisation approaches employed, and of what Robert K Merton called 'theories of the middle range', of allowing social hypotheses to 'emerge upwards', inductively or abductively from data exploration, rather than simply being 'applied downwards', beginning in canonical social texts, then operationalised and empirically tested in a hypothetico-deductive fashion. (Menand, 2009; Merton, 1968) This research is innovative in its use of Lexis surface visualisations for model diagnostics (as shown in Figure 7), and for showcasing an approach to model development which follows from effective and appropriate visual exploration of population data, and which uses Lexis surface visualisations throughout a broader process of research workflow. This broader research workflow, first applied and developed in this paper, has been described more explicitly in two additional papers currently available as Open Science Federation (OSF) pre-prints. [REFs]

The specific model specification, including first an impulse component then an exponential decay, can be used to model particular types of mortality pattern disruption, likely attributable to violence or more general social disorder, even when only relatively limited all-cause mortality data are available, and specific death codes, such as ICD-10 codes, are not recorded consistently. This situation is likely to be the case both for less affluent nations in more recent years, as well as for historic demographic data from more affluent data. One specific benefit of the modelling approach used here is in allowing conflict-attributable mortality to be compared in terms of both initial intensity (the height of the initiation in the first year) and also duration in terms of decay rates and so conflict half-life.

The model appears characteristic of a population that was in some senses 'febrile' or 'fissile' in its response to exogenous social, political and economic events and processes, and is to some extent consistent with previous attempts to model processes of violence as complex systems involving either systems of nonlinear equations or agent-based models. (Wright, 2006) A paper describing an agent-based model of processes and dynamics of civil war emphasises the punctuated equilibria – sudden increases in violence punctuating longer periods of relative calm – can be expected in such complex systems, and that it is important to consider the ways that agents involved in war adapt over time in their attitudes and behaviour.(Findley, 2008) Though it took a number of years, possibly three years, for the series of events which began in the late 1960s to lead to the initiation of conflict, this effect of this conflict was then sustained endogenously over many decades. This appears to represent the essence of cycles of violence driven by tit-for-tat processes of recrimination and revenge. For both sides, justice meant responding to violence with violence, a process of call and response in deadly conflict that, like an echo in a cave, only diminished slowly in intensity over time. Once this wave of conflict was initiated, it may have been that there was little that external agents could have done to either exacerbate or hasten the process of decline in violence.

Implications of the initiation-decay model to conflict in Northern Ireland

If, once initiated, the conflict was largely endogenously sustained, this has important implications for how the various peace initiatives and processes which were attempted after 1972 should be interpreted in terms of their effectiveness. Up to seven prior attempts at bringing peace to Northern Ireland were made between 1969 and the Belfast Agreement of 1998, including the Sunningdale Agreement of 1973. It has been argued that what made the Belfast successful was the presence of key individuals acting effectively as 'brokers' in the complex social networks which had to be negotiated at the time.(Goddard, 2012) However, if the underlying dynamics of the model are accurate, then such factors may be greatly overstated. If the half-life of the conflict was 6.76 years and began in 1972, it follows that by 1994 the intensity of the conflict had diminished to around one-tenth of its initial level. (i.e. $(1-k)^{(1994-1972)} = 0.105$). Similarly, by the time of the Good Friday Agreement in 1998 the underlying conflict intensity had diminished to around 7% of its initial value (i.e. $(1-k)^{(1998-1972)} = 0.069$). Note that these intensity values apply to $\log_{10}$ mortality risks, so the actual level of decline of conflict intensity on deaths by the mid to late 1990s will have been even greater.

The power sharing arrangement following the Good Friday Agreement (GFA) has been described as an example of ‘consociationalism’, a system of government in which coalition by both Republicans and Loyalists is mandated.(Anderson, 2008) The consociational arrangement following the GFA has led to little change in the ethno-sectarian identity focus of any of the main parties within Northern Ireland. Indeed, the political success of Sinn Fein at the expense of the more moderate Social Democratic and Labour Party (SDLP) in capturing the Irish Nationalist voting block after the GFA suggests sectarian identity may have come to matter more, not less, to voting intentions following the GFA.(McGlynn, Tonge, & McAuley, 2014) Cross-ethnic political parties have seen only limited success after the GFA compared with sectarian political parties, and this lack of success has been attributed to the consociationalist institutions established in the wake of the GFA to accommodate (rather than attempt to blend) rival identities.(Murtagh, 2015) Questions have therefore been raised about whether the GFA represents or helps to bring about conflict *resolution*, or is simply conflict *management*, or more pessimistically, conflict deferment.(Anderson, 2008)

Whereas ethno-national conflict since the establishment of Northern Ireland in 1921 sharpened the border with the Republic of Ireland, the European Single Market made it more permeable.(Anderson & O’Dowd, 1999) EU Peace Programmes for Northern Ireland and the Border Counties began in 1995 with the Special Support Programme for Peace and Reconciliation (Peace I) which provided €500 million in structural funds to the region, supplemented with an additional €167 from government; followed by the Programme for Peace and Reconciliation (Peace II), which provided €531million via the EU and an additional €304 from national governments between 2000 and 2004.(Buchanan, 2008) The third phase of the EU programme for Peace and Reconciliation in Northern Ireland took place over the years 2007 to 2013. (Karari, Byrne, Skarlato, Ahmed, & Hyde, 2013) Whereas the GFA focused on building peace by addressing the leaders of political factions, EU-led initiatives focused on economic investment and to greater community engagement as a means of building more lasting stability in Northern Ireland and the Irish border. The UK's departure places the future of further initiatives in doubt, though the Irish border remains a key priority for EU-UK Brexit negotiations.

References

Abadie, A., Diamond, A., & Hainmueller, J. (2015). Comparative Politics and the Synthetic Control Method. *American Journal of Political Science*, *59*(2), 495–510. http://doi.org/10.1111/ajps.12116

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*(6), 716–723. http://doi.org/10.1109/TAC.1974.1100705

Anderson, J. (2008). Partition, consociation, border-crossing: some lessons from the national conflict in Ireland/Northern Ireland. *Nations and Nationalism*, *14*(1), 85–104. http://doi.org/10.1111/j.1469-8129.2008.00340.x

Anderson, J., & O'Dowd, L. (1999). Contested Borders: Globalization and Ethnonational Conflict in Ireland. *Regional Studies*, *33*(7), 681–696. http://doi.org/10.1080/00343409950078710

Anderson, J., & O'Dowd, L. (2007). Imperialism and nationalism: The Home Rule struggle and border creation in Ireland, 1885–1925. *Political Geography*, *26*(8), 934–950. http://doi.org/10.1016/j.polgeo.2007.10.001

Ashe, F. (2009). Iris Robinson's Excitable Speech: Sexuality and Conflict Transformation in Northern Ireland. *Politics*, *29*(1), 20–27.

Buchanan, S. (2008). Transforming Conflict in Northern Ireland and the Border Counties: Some Lessons from the Peace Programmes on Valuing Participative Democracy. *Irish Political Studies*, *23*(3), 387–409. http://doi.org/10.1080/07907180802246719

Curran, P. S. (2001). Psychiatric implications of chronic civilian strife or war: Northern Ireland. *Advances in Psychiatric Treatment*, *7*(1), 73–80. http://doi.org/10.1192/apt.7.1.73

Durkheim, E. (1951). Suicide, a study in sociology. *New York Free Press*, *3*, 405. http://doi.org/10.2307/2088294

Findley, M. G. (2008). Agents and conflict: Adaptation and the dynamics of war. *Complexity*, *14*(1), 22–35. http://doi.org/10.1002/cplx.20232

Gerike, R., de Nazelle, A., Nieuwenhuijsen, M., Panis, L. I., Anaya, E., Avila-Palencia, I., … Götschi, T. (2016). Physical Activity through Sustainable Transport Approaches (PASTA): a study protocol for a multicentre project. *BMJ Open*, *6*(1), e009924. http://doi.org/10.1136/bmjopen-2015-009924

Goddard, S. E. (2012). Brokering Peace: Networks, Legitimacy, and the Northern Ireland Peace Process. *International Studies Quarterly*, *56*(3), 501–515. http://doi.org/10.1111/j.1468-2478.2012.00737.x

Karari, P., Byrne, S., Skarlato, O., Ahmed, K., & Hyde, J. M. (2013). The role of external economic assistance in nurturing cross-community contact and reconciliation in Northern Ireland and the Border Counties. *Community Development Journal*, *48*(4), 587–604. http://doi.org/10.1093/cdj/bss054

Leonard, M. (2004). Bonding and bridging social capital: Reflections from Belfast. *Sociology-the Journal of the British Sociological Association*, *38*(5), 927–944.

Lester, D. (2002). The "troubles" in Northern Ireland and suicide. *Psychological Reports*, *90*(3), 722.

McDowell, S. (2008). Selling Conflict Heritage through Tourism in Peacetime Northern Ireland: Transforming Conflict or Exacerbating Difference? *International Journal of Heritage Studies*, *14*(5), 405–421. http://doi.org/10.1080/13527250802284859

McGlynn, C., Tonge, J., & McAuley, J. (2014). The Party Politics of Post-Devolution Identity in Northern Ireland. *The British Journal of Politics and International Relations*, *16*(2), 273–290. http://doi.org/10.1111/j.1467-856X.2012.00528.x

Menand, L. (2009). The Metaphysical Club. *Harvard Library Bulletin*, *20*(2), 22–23.

Merton, R. (1968). *Social Theory and Social Structure*. New York: Free Press.

Minton, J. (2014). Real geographies and virtual landscapes: Exploring the influence on place and space on mortality Lexis surfaces using shaded contour maps. *Spatial and Spatio-Temporal Epidemiology*, *10*, 49–66. http://doi.org/10.1016/j.sste.2014.04.003

Minton, J., Shaw, R., Green, M. A., Vanderbloemen, L., Popham, F., & McCartney, G. (2017). Visualising and quantifying “excess deaths” in Scotland compared with the rest of the UK and the rest of Western Europe. *Journal of Epidemiology and Community Health*, *71*(5), 461–467. http://doi.org/10.1136/jech-2016-207379

Murtagh, C. (2015). Reaching across: institutional barriers to cross-ethnic parties in post-conflict societies and the case of Northern Ireland. *Nations and Nationalism*, *21*(3), 544–565. http://doi.org/10.1111/nana.12129

R Core Team. (2016). R: A language and environment for statistical computing. Vienna, Austria: Foundation for Statistical Computing,. Retrieved from https://www.r-project.org/

Schmid, K., Hewstone, M., & Tausch, N. (2014). Secondary transfer effects of intergroup contact via social identity complexity. *The British Journal of Social Psychology*, *53*(3), 443–62. http://doi.org/10.1111/bjso.12045

Smyth, M. (1998). *Half the Battle: Understanding the impact of “the Troubles” on children and young people*. Derry: INCORE. Retrieved from http://cain.ulst.ac.uk/issues/violence/cts/smyth1.htm

Tausch, N., Hewstone, M., Kenworthy, J. B., Psaltis, C., Schmid, K., Popan, J. R., … Hughes, J. (2010).

Secondary transfer effects of intergroup contact: Alternative accounts and underlying processes. *Journal of Personality and Social Psychology*, *99*(2), 282–302. http://doi.org/10.1037/a0018553

Thornton, R. (2007). Getting it Wrong: The Crucial Mistakes Made in the Early Stages of the British Army's Deployment to Northern Ireland (August 1969 to March 1972). *Journal of Strategic Studies*, *30*(1), 73–107. http://doi.org/10.1080/01402390701210848

Turchin, P., & Gavrilets, S. (2009). Evolution of Complex Hierarchical Societies. *Social Evolution & History*, *8*(2), 167–198.

University of California, B. (USA); M. P. I. for D. R. (Germany). (2017). Human Mortality Database. Retrieved June 13, 2017, from www.mortality.org

Vaupel, J. W., Wang, Z., Andreev, K., & Yashin, A. I. (1997). *Population Data at a Glance: Shaded Contour Maps of Demographic Surfaces over Age and Time*. University Press of Southern Denmark. Retrieved from http://www.abebooks.co.uk/servlet/BookDetailsPL?bi=2944819605

Wright, S. (2006). A systems approach to analysing sub-state conflicts. *Kybernetes*, *35*(1/2), 182–194. http://doi.org/10.1108/03684920610640308