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Public Health Information for Scotland

Informing Interventions to reduce health Inequalities (Triple I)

Technical report

Triple I: Informing • Inequalities • Interventions

Comparing the potential population impact of interventions on health inequalities in Scotland

NHS Health Scotland

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1. Introduction

1.1 Background

Informing Interventions to reduce health Inequalities (Triple I) is an NHS Health Scotland modelling study. It has been designed to inform discussions and decisions about the potential impacts of various interventions on health and health inequalities across the Scottish population. The work aims to address the lack of evidence about the population-level impacts of interventions.

Triple I uses epidemiological modelling to estimate the potential impacts of various interventions on all-cause premature deaths, years of life lost and hospitalisations, and on inequalities in these outcomes. The outcomes are available by area (Scotland, Health Boards, local authorities, Integrated Joint Boards or city regions) and for different time horizons (up to 20 years). For interventions that are delivered to individuals, the number of interventions delivered and the targeting strategy can also be adjusted.

The first phase of Triple I was published by the Scottish Public Health Observatory in 2014 (ScotPHO 2014a). The work was subsequently revisited to update the evidence and underlying data, incorporate additional interventions and improve the accessibility of the work to national and local users. A briefing paper about income-based interventions and an accompanying spreadsheet tool were the first outputs from this second phase, published in 2018 (Richardson et al. 2018). This technical report is being published in 2019 alongside a national overview report (Pulford et al. 2019), the remaining spreadsheet tools and an interactive results browser website. All of these outputs can be found on the NHS Health Scotland website at www.healthscotland.scot/triplei

1.2 Study objectives

Following a review of the impact of the first phase of Triple I, three key objectives were outlined for the second phase:

1. To better understand how Triple I could be made more useful to local users and decision-makers.

2. To broaden the range of modelled interventions.
3. To improve the tools and their dissemination.

1.3 Report overview

This report explains the methods involved in this phase of the study. It begins by explaining the work undertaken to better understand how Triple I could be made more useful at the local level. How the interventions were selected, and how evidence of their effectiveness was collated and assessed, is then summarised. Triple I's 'back end' – the epidemiological modelling and its assumptions – is then described, along with the data we used to implement the model. The two complementary 'front ends' of Triple I – the spreadsheet tools and the interactive results browser website – are then described. Finally, we present a summary of the results for the interventions.

2. Objective 1: Understanding how to improve local usefulness of Triple I

The Triple I work published in 2014 was widely disseminated and well-received at the national level, but had little impact in local areas. We engaged with a range of stakeholders across public services and academia to improve our understanding of how Triple I could better inform local decision-making. In this process we met with representatives from Community Planning Partnerships, Health and Social Care Partnerships, Health Boards, local authorities, the Convention of Scottish Local Authorities (COSLA), Public Health England, the third sector and academic institutions.

This exercise revealed that there is demand for evidence-based decision-making tools like Triple I, particularly in the context of increasingly tightened resources. The stakeholders stressed, however, that the messages would need to be relevant to their local area and the populations they serve. They also highlighted a need for the results to be presented in a simpler way than in the first phase. It was noted that Triple I would not be the most appropriate tool for every decision, and we highlighted the wider range of complementary decision-making aids that are available (e.g. Scottish Burden of Disease, the ScotPHO profiles or the Place Standard). In summary, engaging with stakeholders was a useful exercise that informed the rest of the Triple I work.

3. Objective 2: Broadening the range of interventions included

We aimed to include interventions spanning the range of action types needed to reduce health inequalities:

- Changes that aim to **undo** the fundamental causes of health inequality by redistributing income, power and wealth (e.g. changes to benefits).
- Changes that aim to **prevent** health harms and health inequalities (e.g. tobacco taxation).
- Action to **mitigate** health harms and health inequalities (e.g. smoking cessation programmes).

First, we assessed if any topic areas not included in the first phase of Triple I[1] should be included in this phase. A number of further priority topics[2] were identified through an analysis of key policy-relevant documents and agreed in consultation with the project's Project Advisory Group.

Second, we conducted a high-level scoping exercise for each topic area, to identify interventions that could be considered for modelling in Triple I. We contacted experts in the topic area, and searched the websites and publications of key organisations involved in synthesising evidence.[3] We searched for English-language post-2000 reviews of any relevant interventions implemented in Organisation for Economic

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[1] First phase topics were: Counterweight (weight management advice service), alcohol brief intervention (ABI), smoking cessation advice, tobacco taxation increase, active travel to work (notional intervention), employment (notional intervention) and income-based interventions (changes to benefits and taxation, and introduction of Living Wage).

[2] Additional topics considered for the current phase were: physical environment, mental health, adult education, housing, early years, job quality, workplace mental health and models of social care designed to reduce hospitalisation.

[3] National Institute for Health and Care Excellence (NICE), The Cochrane Library, The Knowledge Service, National Institute for Health Research (NIHR) Journals Library, What Works Scotland, Scottish Government, Scottish Intercollegiate Guidelines Network (SIGN), The Campbell Collaboration, Evidence for Policy and Practice Information and Coordinating Centre (EPPI-Centre), Foresight, Social Care Institute for Excellence, World Health Organization (WHO) Health Evidence Network (HEN), Institute for Policy Research, Economic and Social Research Council evidence briefings, Institute for Work and Health Research, Scottish Parliament research briefings, Audit Scotland, Lancet UK Policy Matters and European Commission.

Co-operation and Development (OECD) countries with effects reported for the general adult population.

Third, we undertook a focused literature review based on the interventions identified by the high-level scoping phase. Databases such as PubMed, Embase and Medline were searched, and the reference lists of identified studies were searched by hand to locate additional potential studies that met the eligibility criteria. Interventions were considered appropriate for inclusion in Triple I if they were clearly defined, and had effectiveness evidence that could be generalised to the adult population of Scotland (e.g. meta-analysis). Additionally, we required evidence of the intervention's effectiveness on all-cause mortality or hospitalisation, or on a risk factor that is known to be associated with these outcomes.

We recognised that the requirement for published effectiveness evidence for clearly defined interventions might result in a focus on individual-level interventions (known as 'lifestyle drift'). Therefore, to include a wider range of interventions we broadened the types of evidence deemed appropriate, while maintaining a rigorous approach to the assessment of this evidence. For example, we included job provision as a 'notional' intervention, as we had not identified effectiveness evidence for a generalisable and clearly defined intervention, but had good evidence of the benefits of employment for health.

Following the rigorous assessment of interventions by the Triple I team we made the following changes to the interventions included in the 2014 phase[4]:

- Three interventions for depression were included: computerised cognitive behavioural therapy (CBT), individual guided self-help and group physical activity.
- Two interventions for physical activity were included: physical activity brief intervention and pedometer-based intervention.
- An intervention for the physical environment was included: 20 miles per hour (mph) speed limits in urban areas.

[4] Counterweight (weight management advice service), ABI, smoking cessation advice, tobacco taxation increase, active travel to work (notional intervention), employment (notional intervention) and income-based interventions (changes to benefits and taxation, and introduction of Living Wage).

- Instead of the Counterweight programme we adopted generic lifestyle weight management services as the intervention, in view of the breadth and quality of available evidence, and the range of approaches currently used in Scotland.
- The range of income-based interventions was augmented to include policies with current relevance and interest, including Citizen's Basic Income and increasing benefit uptake rates.
- Active travel to work was removed because it lacked the specificity of evidence of the other interventions, and two more specific physical activity interventions (see above) were now able to be included in this phase.

The full list of interventions included in this phase of Triple I, and their definitions, is given in **Appendix 9.1**. Evidence for the prevalence of relevant risk factors and the costs of the interventions was obtained, and is summarised along with the effectiveness evidence in the 'Evidence' tabs of the relevant spreadsheet tool. The evidence is also summarised in subsequent sections.

4. Objective 3: Improving the tools and their dissemination

4.1 The Triple I 'back end': the model

The Triple I results are produced by running a predictive epidemiological model on the best available data and selected intervention evidence. The model can be thought of as the 'back end' of Triple I. The model predicts numbers of hospitalisations and deaths for the baseline and intervention scenarios to estimate the net intervention effect.

In this section we first describe the evidence and data inputs required for the model, and then describe the Triple I model.

4.1.1 Evidence and data required

Inputs required by the model are:

- Population (by age group, sex and socioeconomic deprivation).
- Exposed population: the proportion of the population exposed to the risk factor being addressed by the intervention.
- Effect of exposure: the effect of exposure to the risk factor on all-cause hospitalisation and mortality.
- Eligible population: the proportion of the exposed population eligible (i.e. willing and able) to be treated by the intervention.
- Treated population: the number of interventions to be delivered (applies to individual-level interventions only).
- Effect of treatment (i.e. intervention): the effect of the intervention on all-cause hospitalisation and mortality, and any changes in the effect over time.

4.1.2 The population

The model calculates hospitalisations and deaths each year for a closed cohort, defined as the adult population (16 years old and over) in Scotland in 2016. This means that inward movement from births or immigration or outward movement from emigration is not taken into account for the duration of the follow-up period (up to 20 years). Only deaths (predicted by the model) affect the composition of the population.

We aggregated National Records of Scotland (NRS) population estimates (single year of age) by sex, five-year age group[5] and Scottish Index of Multiple Deprivation (SIMD) 2016 quintile (fifths of the population). The data are described in **Appendix 9.2.1**. The single year of age population estimates were also used to calculate a mean age for each age group in 2016. In each spreadsheet tool the hidden tab called ‘Population 2016’ contains these population data.

Figure 1 illustrates the relationship between the population types used in Triple I. Out of a hypothetical general population of 100, 30% (n = 30) are exposed to a risk factor (shown by grey-shaded cells). Two-thirds of the exposed population (n = 20) are potentially eligible for the intervention, but only 10 interventions are delivered (10% of the population). These population types are described in greater detail below.

Figure 1: Hypothetical population of 100, illustrating the unexposed, exposed, eligible and treated populations.

[5] Specifically 16–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89 and 90+ years.

4.1.3 The exposed population

The population is divided into 'exposed' and 'unexposed' populations. The exposed population is also referred to as the 'population at risk' (PAR). Exposure pertains to the risk factor that the intervention is designed to address, hence the exposed population varies between the interventions. For most interventions the exposed proportion of the population is identified using prevalence data from surveys (e.g. smoking, harmful/hazardous drinking or obesity) but for income-related interventions and 20 mph speed limits the exposures (income level, or road traffic accident risk and air pollution exposure, respectively) are considered to affect the whole population. The relevant risk factors and the data used to estimate prevalence are outlined in columns 2 and 3 of **Table 1**.

Where possible, local area prevalence estimates by sex were used to weight national prevalence estimates by SIMD quintile, age group and sex to produce estimates for each subgroup. In some cases the survey sample sizes were too small to enable us to robustly estimate prevalence for local areas and, in these cases, we estimated prevalence using aggregated areas. We used Office for National Statistics (ONS) local authority matching tables to identify the most appropriate areas to aggregate (**Appendix 9.3**).

In each spreadsheet tool the hidden tab 'Prevalence rates' gives the prevalence estimates by population subgroup, which are used to estimate the number of exposed individuals in each subgroup for the hidden 'Population at risk' tab. Further information about how the exposed population was estimated can be found on the 'Evidence' tab of the relevant Excel spreadsheet tool.

4.1.4 Effect of exposure

Robust evidence for the effect of exposure to the risk factor on all-cause hospitalisation and all-cause mortality (the exposure rate ratios, or ERRs) was sought (see Section 3). In some cases the ERR for exposed individuals relative to unexposed individuals was not directly available, and needed to be derived from the available evidence. The evidence collated is summarised in **Table 1**, and described in more detail in the 'Evidence' tab of the relevant spreadsheet tool. The risk values are expressed as ratios so, for example, the mortality risk of 1.43 for physical inactivity means that adults who do not meet the 2011 physical activity guidelines have a 43% higher risk of all-cause mortality than those who do.

For 20 mph speed limits and the income-based interventions, exposure to the risk factor (air pollution, road traffic accident risk or income levels) was population wide, and there was no unexposed population. This is not to say that exposure was uniform across the population, only that every individual was exposed to some level of health-relevant risk. For example, studies of particulate air pollution have found no threshold below which there are no health effects (Hoek et al. 2013). To reflect this we applied mortality and hospitalisation ERRs of 1.00 for these interventions, because the risk for each subgroup is assumed to be captured in the rate predictions.

Table 1: Risk factor prevalence and the relevant mortality and hospitalisation ERRs used in the Triple I modelling, by topic area. Further information can be found on the 'Evidence' tab of the relevant Excel spreadsheet tool.

Topic	Exposure/ risk factor	Definition of exposure, and source data	Mortality ERR (relative to unexposed)[a]	Source of mortality ERR	Hosp. ERR (relative to unexposed)[a]	Source of hosp. ERR
Physical activity	Physical inactivity	% adults not meeting 2011 physical activity guidelines (150 mins/week moderate or 75 mins/week vigorous). Weighted proportions for subgroups obtained from Scottish Health Survey (SHeS) (2013–2016)	1.43	Derived from Department of Health (2011) (review-level evidence comparing least active and most active groups)	Not available	None identified
Alcohol	Harmful/ hazardous drinking	% adults exceeding the 1995 weekly drinking guidelines (women > 14 units, men > 21 units). Weighted proportions for subgroups extracted from SHeS (2013–2016)	Men 1.64, Women 1.45	Derived from Wood et al. (2018)	Men 1.10, Women 1.08	Derived from Hart and Smith (2008)
Obesity	Obesity	% adults with body mass index (BMI) ≥ 30 kg/m^2. Weighted proportions for subgroups extracted from SHeS (2013–2016)	Men 1.49, Women 1.31	Korda et al. (2015)	1.79	Global BMI Collaboration (2016)
Mental health	Depression	% adults with persistent subthreshold, mild or moderate depression. Estimated using SHeS (2013–2016) and validated	1.33	Cuijpers et al. (2013)	1.36	Prina et al. (2015)

Topic	Exposure/ risk factor	Definition of exposure, and source data	Mortality ERR (relative to unexposed)[a]	Source of mortality ERR	Hosp. ERR (relative to unexposed)[a]	Source of hosp. ERR
		against the Adult Psychiatric Morbidity Survey 2000. Owing to small sample sizes we did not produce estimates for local areas, and collapsed age groups into 16–54 years and 55+ years				
Smoking	Smoking	% adults who smoke. Proportions by subgroup extracted from the Scottish Surveys Core Questions data set (2015 for local areas, by sex, and 2012–2015 for SIMD 2016 quintiles by age group and sex)	Men 1.90, Women 1.80	Gellert et al. (2012)	Men 1.48, Women 1.55	Lawder et al. (2007)
Employment	Unemployment	% 16–64-year-olds unemployed (International Labour Organisation definition, ILO 2013) or economically inactive, excluding 16–24-year-olds in full-time education. Proportions by subgroup extracted from Annual Population Survey 2016	Men 1.78, Women 1.37	Roelfs et al. (2011)	Men 1.02 (assumed same for women)	Browning and Heinesen (2012)

[a] Unless indicated, the ERR was assumed identical across the age groups, sexes, SIMD quintiles and calendar years.

4.1.5 The eligible population

In most cases it is not realistic to expect that the entire exposed population would want or be able to receive the intervention. We defined the ‘eligible’ fraction of the exposed population as those who could be expected to benefit from the intervention (e.g. smokers who displayed motivation to quit, or unemployed people willing and able to take up a job) (**Table 2**). The eligible population is thus the highest number realistically available to be treated under each intervention. Further detail about the estimation of the eligible population is included in the ‘Evidence’ tab of the relevant spreadsheet tool.

Income-based interventions are the exception as they are modelled differently. Although not every individual will directly experience a change in income as a result of each intervention (e.g. an increase in means-tested benefits), the intervention effect is calculated as an average across all individuals in the same SIMD 2016 deprivation quintile. Hence the entire population is considered eligible and treated.

Table 2. Details of the eligible population for each intervention. Further information can be found on the 'Evidence' tab of the relevant Excel spreadsheet tool.

Topic	Intervention(s)	Eligible population	Eligibility prevalence	Source
Physical activity	Pedometer-based intervention and physical activity brief intervention	% adults not meeting the physical activity 2011 guidelines who are motivated to increase their physical activity levels	45.2%	SHeS 2008–11 (Knowledge and Attitudes Module)
Alcohol	Alcohol Brief Intervention (ABI)	% adults exceeding 1995 drinking guidelines who wish to reduce their alcohol consumption	39.0%	SHeS 2008–11 (Knowledge and Attitudes Module)
Obesity	Lifestyle weight management services	% obese adults who wish to lose weight	71.1%	SHeS 2008–11 (Knowledge and Attitudes Module)
Mental health	Computerised CBT, individual guided self-help, and group physical activity	% adults with mild/moderate depression who seek help/treatment	26.0%	Mid-range value from Andrews et al. 2001, van Zoonen et al. 2015, Hengartner et al. 2016, Beekman et al. 1997, Rokke and Klenow 1998, and Olfson and Klerman 1992.
Smoking	Smoking cessation services	% smokers who want to give up smoking	69.8%	SHeS 2016

Topic	Intervention(s)	Eligible population	Eligibility prevalence	Source
Smoking	Tobacco taxation +10%	% smokers obtaining their tobacco not from illicit sources	80.7%	Derived from illicit market share (Her Majesty's Revenue and Customs, HMRC 2017) and tobacco usage statistics (Young et al. 2006, Brown et al. 2015, Gilmore et al. 2014)
Employment	Job provision (notional intervention)	% of the unemployed and economically inactive population who are defined as 'real unemployed', i.e. willing and able to take up a job if offered one	30.0%	Derived from Beatty et al. (2017)
Physical environment	20 mph speed limits	% of the subgroup population living in urban settlements in 2016. Three local authority areas (Fife, City of Edinburgh and Clackmannanshire) were ineligible as they have already implemented 20 mph schemes on most of their urban residential roads	67.9% for Scotland (varies by area and SIMD quintile)	Derived using NRS data zone population estimates for 2016 and NRS settlement boundary data

4.1.6 The treated population

A key aspect of Triple I's value as an interactive tool is the ability for users to change the number of individual-level interventions delivered (i.e. the number of individuals treated). Any figure from zero to the maximum eligible population can be chosen on the 'Options' tab of the spreadsheet tools.

The strategy for delivering the intervention to the chosen number of individuals can also be altered by the user. Four options are available:

- Even distribution: treat the same proportion of the eligible population in each subgroup (i.e. age group, sex and SIMD 2016 quintile).
- Proportionate to need: the proportion of each subgroup treated is proportionate to the prevalence of the exposure.
- Most deprived 20% only: treat only those in SIMD quintile 1 (even distribution within this quintile).
- Most deprived 40% only: treat only those in SIMD quintiles 1 and 2 (even distribution within these quintiles).

The interventions are distributed between the population subgroups according to the selected targeting strategy; the numbers for each subgroup are calculated on the hidden 'Targeting' tab of relevant spreadsheet tools.

4.1.7 Effect of treatment

The interventions we chose were included in Triple I because they had sufficiently generalisable effectiveness evidence. In some cases there was direct evidence about the implications of the intervention for all-cause hospitalisation and mortality. For example, Hart et al. (2013) found that male ex-smokers have a 24% reduction in all-cause mortality risk, relative to smokers (an intervention rate ratio (IRR) of 0.76). For other interventions we had to bring together different sources of evidence to calculate the IRR. The intervention effects and IRRs are summarised in **Table 3** (mortality) and **Table 4** (hospitalisation), and their calculation is described in greater detail in the 'Evidence' tab of the relevant spreadsheet tool.

We also sought evidence about how the intervention effect among the treated population would be likely to change over time (summarised in the last column of **Tables 3** and **4**). It is important to note that the individual-level interventions are delivered over one year, while the other interventions (tobacco taxation, physical environment and income based) represent permanent changes. For the individual-level interventions we found evidence of some attenuation of the initial intervention effect back to pre-intervention levels over time (also known as effect decay). This attenuation combined estimates of drop-out and relapse as appropriate, reflecting the fact that not all who receive an intervention will benefit from it to the same extent (see **Tables 3** and **4,** and the ‘Evidence’ tab of the relevant spreadsheet tool for more information). We also assumed that some of the smokers who quit because of tobacco taxation increases would begin smoking again. For the physical environment and income-based interventions the intervention effect was assumed to be constant over time.

The evidence we collated about how the intervention effect would translate into an all-cause mortality or hospitalisation effect typically involved longer follow-up periods than the duration of the intervention. Many of the specific health conditions affected by the interventions (e.g. lung cancer, respiratory disease or liver disease) develop over longer periods of time, meaning that health benefits of an intervention may not be experienced or detected for a number of years. However, due to insufficient or inconsistent evidence about this ‘disease latency’, and particularly its implications for all-cause health outcomes, we chose not to incorporate disease latency in the change in intervention effect over time. Therefore, an important underlying assumption in our modelling is that the health benefits of an intervention are experienced immediately: for example, males who give up smoking are instantly 24% less likely to die that year than those who keep smoking.

Table 3. Effects of each intervention on all-cause mortality.

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
Pedometer-based intervention	33 mins/week increase in moderate/vigorous physical activity (Harris et al. 2017)	0.954	Derived from Harris et al. (2017) and Wen et al. (2011)	Attenuates linearly to 0.961 at year 3, and no effect at year 10 (Harris et al. 2018, Mallender et al. 2013). Drop-out was 7% within 12 months, 33% within 3 years (Harris et al. 2017, 2018) and assumed 100% by year 10
Physical activity brief intervention	35 mins/week increase in physical activity (Campbell et al. 2012)	0.951	Derived from Campbell et al. (2012) and Wen et al. (2011)	Attenuates linearly to no effect at year 10. Drop-out increases linearly to 100% at year 10
ABI	20 g/week decrease in alcohol consumption (Kaner et al. 2018)	0.956	Derived from Kaner et al. (2018) and Wood et al. (2018)	Attenuates linearly to no effect after year 7 (Fleming et al. 2002)
Lifestyle weight management services	Average BMI reduction of 0.95 kg/m^2 (derived from National Institute for Health and Care Excellence (NICE) 2013a and Ross et al. 2008)	0.860	Derived from Ma et al. (2017)	Average BMI increase in adult population is 0.9% per year (Li et al. 2015) and treated individuals gain 0.21 kg/m^2/year more than general population (NICE 2013b). Effect attenuates to no effect by year 8
Computerised CBT (for depression)	Mean reduction in generic depression scale score of 0.40 standard deviations (standardised	0.941	Effect from NICE (2009) converted to mortality effect using Wulsin et al. (2005)	Intervention drop-out rate of 32% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from various related

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
	mean difference (SMD), from NICE 2009)			CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12
Individual guided self-help (for depression)	Mean reduction in generic depression scale score of 0.98 standard deviations (SMD from NICE 2009)	0.861	Effect from NICE (2009) converted to mortality effect using Wulsin et al. (2005)	Intervention drop-out rate of 11% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from various related CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12
Group physical activity (for depression)	Mean reduction in generic depression scale score of 0.71 standard deviations (SMD from NICE 2009)	0.898	Effect from NICE (2009) converted to mortality effect using Wulsin et al. (2005)	Intervention drop-out rate of 18% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from various related CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
Smoking cessation services	Smoking cessation	Men 0.760, Women 0.640	Hart et al. (2013)	Treatment success rate averages 5.8% (NHS Information Services Division (ISD) 2014). 30.0% then relapse over next 8 years (Etter and Stapleton 2006). 70.0% remain ex-smokers
Tobacco taxation +10%	Smoking cessation	Men 0.760, Women 0.640	Hart et al. (2013)	Smoking prevalence estimated to decrease by 2.8% (derived from Reed et al. 2013 and Golden et al. 2016). 30.0% then relapse over next 8 years (Etter and Stapleton 2006). 70.0% remain ex-smokers
Job provision (notional intervention)	Employment	0.559	Derived from hazard ratios for job loss (Browning and Heinesen 2012)	Intervention effect attenuated as per Browning and Heinesen (2012) results, reaching 0.901 for mortality by year 20
20 mph speed limits	16.2% reduction in fatal road traffic accident (RTA) casualties	> 0.999	Derived by applying Elvik's (2009) power model to average speed reductions from UK 20 mph limit schemes (Turley 2013, Atkins 2010, Bristol City Council 2012, Cross River Partnership 2017) to estimate the proportional reduction in fatal RTA casualties, and calculating the	Permanent intervention. Constant effect over time assumed

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
			implication for all-cause mortality rates (from NRS data)	
20 mph speed limits	Average $PM_{2.5}$ reduction of 5.23% for urban settlements	> 0.999 (varying by subgroup)	Predicted % reductions in coarse particulate matter (PM_{10}, TEAG 2013) were converted to reductions in fine particulate matter ($PM_{2.5}$, Ricardo 2016) and applied to modelled $PM_{2.5}$ concentrations for Scotland (1 km x 1 km grid, Department for the Environment, Food and Rural Affairs (DEFRA) 2016). Population-weighted average $PM_{2.5}$ reductions were then calculated for each subgroup, and converted to an intervention effect based on the work of Hoek et al. (2013)	Permanent intervention. Constant effect over time assumed
20 mph speed limits	Average nitrogen dioxide (NO_2) reduction of 0.21% for urban settlements	> 0.999 (varying by subgroup)	Predicted % reductions in nitrous oxides (NOx) (TEAG 2013) were converted to NO_2 reductions (DEFRA 2017) and applied to modelled NO_2 concentrations for Scotland (1 km x 1 km grid, DEFRA 2016).	Permanent intervention. Constant effect over time assumed

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
			Population-weighted average NO_2 reductions were then calculated for each subgroup, and converted to an intervention effect based on the work of the Committee on the Medical Effects of Air Pollutants (COMEAP 2015). The effect size was reduced by 33% to take account of double counting of effects associated with $PM_{2.5}$ (see COMEAP 2016 and World Health Organization (WHO) 2013)	
Income-based interventions	Average change in equivalised household income (before housing costs) ranged from -3.0% for the least deprived quintile under Citizen's Basic Income Plus, to +8.6% for the most deprived quintile under a 50% increase to means-tested benefits. See Appendix 9.4 (Table 10)	Ranged between 0.910 and 1.036, depending on intervention and SIMD 2016 quintile. Full details in Appendix 9.4 (Table 11).	Income change estimated using EUROMOD (de Agostini 2017), and converted to a mortality effect using a coefficient from a model of the cross-sectional relationship between income and mortality in Scotland in 2016 (NRS and Family Resources Survey (FRS) data, Department for Work and Pensions (DWP) 2016))	Permanent intervention. Constant effect over time assumed

[a] Unless indicated, the IRR was assumed identical across the age groups, sexes and SIMD quintiles.

Table 4. Effects of each intervention on all-cause hospitalisation.

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
ABI	20 g/week decrease in alcohol consumption (Kaner et al. 2018)	0.955	Derived from Kaner et al. (2018) and Hart and Smith (2008)	Attenuates linearly to no effect after year 7 (Fleming et al. 2002)
Lifestyle weight management services	Average BMI reduction of 0.95 kg/m^2 (derived from NICE 2013a and Ross et al. 2008)	0.980	Derived from Reeves et al. (2014)	Average BMI increase in adult population is 0.9% per year (Li et al. 2015) and treated individuals gain 0.21 kg/m^2/year more than general population (NICE 2013b). Effect attenuates to no effect by year 8
Computerised CBT (for depression)	Mean reduction in generic depression scale score of 0.40 standard deviations (SMD from NICE 2009)	0.889	Effect from NICE (2009) converted to hospitalisation effect using Laudisio et al. (2010)	Intervention drop-out rate of 32% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from various related CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12
Individual guided self-help (for depression)	Mean reduction in generic depression scale score of 0.98 standard deviations (SMD from NICE 2009)	0.751	Effect from NICE (2009) converted to hospitalisation effect using Laudisio et al. (2010)	Intervention drop-out rate of 11% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
				various related CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12
Group physical activity (for depression)	Mean reduction in generic depression scale score of 0.71 standard deviations (SMD from NICE 2009)	0.812	Effect from NICE (2009) converted to hospitalisation effect using Laudisio et al. (2010)	Intervention drop-out rate of 18% (NICE 2009). Relapse to previous level of depression among the treated individuals estimated at 8.3% per year from various related CBT evaluations (Thase et al. 1992; Fava et al. 1998a, 1998b, 2004; Bockting et al. 2015). Attenuation to no effect estimated after year 12
Smoking cessation services	Smoking cessation	Men 0.820, Women 0.760	Derived from Lawder et al. (2007)	Treatment success rate averages 5.8% (NHS ISD 2014). 30.0% then relapse over next 8 years (Etter and Stapleton 2006). 70.0% remain ex-smokers
Tobacco taxation +10%	Smoking cessation	Men 0.820, Women 0.760	Derived from Lawder et al. (2007)	Smoking prevalence estimated to decrease by 2.8% (derived from Reed et al. 2013 and Golden et al. 2016). 30.0% then relapse over next 8 years (Etter

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
				and Stapleton 2006). 70.0% remain ex-smokers
Job provision (notional intervention)	Employment	0.952	Derived from hazard ratios for job loss (Browning and Heinesen 2012)	Intervention effect attenuated as per Browning and Heinesen (2012) results, reaching 0.971 for hospitalisation by year 20
20 mph speed limits	11.1% reduction in serious RTA casualties	>0.999	Derived by applying Elvik's (2009) power model to average speed reductions from UK 20 mph limit schemes (Turley 2013, Atkins 2010, Bristol City Council 2012, Cross River Partnership 2017) to estimate the proportional reduction in serious RTA casualties, and calculating the implication for all-cause hospitalisation rates (from ISD data)	Permanent intervention. Constant effect over time assumed
20 mph speed limits	Average $PM_{2.5}$ reduction of 5.23% for urban settlements	>0.999 (varying by subgroup)	Predicted % reductions in PM_{10} (TEAG 2013) were converted to $PM_{2.5}$ reductions (Ricardo 2016) and applied to modelled $PM_{2.5}$ concentrations for Scotland (1 km x 1 km grid, DEFRA 2016). Population-weighted	Permanent intervention. Constant effect over time assumed

Intervention	Intervention effect (for successful interventions)	Intervention effect on outcome (IRR, relative to untreated)[a]	Source	Change in intervention effect over time
			average $PM_{2.5}$ reductions were then calculated for each subgroup, and converted to an intervention effect based on Makar et al. (2017)	
20 mph speed limits	Average NO_2 reduction of 0.21% for urban settlements	No evidence identified	None	Not applicable
Income-based interventions	Average change in equivalised household income (before housing costs) ranged from -3.0% for the least deprived quintile under Citizen's Basic Income Plus, to +8.6% for the most deprived quintile under a 50% increase to means-tested benefits. See Appendix 9.4 (Table 10)	Ranged between 0.922 and 1.031, depending on intervention and SIMD quintile. Full details in Appendix 9.4 (Table 12)	Income change estimated using EUROMOD, and converted to a hospitalisation effect using a coefficient from a model of the cross-sectional relationship between income and hospitalisation in Scotland in 2016 (ISD and FRS data (DWP 2016))	Permanent intervention. Constant effect over time assumed

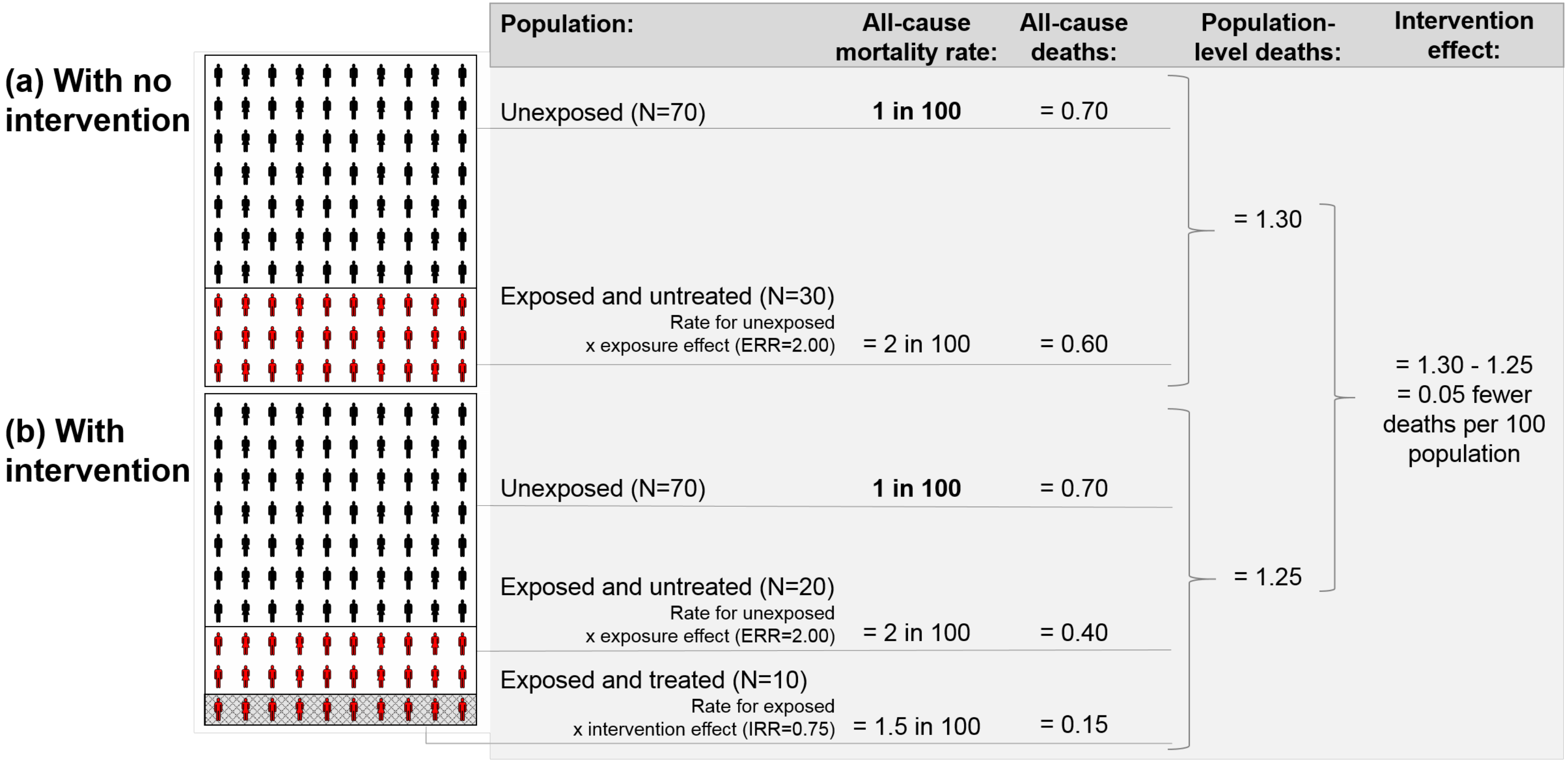
[a] Unless indicated, the IRR was assumed identical across the age groups, sexes and SIMD quintiles.

4.2 The Triple I model

The Triple I model is based on predicting all-cause mortality for the unexposed, exposed and treated populations for years 2 to 20 (after the intervention is implemented in year 1). After the mortality predictions are made, the all-cause hospitalisation predictions are made for the remaining individuals in the subgroup that year.

The modelling process is described in detail in the following sections, but is illustrated with a hypothetical and basic worked example in **Figure 2**. As in the hypothetical population in **Figure 1**, the risk factor affects 30 out of a population of 100 (prevalence = 0.30) and the intervention is delivered to 10 individuals. Illustrative ERR and IRR values are applied to the different populations and the intervention effect on all-cause mortality is calculated as the difference in deaths between the intervention and no intervention scenarios. This example applies to the first year of follow up: in subsequent years attenuation of the intervention effect (see section 4.1.7) and adjustment of the population to remove deaths in previous years (see section 4.2.5, below) adds complexity to the modelling.

Figure 2: Visualisation and worked example of the Triple I modelling process. In this example the intervention effect is calculated for the first year of follow-up for a hypothetical intervention delivered to 10 out of a population of 100.



4.2.1 Overall all-cause mortality rate

Rates of all-cause mortality over time for the population subgroups (by SIMD quintile, age group and sex) were estimated using historical mortality data from NRS (see **Appendix 9.2.2**). Projected mortality data were available from NRS, but not for SIMD quintiles or for hospitalisations, so these were not used. Parametric survival models (exponential distribution) were used to estimate changes in mortality rates over time, giving the following formula:

$$\text{All-cause mortality rate} = e^{(38.37 + 0.09*\text{age} + 1.05*\text{male} - 0.01*\text{age}*\text{male} - 0.02*\text{year} + 0.57*\text{Q1} + 0.21*\text{Q2} - 0.23*\text{Q4} - 0.54*\text{Q5})}$$

where Q1–5 were SIMD quintiles (dummy variables), and SIMD Q3 and female were reference categories. This modelling assumed that survival over time would follow an exponential distribution, and would be a function of the year and the subgroup's sex, average age and SIMD quintile. The modelling assumes that trends in the data (2002 to 2016) would continue over the subsequent 20 years.

Visual inspection of plots of the data and predictions showed that the model fitted the mortality data well. The survival modelling was conducted in the open-source statistical programming language R (R Core Team 2013), and the R code is given in **Appendix 9.5**.

4.2.2 All-cause mortality rate for unexposed population

The overall all-cause mortality rate (**section 4.2.1**) combines deaths in exposed and unexposed individuals, so must be disaggregated into separate rates for the Triple I modelling. We know that the overall all-cause mortality rate is the sum of the mortality rate in the exposed population and the unexposed population, weighted by the proportion exposed and unexposed, respectively, and we also know that the ERR is the mortality rate in the exposed divided by the mortality rate in the unexposed. Based on these relationships we can derive the following equation:

$$\text{All-cause mortality rate in unexposed} = \frac{\text{All-cause mortality rate}}{(\text{Prevalence}\times\text{ERR})+1-\text{Prevalence}}$$

where prevalence is the risk factor prevalence proportion and ERR is the exposure rate ratio (ScotPHO 2014b).

For example, if the all-cause mortality rate is 1,000 per 100,000 people, the prevalence proportion for physical inactivity in females is 0.41 and the ERR for physical inactivity is 1.43, we can calculate the mortality rate in the unexposed population (physically active females) as 1,000 / ((0.41 x 1.43) + 1 - 0.41) = 850 per 100,000.

4.2.3 All-cause mortality rate for exposed population

The all-cause mortality rate for the exposed population is simply the rate for the unexposed (**section 4.2.2**) multiplied by the ERR. For the example above this would be 850 x 1.43 = 1,216 per 100,000 for physically inactive females.

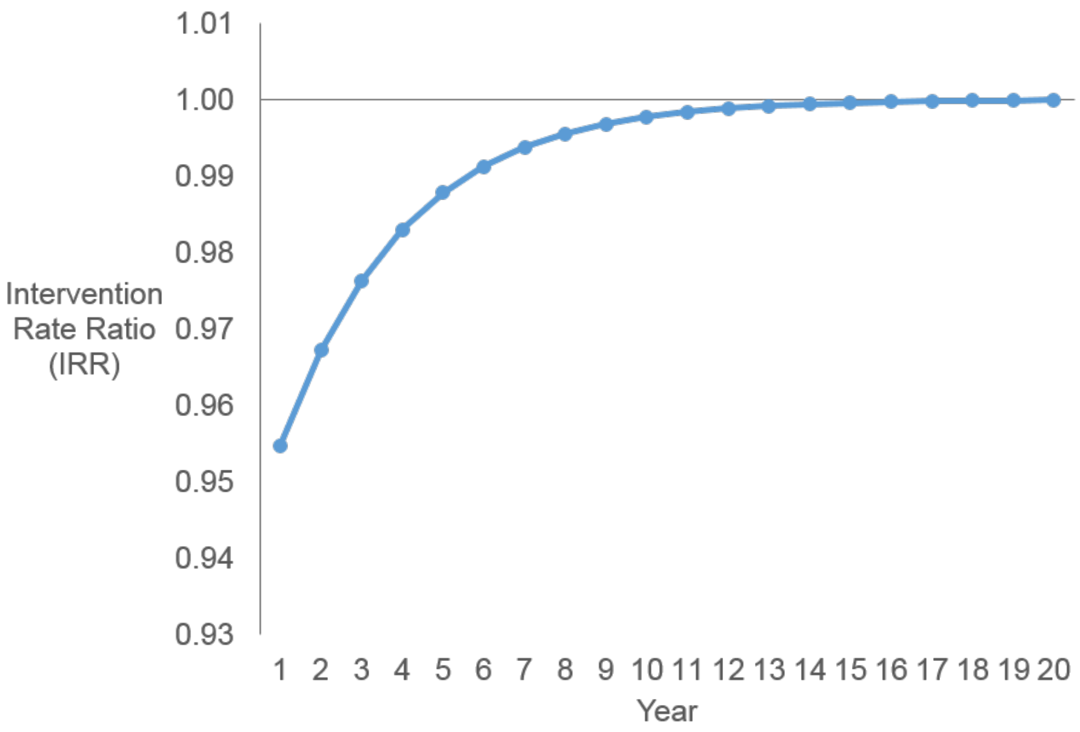
4.2.4 All-cause mortality rate for treated population

The all-cause mortality rate for the exposed population who have been treated by the intervention is then calculated as the rate for the exposed population (**section 4.2.3**) multiplied by the IRR. For example, if some of the physically inactive females from the example above were given a pedometer-based intervention (IRR = 0.954) their all-cause mortality rate as a result of the intervention is predicted to decrease from 1,216 per 100,000 to 1,160 per 100,000 (1,216 x 0.954) in the first year of follow-up.

Constant intervention effects over time were assumed for the permanent 20 mph limits and income-based interventions. For the other interventions the IRR was allowed to vary over time, to reflect the evidence about intervention effect attenuation summarised in **Tables 3** and **4**. Using the evidence, we estimated the IRRs for each year of the follow-up period, and then modelled these using a non-linear function (a 'sigmoid' curve) to smooth the trajectory. This provided us with two parameters – the 'gain' and 'threshold' – that could then be used by the Triple I model to estimate the IRR at a given point in time. **Figure 3** shows the sigmoid curve that describes the attenuation of the effect of ABIs on all-cause hospitalisations over time: the effect decreases from 0.95 (an initial 5% reduction relative to the untreated population) and approaches 1.00 (no effect) over the follow-up period.

We wrote an R program to fit the sigmoid function (code provided in **Appendix 9.6**). The input IRRs and the output gain and threshold values are given in **Appendix 9.7** (**Table 13** for hospitalisation, **Table 14 f**or mortality).

Figure 3. Modelled change in IRR over time for the effect of ABIs on all-cause hospitalisation (relative to the untreated exposed population). Year 1 is the first year of follow-up.



4.2.5 Calculating mortality over time

To calculate the impact of the intervention on the population over a given period of time we needed to sum the deaths in the unexposed, exposed and treated populations for the intervention scenario, and subtract the deaths in the baseline scenario (i.e. if the treated population had not been treated).

The total number of deaths over time in a closed cohort is called the cumulative incidence (CI) of mortality. We obtained the CI by calculating the area under the mortality rate curve for each population over time (giving the CI rate) and multiplying by the population size at year one. As the mortality rate changes over time as a population ages we used integration to calculate the CI rate:

$$\text{CI rate} = 1 - e^{-\int_1^t (M)}$$

where e is a mathematical constant (approximately 2.72), M is the function to be integrated (the predicted mortality rate over time), and the function is integrated between the first year of follow-up and year t (user-selected end point). The CI rate formula was taken from Rothman et al. (2008), and is described in more detail in the technical document from the last phase of Triple I (ScotPHO 2014b).

For a given follow-up period, the Triple I model calculates the mortality CI count for each population (unexposed, exposed and treated) and sums these for each subgroup (i.e. by age group, sex and SIMD quintile).

4.2.6 Calculating hospitalisation over time

The calculation for hospitalisations is similar to that for mortality, although because hospitalisation can reoccur for the same individual we calculate hospitalisations each year rather than applying a CI rate once across the whole period.

After predicted deaths have been subtracted from each subgroup each year we estimate hospitalisations by multiplying the remaining population by the hospitalisation rate corresponding to their population (unexposed, exposed or treated). Calculation of these rates is described below.

4.2.7 Overall all-cause hospitalisation rate

Rates of all-cause hospitalisation over time for the population subgroups (i.e. by SIMD quintile, age group and sex) were estimated using historical hospitalisation data from NHS ISD (Scottish Morbidity Record data sets SMR01 (general) and SMR04 (psychiatric), see **Appendices 9.2.3** and **9.2.4**). Parametric survival models (exponential distribution) were used to estimate changes in hospitalisation rates over time, giving the following formula:

$$\text{All-cause hospitalisation rate} = e^{(-5.61 - 0.03*age - 0.58*male - 0.01*age*male - 0.001*year + 0.35*Q1 + 0.15*Q2 - 0.13*Q4 - 0.24*Q5)}$$

where Q1–5 were SIMD quintiles, and SIMD Q3 and female were reference categories. The model fitted the hospitalisation data well. The R code written for the survival modelling is given in **Appendix 9.5**.

4.2.8 All-cause hospitalisation rates for populations

The overall all-cause hospitalisation rate was then disaggregated to give the rates for the unexposed, exposed and treated populations, as previously described for mortality (see **sections 4.2.2–4.2.4**).

4.2.9 Outcome measures

The Triple I model estimates the intervention effect on absolute and percentage change in three health outcomes:

- **Hospitalisation:** the estimated number of all-cause acute or psychiatric hospital admissions occurring within the whole adult population.
- **Premature mortality:** the estimated number of all-cause deaths occurring within the adult population aged under 75 years.
- **Years of life lost:** the total number of additional years that the adult population would have been expected to live if individuals had not died before their estimated age group- and sex-specific life expectancy (extracted from NRS National Life Tables for Scotland, 2014–2016, see **Appendix 9.2.5**).

Four estimates of health inequality are also generated, based on European Age-Standardised Rates (EASRs) of all-cause mortality and all-cause hospitalisation (European Standard Population 2013):

- **Absolute gap:** the difference between the most and least deprived SIMD quintiles (= rate in most deprived – rate in least deprived).
- **Relative gap:** the relative difference between the most and least deprived SIMD quintiles (= rate in most deprived ÷ rate in least deprived).
- **Slope index of inequality (SII):** A summary measure of absolute inequality, which takes into account differences across the whole gradient of inequality, not just the gap in health outcome between the most and least deprived. The SII we calculated was based on a linear regression model (Pamuk 1985).

- **Relative index of inequality (RII):** The SII divided by the mean rate in the population (Pamuk 1985).

The Western Isles (Eilean Siar) and Shetland Islands had no population in the most and least deprived SIMD 2016 deprivation quintiles, and the Orkney Islands had no population in the most deprived quintile, therefore inequalities were calculated between the most and least deprived national-level quintiles available for these areas.

4.3 Key assumptions

All models are a simplification of how the real world works. The following aspects of Triple I should be considered when interpreting the findings:

1. We relied on the existing evidence base to inform the intervention effect estimates. As a result, some interventions that may have population health benefits could not be included, and those that were included should not be considered to be the only interventions likely to have population relevance for Scotland. Relying on published effectiveness evidence can also lead to a focus on individual-level interventions, as these are easier to implement and study in generalisable ways. Therefore, to permit inclusion of a wider range of interventions we broadened the types of evidence deemed appropriate to support estimation of effect size, while maintaining a rigorous approach to the assessment of this evidence. For example, we did not identify synthesised evidence for the income-based interventions and 20 mph speed limits.

2. We assumed a causal relationship between each risk factor and the health outcomes (e.g. income level and risk of mortality). The epidemiological evidence we assembled provides good evidence of the relationship between each risk factor and health, but the potential for reverse causality (e.g. poor health resulting in the risk factor) should be considered, as well as the influence of unmeasured confounders.

3. We assumed that all-cause mortality and hospitalisation rates over the next 20 years can be adequately predicted from historical rates (2002–2016).

4. We assumed that all-cause mortality and hospitalisation rates are an exponential function of age, sex, age*sex interaction, SIMD quintile and calendar year. Graphical testing of this assumption showed that the function fits the data well. We note, however, that if hospitalisation rates reduce as a result of a particular intervention any spare capacity in the healthcare system may be used by currently unmet need.

5. We assumed that ERRs do not vary by age group, area or calendar year. Apart from in the case of unemployment, alcohol, obesity and smoking, they also do not vary by sex.

6. We assumed that IRRs do not vary by age group, sex (except in the case of smoking cessation services), calendar year, area or SIMD quintile (except for in the case of income-based interventions).

7. Assumptions specific to certain interventions are included in the relevant spreadsheet tool.

4.4 Limitations of the Triple I modelling

1. We were unable to estimate indirect effects of the interventions. For example, revenue-raising interventions (e.g. tobacco taxation or Council Tax increases) could have benefits that we have not modelled, as a result of re-investment of the additional revenue. Tobacco taxation would also lead to increased disposable income for smokers who quit as a result, or decreased disposable income for those who keep smoking, and these changes may have health effects.

2. The interventions were applied to a closed cohort which excluded children. The assumption is that the intervention will only affect deaths and hospitalisations, and will not affect birth rates or immigration.

3. Within Triple I single interventions were implemented in isolation and not combined with other interventions or policies. In reality these interventions may be implemented concurrently, and may have synergistic or antagonistic effects.

4. We assumed that the predicted health benefits of an intervention are experienced immediately.

4.5 Sensitivity analyses

We performed a range of sensitivity analyses to assess the impact of changing key parameters in our modelling approach on the results produced for different interventions. Given the number of permutations available from the range of adjustable options in the Triple I tools (i.e. area of interest, follow-up period, targeting strategy), we adopted a consistent and pragmatic approach to the sensitivity analyses we performed. This was based on assessing the impact on results of a change in a single model parameter, compared with the results produced from the original model. Results were based on those estimated for the whole of Scotland, after five years and, where applicable, based on delivery of interventions to the maximum eligible population and distributed evenly across the population.

4.6 Estimating costs and savings in Triple I

4.6.1 Direct and indirect costs

The interventions included in Triple I vary markedly in the level of investment they would require to implement. A key reason for this is that some are designed to be delivered at the individual level (e.g. weight management services or pedometer-based interventions), while others can only be implemented on larger scales (e.g. benefit increases or 20 mph speed limits). Therefore, to inform fairer comparisons of their impacts on health and health inequalities, we must take account of differences in their costs and population reach. Another reason is that the individual-level interventions were modelled as being delivered for one year only, while the population-level interventions were permanent, and generally involved recurring annual costs. In reality most individual-level interventions are also not delivered in a single year, and are part of ongoing service models that require sustained funding.

We assembled the best available evidence about the direct cost of delivering each intervention in Scotland, in 2015/16 prices. We estimated costs from a health sector perspective, so only direct costs associated with delivering and/or enforcing each intervention have been estimated. We have excluded all indirect costs related to patient or any other department or aspect. Furthermore, we have excluded any set-up or special training costs required to deliver the intervention and have assumed that all interventions are operating under steady-state conditions. We have primarily used existing reference costs (Personal Social Services Research Unit (PSSRU) 2016) to estimate the cost of resource use (e.g. staff time) for delivering the interventions. Where needed, we also derived cost estimates from published literature or by contacting experts for a particular intervention. The costs included in the Triple I modelling are summarised in **Appendix 9.8** for individual- and population-level interventions (**Tables 15**, and **16** and **17**, respectively).

As outlined above, the cost information should be considered indicative only, because although it is based on the best available information it does not capture the full costs of delivering the intervention, and excludes indirect costs. We have not estimated the opportunity costs of the modelled interventions in terms of the implications for health and health inequalities of alternative uses of the funding required to invest in them. Similarly, some population-level interventions result in increased revenue (e.g. increases in tobacco taxation or Income Tax rates), but the impacts of redistributing that money have not been considered here.

4.6.2 Direct financial savings

We estimated savings resulting from the interventions in a partial way, and recognise that our approach is limited, and likely to be conservative. We modelled the direct savings to the NHS of fewer hospital stays, using the 2006/7 estimate of £2,113 per continuous inpatient stay (Geue et al. 2012). We inflated this to £2,512 in 2015/16 prices using the Hospital and Community Health Service (HCHS) inflation index. This crude analysis assumes that no other healthcare need arises if an intervention reduces the demand for services from a particular cause or mechanism. It does not account for the fact that there is unmet need in the healthcare system that might use any spare capacity that may be freed up if an intervention reduced hospital stays.

No attempt was made to quantify savings in terms of fewer premature deaths or years of life lost, or wider savings arising from reduced prescription costs or sickness benefits, for example. Nor was any attempt made to cost the additional services people might use as a result of living longer. Additionally, some interventions have wider benefits that have not been captured (e.g. the societal benefits of income-based interventions).

4.7 Triple I 'front ends'

We have produced two ways of interacting with the Triple I model to produce bespoke results: the spreadsheet tools and the interactive results browser website, available at www.healthscotland.scot/triplei

4.7.1 The spreadsheet tools

The spreadsheet tools are designed so that a user can adjust intervention parameters to suit their particular area of interest, and produce detailed results as required. Some interventions have been grouped,[6] resulting in nine spreadsheet tools:

- income-based interventions
- mental health (depression) interventions
- physical activity interventions
- lifestyle weight-management services
- smoking cessation services
- ABIs
- tobacco taxation
- job provision
- 20 mph speed limits.

Within each spreadsheet tool users can select the area of interest (Scotland, local authorities, Health Boards, Integrated Joint Boards and city regions) and the follow-up period (up to 20 years after the start of the intervention). For individual-level interventions the targeting strategy (even distribution, proportionate to need, most deprived SIMD quintile only or most deprived two SIMD quintiles only) and the number of interventions to deliver (up to the eligible population size) can also be

[6] These interventions have been grouped:

- all income-based interventions (n = 29)
- all interventions for depression (n = 3)
- both physical activity interventions (n = 2).

amended. The model recalculates each time a parameter is changed on the 'Options' tab, and the results are summarised on the same tab and given in greater detail on the 'Results' tab.

A number of bespoke functions were written to implement the Triple I model in Excel. The Visual Basic for Applications (VBA) code for these functions is given in **Appendix 9.9**. As Excel does not have an integration function our function to calculate the CI rate used Simpson's rule (Jeffreys and Jeffreys 1988) to approximate the integral.

4.7.2 The interactive results browser website

We sought to improve dissemination of Triple I and make it easier for potential users to interact with the model, so we developed an interactive results browser. We used the R package 'Shiny' to create the browser. The browser extracts records that meet the user's requirements from a pre-calculated data set. The data set was generated using an R program written to replicate how the Triple I model is implemented in Excel.

The browser makes it simple for a user to change intervention parameters for a selected area of interest and visualise the results. It also enables users to compare multiple interventions easily. Graphs and data tables specific to the user's requirements can then be downloaded, along with explanatory information about the modelling.

5. Results

In this section we tabulate results for the illustrative 'maximum effect' scenarios that are presented in the national overview report. We refer readers to the national overview report for interpretation of these results.

5.1 Intervention effects and cost-effectiveness

Using the spreadsheet tools there are numerous combinations of the intervention parameters that can be modelled. In this report we provide results for year five for interventions delivered across Scotland. Individual-level interventions are delivered to the entire eligible population for the relevant risk factor, thus maximising their reach, and are delivered proportionate to need. The reach of the population-wide interventions cannot be altered. The results are presented separately for premature deaths (**Table 5**), years of life lost (**Table 6**) and hospital stays (**Table 7**). Owing to the differing levels of reach and investment for the interventions in these tables it is not recommended that they are used to make direct comparisons.

Given our joint policy objectives to **improve** health and **reduce** health inequalities, in these tables (as well as in the spreadsheet tools and the interactive browser) we refer to changes in the health outcomes as **positive** if they represent an improvement (negative if they represent a worsening), and changes in health inequalities as **negative** if they represent a narrowing of the gap (positive for a widening). As a result we have inverted the health outcome measures, and refer to 'hospital stays prevented', 'premature deaths prevented' and 'years of life saved'.

The tables also present an indication of the cost-effectiveness for each intervention by representing the estimated impact in relation to the size of the investment required to achieve it. The estimates are not based on full economic evaluations or cost-effectiveness evaluations but it is important to consider the estimated impacts relative to their cost. Direct costs have been estimated for each, and used to calculate the cost per percentage-point improvement in the outcome or percentage-point narrowing in inequality in the outcome. The income-based interventions and tobacco taxation increase involve recurring annual costs or savings, and these have been accounted for in the calculation. The individual-level interventions (all mitigate-type interventions and job provision) are delivered for only one year in Triple I, hence do not involve recurring annual costs. The 20 mph limits intervention also involves one-off set-up costs in year one.

Table 5. Effects on premature deaths and inequalities in premature deaths in Scotland for the interventions in Triple I. Interventions were implemented at their maximum possible scale (whole population or entire eligible population), targeted proportionate to need (where appropriate), and effects were estimated in year five. All costs given in £ million (2016 values).

Intervention	Number treated	Cost (£ million)[1]	Premature deaths prevented	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer premature deaths	Cost (£m) per 1%-pt narrowing in relative inequality
Undo						
Citizen's Basic Income	Population[3]	£1,768	582 (0.68%)	-0.046 (-3.65%)	£2,616	£485
Citizen's Basic Income Plus	Population	£2,141	1,167 (1.36%)	-0.075 (-5.93%)	£1,579	£361
Council Tax increase	Population	-£542	-127 (-0.15%)	-0.004 (-0.35%)	N/A	-£1,548
Devolved benefits +50%	Population	£3,094	1,507 (1.75%)	-0.027 (-2.15%)	£1,766	£1,438
Income Tax rates +1p	Population	-£1,714	-519 (-0.60%)	-0.006 (-0.47%)	N/A	-£3,650
Income Tax rates -1p	Population	£1,714	513 (0.60%)	0.006 (0.46%)	£2,878	N/A
Living Wage	Population	£5,056	2,062 (2.40%)	-0.022 (-1.76%)	£2,110	£2,871
Local Income Tax	Population	£5,152	1,926 (2.24%)	< -0.001 (-0.01%)	£2,302	£402,616
Means-tested benefits +50%	Population	£8,691	4,060 (4.72%)	-0.101 (-7.96%)	£1,842	£1,092
Personal Allowance +£1,000	Population	£2,052	683 (0.79%)	0.003 (0.21%)	£2,584	N/A
Personal Allowance -£1,000	Population	-£2,163	-734 (-0.85%)	-0.003 (-0.21%)	N/A	-£10,473
Prevent						
Job provision	236,916	£1,096	1,739 (2.02%)	-0.016 (-1.24%)	£542	£884
Benefit uptake +1%	Population	£36	80 (0.09%)	-0.003 (-0.24%)	£386	£146
20 mph speed limits	Population	£35	22 (0.03%)	< -0.001 (-0.01%)	£1,482	£3,032
Tobacco tax +10%	Population	-£283	143 (0.17%)	-0.002 (-0.14%)	-£1,691	-£1,967
Mitigate						
ABI	339,384	£13	271 (0.31%)	0.001 (0.10%)	£42	N/A

Intervention	Number treated	Cost (£ million)[1]	Premature deaths prevented	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer premature deaths	Cost (£m) per 1%-pt narrowing in relative inequality
Computerised CBT (for depression)	132,940	£5	100 (0.12%)	-0.001 (-0.07%)	£39	£64
Group physical activity (for depression)	132,940	£34	210 (0.24%)	-0.002 (-0.15%)	£140	£230
Individual guided self-help (for depression)	132,940	£19	310 (0.36%)	-0.003 (-0.22%)	£52	£85
Pedometer-based interventions	737,010	£5	514 (0.60%)	-0.003 (-0.24%)	£9	£22
Physical activity brief intervention	737,010	£5	523 (0.61%)	-0.003 (-0.24%)	£8	£21
Smoking cessation services	691,607	£72	298 (0.35%)	-0.004 (-0.30%)	£207	£240
Lifestyle weight management services	905,724	£68	2,074 (2.42%)	-0.006 (-0.48%)	£28	£142

N/A indicates that a cost per 1% improvement was not available because the intervention did not improve the outcome or reduce the inequality.

[1] Negative costs represent savings. Costs are not net of savings due to hospitalisations prevented (Table 8).

[2] Relative inequality measured using the RII. Negative change represents a narrowing of relative inequality.

[3] For population-level interventions the number treated is noted as ‘Population’ because they are delivered across the Scottish population (or the urban Scottish population in the case of 20 mph speed limits), rather than to individuals. Most of these interventions will directly affect a smaller number of people. For example, people in receipt of means-tested benefits will be affected by the increase in these benefits, smokers will be affected by the increase in tobacco taxation and people in Council Tax bands E to H will be affected by the Council Tax increase.

Table 6. Effects on years of life lost (YLL) and inequalities in YLL in Scotland for the interventions in Triple I. Interventions were implemented at their maximum possible scale (whole population or entire eligible population), targeted proportionate to need (where appropriate) and effects were estimated in year five. All costs given in £ million (2016 values).

Intervention	Number treated	Cost (£ million)[1]	Years of life saved (i.e. YLL prevented)	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer YLLs	Cost (£m) per 1%-pt narrowing in relative inequality
Undo						
Citizen's Basic Income	Population[3]	£1,768	15,167 (0.68%)	-0.046 (-3.65%)	£2,613	£484
Citizen's Basic Income Plus	Population	£2,140	30,448 (1.36%)	-0.074 (-5.93%)	£1,576	£361
Council Tax increase	Population	-£542	-3,250 (-0.15%)	-0.004 (-0.35%)	N/A	-£1,540
Devolved benefits +50%	Population	£3,094	39,053 (1.74%)	-0.027 (-2.14%)	£1,776	£1,447
Income Tax rates +1p	Population	-£1,714	-13,358 (-0.60%)	-0.006 (-0.47%)	N/A	-£3,611
Income Tax rates -1p	Population	£1,714	13,200 (0.59%)	0.006 (0.47%)	£2,910	N/A
Living Wage	Population	£5,056	53,312 (2.38%)	-0.022 (-1.74%)	£2,126	£2,902
Local Income Tax	Population	£5,152	49,711 (2.22%)	0.000 (0.01%)	£2,323	N/A
Means-tested benefits +50%	Population	£8,691	105,425 (4.70%)	-0.099 (-7.92%)	£1,847	£1,098
Personal Allowance +£1,000	Population	£2,052	17,620 (0.79%)	0.003 (0.22%)	£2,609	N/A
Personal Allowance -£1,000	Population	-£2,163	-18,939 (-0.85%)	-0.003 (-0.21%)	N/A	-£10,147
Prevent						
Job provision	236,916	£1,096	43,416 (1.94%)	-0.017 (-1.36%)	£564	£806
Benefit uptake +1%	Population	£36	2,075 (0.09%)	-0.003 (-0.24%)	£386	£147
20 mph speed limits	Population	£35	576 (0.03%)	< -0.001 (-0.01%)	£1,478	£3,086
Tobacco tax +10%	Population	-£283	3,526 (0.16%)	-0.002 (-0.13%)	-£1,786	-£2,110
Mitigate						
ABI	339,384	£13	6,204 (0.28%)	0.001 (0.10%)	£48	N/A

Intervention	Number treated	Cost (£ million)[1]	Years of life saved (i.e. YLL prevented)	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer YLLs	Cost (£m) per 1%-pt narrowing in relative inequality
Computerised CBT (for depression)	132,940	£5	2,651 (0.12%)	-0.001 (-0.07%)	£38	£64
Group physical activity (for depression)	132,940	£34	5,562 (0.25%)	-0.002 (-0.15%)	£137	£229
Individual guided self-help (for depression)	132,940	£19	8,234 (0.37%)	-0.003 (-0.22%)	£50	£84
Pedometer-based interventions	737,010	£5	13,598 (0.61%)	-0.002 (-0.19%)	£8	£27
Physical activity brief intervention	737,010	£5	13,854 (0.62%)	-0.002 (-0.20%)	£8	£26
Smoking cessation services	691,607	£72	7,328 (0.33%)	-0.003 (-0.28%)	£219	£258
Lifestyle weight management services	905,724	£68	50,448 (2.26%)	-0.006 (-0.47%)	£30	£143

N/A indicates that a cost per 1% improvement was not available because the intervention did not improve the outcome or reduce the inequality.

[1] Negative costs represent savings. Costs are not net of savings due to hospitalisations prevented (Table 8).

[2] Relative inequality measured using the RII. Negative change represents a narrowing of relative inequality.

[3] For population-level interventions the number treated is noted as ‘Population’ because they are delivered across the Scottish population (or the urban Scottish population in the case of 20 mph speed limits), rather than to individuals. Most of these interventions will directly affect a smaller number of people. For example, people in receipt of means-tested benefits will be affected by the increase in these benefits, smokers will be affected by the increase in tobacco taxation, and people in Council Tax bands E to H will be affected by the Council Tax increase.

Table 7. Effects on hospital stays and inequalities in hospital stays in Scotland for the interventions in Triple I. Interventions were implemented at their maximum possible scale (whole population or entire eligible population), targeted proportionate to need (where appropriate), and effects were estimated in year five. All costs given in £ million (2016 values).

Intervention	Number treated	Cost (£ million)[1]	Hospital stays prevented	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer hospital stays	Cost (£m) per 1%-pt narrowing in relative inequality
Undo						
Citizen's Basic Income	Population[3]	£1,768	17,793 (0.38%)	-0.044 (-6.44%)	£4,621	£275
Citizen's Basic Income Plus	Population	£2,141	40,180 (0.86%)	-0.070 (-10.14%)	£2,477	£211
Council Tax increase	Population	-£542	-6,639 (-0.14%)	-0.004 (-0.61%)	£3,795	-£892
Devolved benefits +50%	Population	£3,094	64,818 (1.39%)	-0.024 (-3.50%)	£2,219	£884
Income Tax rates +1p	Population	-£1,714	-24,842 (-0.53%)	-0.005 (-0.79%)	£3,208	-£2,181
Income Tax rates -1p	Population	£1,714	24,560 (0.53%)	0.005 (0.78%)	£3,245	N/A
Living Wage	Population	£5,056	90,825 (1.95%)	-0.020 (-2.89%)	£2,588	£1,751
Local Income Tax	Population	£5,152	88,499 (1.90%)	< 0.001 (0.01%)	£2,707	N/A
Means-tested benefits +50%	Population	£8,691	171,728 (3.69%)	-0.086 (-12.51%)	£2,353	£694
Personal Allowance +£1,000	Population	£2,052	31,811 (0.68%)	0.002 (0.34%)	£2,999	N/A
Personal Allowance -£1,000	Population	-£2,163	-34,115 (-0.73%)	-0.002 (-0.33%)	£2,948	-£6,497
Prevent						
Job provision	236,916	£1,096	6,010 (0.13%)	-0.001 (-0.16%)	£8,478	£6,782
Benefit uptake +1%	Population	£36	3,168 (0.07%)	-0.003 (-0.37%)	£524	£97
20 mph speed limits	Population	£35	1,206 (0.03%)	< -0.001 (-0.02%)	£1,469	£1,705
Tobacco tax +10%	Population	-£283	4,388 (0.09%)	-0.001 (-0.17%)	-£2,991	-£1,695
Mitigate						
ABI	339,384	£13	11,536 (0.25%)	0.001 (0.19%)	£53	N/A

Intervention	Number treated	Cost (£ million)[1]	Hospital stays prevented	Change in relative inequality[2]	Cost (£m) per 1%-pt fewer hospital stays	Cost (£m) per 1%-pt narrowing in relative inequality
Computerised CBT (for depression)	132,940	£5	11,637 (0.25%)	-0.002 (-0.31%)	£18	£15
Group physical activity (for depression)	132,940	£34	23,913 (0.51%)	-0.004 (-0.63%)	£66	£54
Individual guided self-help (for depression)	132,940	£19	34,376 (0.74%)	-0.006 (-0.91%)	£25	£20
Pedometer-based interventions	737,010	£5	Not known	-	-	-
Physical activity brief intervention	737,010	£5	Not known	-	-	-
Smoking cessation services	691,607	£72	9,170 (0.20%)	-0.002 (-0.35%)	£364	£206
Lifestyle weight management services	905,724	£68	11,760 (0.25%)	< 0.001 (< 0.01%)	£268	N/A

N/A indicates that a cost per 1% improvement was not available because the intervention did not improve the outcome or reduce the inequality.

[1] Negative costs represent savings. Costs are not net of savings due to hospitalisations prevented (Table 8).

[2] Relative inequality measured using the RII. Negative change represents a narrowing of relative inequality.

[3] For population-level interventions the number treated is noted as ‘Population’ because they are delivered across the Scottish population (or the urban Scottish population in the case of 20 mph speed limits), rather than to individuals. Most of these interventions will directly affect a smaller number of people. For example, people in receipt of means-tested benefits will be affected by the increase in these benefits, smokers will be affected by the increase in tobacco taxation, and people in Council Tax bands E to H will be affected by the Council Tax increase.

5.2 Direct financial savings (hospitalisations)

The direct financial savings that we estimated could result from reduced hospital stays under each intervention are given in **Table 8**, for the same scenarios modelled in **Tables 5–7**.

Table 8. Estimated direct financial savings resulting from reduced hospital stays under each intervention. Interventions were implemented for Scotland at their maximum possible scale (whole population or entire eligible population), targeted proportionate to need (where appropriate) and effects were estimated in year five. Savings given in £ million (2016 values). Negative savings indicate costs.

Intervention	Hospital stays prevented	Direct saving (£ million)
Undo		
Citizen's Basic Income	17,793	£45
Citizen's Basic Income Plus	40,180	£101
Council Tax increase (bands E–H)	-6,639	-£17
Devolved benefits +50%	64,818	£163
Income Tax rates +1p	-24,842	-£62
Income Tax rates -1p	24,560	£62
Living Wage	90,825	£228
Local Income Tax	88,499	£222
Means-tested benefits +50%	171,728	£431
Personal Allowance +£1,000	31,811	£80
Personal Allowance -£1,000	-34,115	-£86
Prevent		
Job provision	6,010	£15
Benefit uptake +1%	3,168	£8
20 mph speed limits	1,206	£3
Tobacco tax +10%	4,388	£11
Mitigate		
ABI	11,536	£29
Computerised CBT (for depression)	11,637	£29
Group physical activity (for depression)	23,913	£60
Individual guided self-help (for depression)	34,376	£86
Pedometer-based interventions	not known	-
Physical activity brief intervention	not known	-
Smoking cessation services	9,170	£23
Lifestyle weight management services	11,760	£30

5.3 Sensitivity analyses

Sensitivity analyses were performed for the estimated effects of each intervention in year five, based on Scotland-wide implementation, and, where applicable, based on delivery of interventions to the maximum eligible population and distributed evenly across SIMD quintiles.

Additional information on the sensitivity analyses performed for each intervention and the results produced is provided below.

5.3.1 Income-based interventions

In the absence of better evidence, it was assumed in the income-based intervention models that an increase in income results in a reduction in mortality or hospitalisation that can be adequately predicted from a regression analysis of cross-sectional income and health data (i.e. the relationship is not confounded). We performed sensitivity analyses to assess the impact of assuming that the income–health relationship was confounded. Consistent with the approach taken in the last phase of Triple I (McAuley et al. 2016), it was arbitrarily assumed that confounding attenuated the impact of income changes on mortality by 25% and 50%. The results presented in **Table 9** show that the estimated impact on outcomes is reduced by between 31–33% if assuming 25% confounding and between 58–60% if assuming 50% confounding. Thus, the strength of the relationship between income and health is an important factor in the estimated policy effect sizes. Our main results, which assume no confounding of the relationship, are likely to represent the upper limit of the effects.

5.3.2 20 mph speed limits

It was assumed that the average speed reduction resulting from the intervention would be 1.3 mph (22.7 mph before, 21.4 mph after) as this was the average speed reduction found in similar UK schemes. We performed sensitivity analyses to assess the impact of assuming alternative average speed reductions of 0.5 mph (as in one Bristol scheme; Bristol City Council 2012) and 2.0 mph (as in Southwark scheme in London; Cross River

Partnership 2017). The results presented in **Table 9** show that changes to the assumed average speed reduction produced large relative changes when compared to results using the original model parameters. For example, an average speed reduction of 2.0 mph resulted in 1,717 fewer hospital admissions compared with 1,206 based on the original model, equivalent to a further reduction of 42%. However, this translates into only a small increase in the estimated percentage change in hospital admissions prevented (0.04% vs. 0.01%, respectively). In addition, the absolute change in the estimated impact is small when considered alongside the estimated impact of income-based interventions.

Additional sensitivity analyses were also conducted to assess the impact of assumptions relating to the air pollution component of the 20 mph speed limit intervention effect. As shown in **Table 9**, these had a negligible effect on the estimated impact of the intervention when compared to results using the original model parameters.

5.3.3 Job provision

The job provision intervention assumed mortality effects from a 2011 meta-analysis (Roelfs et al. 2011), and we were able to test this assumption using more recent findings from Scotland (Clemens et al. 2015). This study found larger effects of unemployment on mortality risk for males, but no significant effect for females. The results differed only marginally from the original model (**Table 9**): an additional 55 fewer premature deaths (4.2% reduction), 26 more hospitalisations (0.5% increase) and a small decrease in the narrowing of inequalities in both outcomes.

The eligible population for the job provision intervention – those able to start work – was defined as the ‘real’ unemployed (ILO definition of unemployed plus those on incapacity benefits who might be expected to work in a full-employed economy), or 30% of the PAR. We tested the effect of altering the eligible population definition (**Table 9**). Restricting the eligible population to just the ILO definition of unemployment (those who were available for and actively seeking work) would half the eligible population, and the effects would be similarly affected. If, to mirror real-life results, the eligible population corresponded to the number of people finding work through reserved or devolved employment programmes the eligible population would be 1.5% of the PAR, and the effects would be correspondingly reduced.

5.3.4 Tobacco taxation

Owing to a lack of alternative evidence to inform different assumptions and key parameters, we did not perform sensitivity analyses for the tobacco taxation intervention.

5.3.5 Lifestyle weight management services

The IRR for hospitalisation (0.98) is derived from assumed adoption of observed risk of lower BMI achieved through weight management. By contrast, the IRR for mortality (0.86) is derived from a systematic review which assessed mortality risk of participants in randomised controlled trials of weight management services. No alternative data source for an IRR specific to hospitalisation effects of weight management services was identified. We therefore performed sensitivity analyses to assess the impact of assuming the IRR for hospitalisation was the same as that for mortality (0.86). As shown in **Table 9**, this change resulted in a nearly 10-fold increase in the estimated number and proportion of hospitalisations prevented when compared to results using the original model parameters. The size of the effect of this sensitivity analysis demonstrates that there remains considerable uncertainty regarding the size of the effect of weight loss on hospitalisation. This is due to an absence of evidence regarding these long-term outcomes, which would ideally be addressed in future through high-quality longitudinal studies. Overall, it is possible that the current model may overestimate mortality effects, and underestimate hospitalisation effects.

A key parameter in the weight management model is the mean BMI, height and weight of participants, which have been derived from observed data of Counterweight participants reported in the previous phase of Triple I (obtained in 2008). If population BMI has increased since then we may have overestimated the effect of the intervention, because the intervention effect was measured as weight rather than BMI reduction. We therefore performed sensitivity analyses to assess the impact of using estimates of mean BMI, height and weight of the obese adult population in Scotland based on data from the SHeS (2013–2016 combined). The mean BMI of the total SHeS obese population was lower than that of the Counterweight participants (34.6 kg/m^2 vs. 37.1 kg/m^2). This means that application of the expected mean weight loss of -2.59 kg results in a greater BMI change (-1.18 kg/m^2 vs. -0.95 kg/m^2). This greater BMI change results in a greater overall impact on outcomes; however, as shown in **Table 9**, the size of the impact was very small.

5.3.6 Depression interventions

The three depression intervention models include the assumption that 26% of people with sub-threshold/mild/moderate depression seek help or treatment (i.e. the eligible population was 26% of the PAR). This was based on the mid-point from a range of values from different studies. We therefore performed sensitivity analyses to assess the impact of assuming the proportion who seek help was 5% or 36% based on the range of estimates in the identified studies. The results presented in **Table 9** show that changes to the assumed proportion who seek help produced large relative changes when compared to results using the original model parameters. For example, assuming the proportion who seek help is 36% in the computerised CBT intervention model resulted in 16,247 fewer hospital admissions compared with 11,733 based on the original model, equivalent to an additional 39% reduction. However, this translates into only a small increase in the estimated percentage change in hospital admissions prevented (0.35% vs. 0.25%, respectively) and the impact on RII is also very small. In addition, the absolute change in the estimated impact is small when considered alongside the estimated impact of ‘undo’ interventions. A similar conclusion can be drawn when assessing the impact of using IRRs based on alternative effect sizes (**Table 9**).

5.3.7 Physical activity interventions

The ERR for mortality in the physical activity interventions is based on a comparison between the least and most active groups (ERR = 1.43). This may overestimate the effect for those who don't meet the physical activity guidelines, compared with those who do. We therefore performed sensitivity analyses using an alternative estimate of the mortality ERR of 1.25 from Lee and Skerrett (2001). As shown in **Table 9**, this had a negligible effect on the estimated impact of the intervention when compared to results using the original model parameters. Similarly, using the upper and lower estimate of the effect size of the pedometer-based intervention had a negligible impact on results (**Table 9**).

5.3.8 Alcohol Brief Intervention (ABI)

The prevalence of the PAR in the original model is based on estimates for average weekly alcohol consumption in relation to the 1995 drinking guidelines that have now been superseded. This was to maintain consistency with the drinking thresholds used to calculate the ERRs. Sensitivity analysis has been done to assess the impact of using different estimates of the PAR based on:

1. the new drinking guidelines (2016), which reduced the recommended weekly alcohol intake from no more than 21 units to no more than 14 units for men, while retaining the 14 units limit for women
2. the Alcohol Use Disorders Identification Test (AUDIT) questionnaire, which is a well validated screening tool for identifying hazardous and harmful drinkers (a score of 8 or more).

As shown in **Table 9**, using different definitions of the PAR changed the absolute number of outcomes being estimated. However, the impact on the relative effect of the intervention on the modelled outcomes was small. This is particularly the case when considered alongside the estimated impact of other population-level, upstream interventions.

5.3.9 Smoking cessation

A number of sources of robust evidence were available for key parameters in the smoking cessation model, including the ERR and IRR for mortality. We therefore performed sensitivity analyses to assess the impact of using alternative estimates to those included in our original model. Specifically, this involved:

1. a change in the ERR for mortality from 1.90 in men and 1.80 in women (original model parameters obtained from Gellert et al. 2002) to 2.03 for both men and women (based on Mons et al. 2015)
2. a change in the IRR for mortality from 0.76 for men and 0.64 for women (original model parameters derived from Hart et al. 2013) to 0.67 for men and 0.65 for women (based on Mons et al. 2015).

Both of these changes resulted in higher estimates of the number of premature deaths prevented. However, as shown in **Table 9**, this translates into only a small increase in the estimated percentage change in outcomes and the impact on the percentage change in RII was also negligible.

We also assessed the impact of changing the assumed success rate of the smoking cessation intervention of 5.8%. This figure is based on an average for NHS-delivered smoking cessation services in Scotland (2009–13). A more recent estimate of 6.3% (ISD 2018) was used in sensitivity analysis. This change resulted in a greater number of outcomes being estimated for smoking cessation interventions, particularly hospital stays prevented. However, consistent with the other individual-level interventions, the impact on the relative effect of the intervention on outcomes was small.

Table 9. Summary of the sensitivity analyses performed and their results. Interventions were implemented for the whole of Scotland and results are given for year five. Where applicable, interventions were delivered evenly across the population, to the maximum eligible population.

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
Income-based interventions*		Original model	171,728 (3.69%)	-0.0865 (-12.51%)	4,060 (4.72%)	-0.1005 (-7.96%)
	Relationship between income and health is not confounded	Confounding attenuates the effect size by 25%	117,823 (2.53%)	-0.0589 (-8.52%)	2,738 (3.18%)	-0.0670 (-5.31%)
	Relationship between income and health is not confounded	Confounding attenuates the effect size by 50%	72,794 (1.57%)	-0.0361 (-5.23%)	1,672 (1.94%)	-0.0406 (-3.21%)
20 mph speed limits		Original model	1,206 (0.03%)	-0.0002 (-0.02%)	22 (0.03%)	-0.0002 (-0.01%)
	Average speed reduction resulting from the intervention of 1.3 mph	Average speed reduction of 0.5 mph	531 (0.01%)	-0.0001 (-0.01%)	11 (0.01%)	-0.0001 (-0.01%)
	Average speed reduction resulting from the intervention of 1.3 mph	Average speed reduction of 2.0 mph	1,717 (0.04%)	-0.0002 (-0.03%)	35 (0.04%)	-0.0002 (-0.02%)
	Double-counting of air pollution effects is adequately accounted for by reducing the NO_2 rate ratio by 33%	NO_2 effects fully accounted for in $PM_{2.5}$ accounts, so no NO_2 effects modelled	1,206 (0.03%)	-0.0002 (-0.02%)	22 (0.03%)	-0.0002 (-0.01%)
	Double-counting of air pollution effects is adequately accounted for by reducing the NO_2 rate ratio by 33%	No double-counting issue; no adjustment of NO_2 effects	1,206 (0.03%)	-0.0002 (-0.02%)	22 (0.03%)	-0.0002 (-0.01%)

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
	Expected pollutant reductions are 0.7722% for NOx and -8.3% for PM_{10}	Pollutant change 50% lower	1,147 (0.02%)	-0.0001 (-0.02%)	21 (0.02%)	-0.0002 (-0.01%)
	Expected pollutant reductions are 0.7722% for NOx and -8.3% for PM_{10}	Pollutant change 50% higher	1,265 (0.03%)	-0.0002 (-0.02%)	23 (0.03%)	-0.0002 (-0.01%)
Job provision		Original model	1,324 (1.54%)	0.0024 (0.19%)	5,188 (0.11%)	0.0001 (0.02%)
	Mortality ERRs for unemployment are 1.78 (male) and 1.37 (female), based on meta-analysis (Roelfs et al. 2011)	Change mortality ERRs to 1.85 (male) and 1.00 (female) (based on the Scottish study of Clemens et al. 2015)	1,269 (1.48%)	0.0022 (0.18%)	5,214 (0.11%)	0.0001 (0.01%)
	Eligible population is the 'real' unemployed, i.e. ILO unemployed plus the hidden unemployed. This is 30% of the PAR	'Hidden' unemployed excluded from the eligible population, reducing it to 15% of the PAR	662 (0.77%)	0.0012 (0.10%)	2,594 (0.06%)	0.0001 (0.01%)
	Eligible population is the 'real' unemployed, i.e. ILO unemployed plus the hidden unemployed. This is 30% of the PAR	Change the eligible population to the total number of people finding work through reserved or devolved employment programmes, estimated at 1.5% of the PAR	66 (0.08%)	0.0001 (0.01%)	259 (0.01%)	0.0000 (0.00%)

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
Lifestyle weight-management services		Original model	17,252 (0.37%)	0.0019 (0.28%)	2,800 (3.26%)	0.0042 (0.34%)
	An IRR for hospitalisation of 0.98	The IRR for hospitalisation was the same as that for mortality (0.86)	152,211 (3.28%)	0.0033 (0.48%)	2,800 (3.26%)	0.0042 (0.34%)
	Mean BMI, height and weight of treated population is based on Counterweight participants reported in the previous phase of Triple I (obtained in 2008)	Mean BMI, height and weight of treated population is that of the obese adult population in Scotland (SHeS 2013–2016 combined)	21,527 (0.46%)	0.0024 (0.34%)	3,514 (4.09%)	0.0053 (0.42%)
Computerised CBT for depression		Original model	11,733 (0.25%)	0.0002 (0.02%)	103 (0.12%)	0.0001 (0.01%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	5% of people with sub-threshold/mild/ moderate depression seek help or treatment	2,256 (0.05%)	0.0000 (0.00%)	20 (0.02%)	0.000 (0.00%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	36% of people with sub-threshold/mild/ moderate depression seek help or treatment	16,247 (0.35%)	0.0002 (0.03%)	143 (0.17%)	0.0001 (0.01%)

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
	Hospitalisation IRR of 0.889 based on SMD of -0.40 compared with non-active control group	IRR of 0.832 based on SMD of -0.63 compared with waiting list control group (So et al. 2013)	17,913 (0.39%)	0.0002 (0.03%)	Same as original	Same as original
	Hospitalisation IRR of 0.889 based on SMD of -0.40 compared with non-active control group	IRR of 0.935 based on SMD of -0.23 compared with treatment as usual control group (So et al. 2013)	6,759 (0.15%)	0.0001 (0.02%)	Same as original	Same as original
Group physical activity for depression		Original model	24,111 (0.52%)	0.0003 (0.05%)	217 (0.25%)	0.0002 (0.01%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	5% of people with sub-threshold/mild/ moderate depression seek help or treatment	4,636 (0.10%)	0.0001 (0.01%)	42 (0.05%)	0.0000 (0.00%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	36% of people with sub-threshold/mild/ moderate depression seek help or treatment	33,386 (0.72%)	0.0004 (0.06%)	300 (0.35%)	0.0003 (0.02%)
	Hospitalisation IRR of 0.812 based on SMD of -0.71 compared with non-active control group	IRR of 0.763 based on SMD of -0.63 compared with non-active control group (Schuch et al. 2016)	30,579 (0.66%)	0.0004 (0.05%)	Same as original	Same as original

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
Individual guided self-help for depression		Original model	34,662 (0.75%)	0.0004 (0.06%)	321 (0.37%)	0.0004 (0.06%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	5% of people with sub-threshold/mild/ moderate depression seek help or treatment	6,665 (0.14%)	0.0001 (0.01%)	62 (0.07%)	0.0001 (0.00%)
	26% of people with sub-threshold/mild/moderate depression seek help or treatment	36% of people with sub-threshold/mild/ moderate depression seek help or treatment	47,996 (1.03%)	0.0006 (0.09%)	444 (0.52%)	0.0004 (0.03%)
	Hospitalisation IRR of 0.751 based on SMD of -0.98 compared with treatment as usual control group	IRR of 0.866 based on SMD of -0.49 compared with treatment as usual control group (NICE 2009)	18,222 (0.39%)	0.0003 (0.05%)	Same as original	Same as original
Pedometer-based interventions		Original model	Not applicable	Not applicable	417 (0.49%)	0.0007 (0.05%)
	ERR for mortality based on a comparison between the least and most active groups (ERR = 1.43)	ERR of 1.25 based on Lee and Skerrett (2001)	Not applicable	Not applicable	392 (0.46%)	0.0005 (0.04%)
	Effect size assumed to be 4.7 minutes per day based on a single study	Lower confidence interval of effect size of 3 minutes used	Not applicable	Not applicable	407 (0.47%)	0.0007 (0.05%)

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
	Effect size assumed to be 4.7 minutes per day based on a single study	Upper confidence interval of effect size of 7 minutes used	Not applicable	Not applicable	425 (0.49%)	0.0007 (0.05%)
Physical activity brief intervention		Original model	Not applicable	Not applicable	425 (0.49%)	0.0007 (0.05%)
	ERR for mortality based on a comparison between the least and most active groups (ERR = 1.43)	ERR of 1.25 based on Lee and Skerrett (2001)	Not applicable	Not applicable	400 (0.46%)	0.0005 (0.04%)
ABI		Original model	12,226 (0.26%)	0.0001 (0.02%)	249 (0.29%)	0.0001 (0.01%)
	Prevalence of PAR is based on exceeding old (1995) weekly drinking guidelines (> 21 units for men; > 14 units for women)	Prevalence of PAR based on exceeding new (2016) weekly drinking guidelines (> 14 units for men and women)	15,857 (0.34%)	0.0002 (0.02%)	313 (0.36%)	0.0000 (0.00%)
	Prevalence of PAR is based on exceeding old (1995) weekly drinking guidelines (>21 units for men; >14 units for women)	Prevalence of PAR based on AUDIT score of 8 or more	11,021 (0.24%)	0.0001 (0.02%)	231 (0.27%)	0.0003 (0.02%)
Smoking cessation		Original model	9,687 (0.21%)	0.0005 (0.07%)	282 (0.33%)	0.0009 (0.07%)
	Mortality ERR of 1.90 for men and 1.80 for women	Mortality ERR of 2.03 for both men and women (based on Mons et al. 2015)	9,612 (0.21%)	0.0005 (0.07%)	298 (0.35%)	0.0011 (0.08%)

Intervention	Assumption	Sensitivity analysis performed	Hospital stays prevented	Change in hospital stays RII	Premature deaths prevented	Change in premature deaths RII
	Mortality IRR of 0.76 for men and 0.64 for women	Mortality IRR of 0.67 for men and 0.65 for women (based on Mons et al. 2015)	9,589 (0.21%)	0.0005 (0.07%)	329 (0.38%)	0.0010 (0.08%)
	Success rate of smoking cessation interventions assumed to be 5.8% (2009–2013 data)	More recent success rate of 6.3%, based on ISD (2018) 52-week follow-up results	13,355 (0.29%)	0.0006 (0.08%)	309 (0.36%)	0.0010 (0.08%)

* (example = means-tested benefits +50%)

6. Summary

In this technical report we have described the steps we took to update and develop the earlier phase of Triple I from 2014.

We engaged with local stakeholders to understand how to make the work more useful for local areas. We learned that while there is demand for evidence-based decision-making tools in local areas there is also a need to have relevant results presented more simply. This exercise informed the subsequent development of Triple I.

We broadened the range of interventions included in Triple I by scoping interventions that spanned the three action types needed to reduce health inequalities (undo, prevent and mitigate). We identified potential interventions by consulting with our Project Advisory Group, other topic experts, and relevant publications, and applied selection criteria to determine which could be included.

We improved the Triple I tools and the presentation of the work for both local and national users. In this report we describe the Triple I model in detail, and summarise the data and evidence we used to model each intervention. Full transparency about the methods and data inputs was considered crucial to provide clarity about the results, as well as enabling the model to be further developed and improved in future. We then highlight the ways that users can interact with the Triple I model to produce bespoke results: the spreadsheet tools and the interactive results browser website, available at www.healthscotland.scot/triplei

Results for implementing the interventions across Scotland are presented and interpreted in the national overview report. In this technical report we tabulate the estimated effects of these interventions on health and health inequalities, as well as their estimated cost-effectiveness, for the illustrative maximum-effect scenario presented in the national overview report. As a key strength of Triple I is the potential for bespoke results to be generated for the user's interpretation we have not provided any interpretation here. The report finishes with an exploration of how sensitive the results are to the various input parameters we used.

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8. Abbreviations

ABI	Alcohol Brief Intervention
BMI	body mass index
CBT	cognitive behavioural therapy
CI	cumulative incidence
COMEAP	Committee on the Medical Effects of Air Pollutants
DEFRA	Department for Environment, Food and Rural Affairs
DLA/PIP	Disability Living Allowance/Personal Independence Payment
DWP	Department for Work and Pensions
ERR	exposure rate ratio
ILO	International Labour Organisation
IRR	intervention rate ratio
ISD	Information Services Division
mph	miles per hour
NICE	National Institute for Health and Care Excellence
NO_2	nitrogen dioxide
NOx	nitrous oxides
ONS	Office for National Statistics
NRS	National Records of Scotland
PAR	population at risk
PM_{10}	coarse particulate matter (median diameter ≤ 10 μm)
$PM_{2.5}$	fine particulate matter (median diameter ≤ 2.5 μm)
PSSRU	Personal Social Services Research Unit
Q	prefix for quintile number of the SIMD
RII	relative index of inequality
ScotPHO	Scottish Public Health Observatory
SHeS	Scottish Health Survey
SII	slope index of inequality
SIMD	Scottish Index of Multiple Deprivation
SMD	standardised mean difference
SMR	Scottish Morbidity Record
Triple I	Informing Interventions to reduce health Inequalities

VBA	Visual Basic for Applications
WHO	World Health Organization

9. Appendices

9.1 Intervention definitions

9.1.1 Type of action on inequalities: Undo

Topic: Income

N.B. All of the income-based interventions can be modelled in the relevant spreadsheet tool, but results are given for a selection (n = 12) in the national overview report and in the interactive results browser.

- **Attendance Allowance +10%:** 10% increase in the devolved benefit Attendance Allowance.
- **Attendance Allowance +50%:** 50% increase in the devolved benefit Attendance Allowance.
- **Carer's Allowance +10%:** 10% increase in the devolved benefit Carer’s Allowance.
- **Carer's Allowance +50%:** 50% increase in the devolved benefit Carer’s Allowance.
- **Citizen's Basic Income:** Illustrative Citizen's Basic Income scheme introduced: an income from the state received by every citizen, not dependent on need. Rates = £67.01/week for < 18 years old, £73.10/week for women aged 18–62 years old and men aged 18–64 years old; £155.60/week for women aged > 62 years and men aged > 64 years old. Most other benefits withdrawn. National Insurance set to 12% flat rate for all earnings, and Income Tax rates increased by 6p.
- **Citizen's Basic Income Plus:** Introduction of illustrative Citizen's Basic Income scheme with additional payments for disabled adults. Citizen's Basic Income is an income from the state received by every citizen, not dependent on need. Rates = £67.01/week for < 18 years old , £73.10/week for women aged 18–62 years old and men aged 18–64 years old; £155.60/week for women aged > 62 years and men aged > 64 years old. Additional payments for disabled adults (£35.75/week, or £112.40/week for severely disabled) and children

(£24.07/week, or £83.52/week if severely disabled). Most other benefits withdrawn. National Insurance set to 12% flat rate for all earnings. Income Tax rates increased by 7p.

- **Council Tax increase (bands E–H):** Council Tax increased for bands E (+7.5%, representing an increase from the Scottish average of £1,390 to £1,494 pa), F (+12.5%, from £1,643 to £1,848 pa), G (+17.5%, from £1,895 to £2,227 pa), and H (+22.5%, from £2,275 to £2,786 pa).
- **Devolved benefits +10%:** 10% increase in these benefits devolved to the Scottish Government: Attendance Allowance, Carer's Allowance, Disability Living Allowance/Personal Independence Payment (DLA/PIP), Industrial Injuries Disability Benefit, Severe Disability Allowance, and Winter Fuel Allowance.
- **Devolved benefits +50%:** 50% increase in these benefits devolved to the Scottish Government: Attendance Allowance, Carer's Allowance, DLA/PIP, Industrial Injuries Disability Benefit, Severe Disability Allowance, and Winter Fuel Allowance.
- **DLA/PIP +10%:** 10% increase in the devolved benefits DLA/PIP.
- **DLA/PIP +50%:** 50% increase in the devolved benefits DLA/PIP.
- **Income Tax additional rate +5p:** Income Tax additional rate increased by 5p (to 50p).
- **Income Tax basic rate +5p:** Income Tax basic rate increased by 5p (to 25p).
- **Income Tax basic rate -1p:** Income Tax basic rate decreased by 1p (to 19p).
- **Income Tax rates +1p:** All Income Tax rates increased by 1p (to 21p basic rate, 41p higher rate and 46p additional rate).
- **Income Tax rates -1p:** All Income Tax rates decreased by 1p (to 19p basic rate, 39p higher rate and 44p additional rate).
- **Industrial Injuries Disability Benefit +10%:** 10% increase in the devolved benefit Industrial Injuries Disability Benefit.
- **Industrial Injuries Disability Benefit +50%:** 50% increase in the devolved benefit Industrial Injuries Disability Benefit.
- **Living Wage:** Mandatory payment of the real Living Wage to all employees (calculated as £8.25 per hour for 2016/17 by the Living Wage Foundation based on living costs).

- **Local Income Tax:** Council Tax removed, and all Income Tax rates increased by 3p.
- **Means-tested benefits +10%:** 10% increase in these benefits paid to those who pass an income test: Child Tax Credit, Working Tax Credit, Housing Benefit, income-based JobSeeker's Allowance, income-based Employment and Support Allowance, and Income Support.
- **Means-tested benefits +50%:** 50% increase in these benefits paid to those who pass an income test: Child Tax Credit, Working Tax Credit, Housing Benefit, income-based JobSeeker's Allowance, income-based Employment and Support Allowance, and Income Support.
- **Personal Allowance -£1,000:** Income Tax Personal Allowance (ITPA) decreased from £11,000 to £10,000.
- **Personal Allowance +£1,000:** ITPA increased from £11,000 to £12,000.
- **Severe Disability Allowance +10%:** 10% increase in the devolved benefit Severe Disability Allowance.
- **Severe Disability Allowance +50%:** 50% increase in the devolved benefit Severe Disability Allowance.
- **Winter Fuel Allowance +10%:** 10% increase in the devolved benefit Winter Fuel Allowance.
- **Winter Fuel Allowance +50%:** 50% increase in the devolved benefit Winter Fuel Allowance.

9.1.2 Type of action on inequalities: Prevent

Topic: Employment

- **Job provision:** A user-specified number of adults aged 16–64 not in employment (excluding full-time students aged 16–24) move into sustained employment. They are assumed to acquire the risk of mortality and hospitalisation of the employed population.

Topic: Income

- **Benefit uptake +1%:** A 1% increase in the number of claimants of means-tested benefits, which may arise from wider availability of income-maximisation advice services, for example.

Topic: Physical environment

- **20 mph speed limits:** 20 mph speed limits (without physical traffic calming) applied to all minor roads and local streets within urban settlements in Scotland. This intervention was recommended in the NICE (2017) guideline 'Air pollution: Outdoor air quality and health'. Major roads were not included so that a connected network of 30 mph and 40 mph roads would be retained (as in City of Edinburgh Council's city-wide 20 mph scheme that began in 2016). Health effects have been estimated based on changes to road traffic accident risk and air pollution.

Topic: Smoking

- **Tobacco tax +10%:** The intervention to be modelled is a 10% increase in the retail price of tobacco through taxation. Tobacco taxation is one of the tools to reduce demand for tobacco and is an important component of government policies to reduce smoking prevalence.

9.1.3 Type of action on inequalities: Mitigate

Topic: Alcohol

- **Alcohol Brief Intervention (ABI):** Consistent with the Scottish Government's Local Delivery Plan (Scottish Government, 2018), based on NICE guidance, an ABI is described as 'a short, evidence-based, structured conversation about alcohol consumption with a patient/client that seeks in a non-confrontational way to motivate and support the individual to think about and/or plan a change in their drinking behaviour in order to reduce their consumption and/or their risk of harm'. The key components of an ABI and guidance for professionals delivering ABIs are available from NHS Health Scotland at: www.healthscotland.scot/publications/alcohol-brief-intervention-resources. An ABI is an effective approach for reducing consumption among hazardous and harmful drinkers.

Topic: Mental health

- **Computerised CBT: (for depression):** A low-intensity psychosocial intervention recommended by NICE for the treatment of persistent sub-threshold depressive symptoms, mild depression or moderate depression. Computerised CBT is provided via computer, typically over 9–12 weeks. It should be supported by a trained practitioner, who typically provides limited facilitation of the programme and reviews progress and outcomes.
- **Group physical activity (for depression):** A low-intensity psychosocial intervention recommended by NICE for the treatment of persistent sub-threshold depressive symptoms, mild depression or moderate depression. Group physical activity typically consists of three sessions per week of moderate duration (45 minutes to 1 hour) over 10–14 weeks (average 12 weeks). It is delivered in groups with support from a competent practitioner.
- **Individual guided self-help (for depression):** A low-intensity psychosocial intervention recommended by NICE for the treatment of persistent sub-threshold depressive symptoms, mild depression or moderate depression. Individual guided self-help is a self-administered intervention based on CBT, which makes use of a range of books or other self-help manuals derived from an evidence-based intervention and designed specifically for the purpose.

Topic: Physical activity

- **Physical activity brief intervention:** Physical activity brief intervention involves verbal advice, discussion, negotiation or encouragement, with or without written or other support or follow-up. It aims to improve health and wellbeing by raising awareness of the importance of physical activity and encouraging people to increase or maintain their activity level.
- **Pedometer-based intervention:** A 12-week pedometer-based intervention to increase walking among adults delivered in a primary care setting. Participants receive a pedometer, diary and 12-week pedometer-based walking programme, either by post or via a consultation with a practice nurse. It can vary from basic advice to a more extended, individually focused discussion. It could be opportunistic and can take between 1 and 20 minutes.

Topic: Smoking

- **Smoking cessation:** NHS smoking cessation services (Scotland) programme, including brief interventions (opportunistic advice, discussion, negotiation or encouragement, and referral to more intensive treatment where appropriate) and specialist smoking services (NHS-supported services that provide an enhanced level of smoking cessation support from that provided through brief interventions). These services provide intensive group and one-to-one support for a series of planned sessions throughout the quit attempt, in conjunction with pharmacotherapy, and follow up the client beyond the quit date.

Topic: Weight

- **Lifestyle weight management service:** Lifestyle weight management services incorporate the features detailed in NICE Guideline PH53 (2014). Details of implementation may vary, although the intervention should be developed by a multidisciplinary team, delivered by trained staff, and last at least three months, with weekly or fortnightly meetings. The intervention will have multiple components, addressing: dietary intake, physical activity levels and behaviour change.

9.2 Data sets used in the study

9.2.1 Population (NRS)

NRS produces annual mid-year population estimates for Scottish data zones (1996–2016). The data set covers all deaths occurring in Scotland and is collected weekly. For more information, see NRS – Small Area Population Estimates (2001 Data Zone based)[7] and NRS – Small Area Population Estimates (2011 Data Zone based)[8] webpages.

Population data

Data controller:	NRS
A record represents:	Estimated counts of persons
Frequency of collection:	Annual
Number of annual records:	N = approximately 1,200,000
Geography coverage:	Scotland
Population coverage:	All residents of Scotland

Study data

Data period:	2002 to 2016 inclusive
Number of records:	N = 18,015,816
Population coverage:	All residents of Scotland

Variables

Year:	Year
Age:	Age (single year up to 90+)
Sex:	Male, female
Data zone:	2001 data zones for 2002–2013 counts, 2011 data zones for 2014–2016 counts.

[7] www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-estimates/special-area-population-estimates/small-area-population-estimates

[8] www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-estimates/2011-based-special-area-population-estimates/small-area-population-estimates

9.2.2 Deaths (NRS)

The NRS produces general publications for vital events, specifically, for births, deaths and marriages in Scotland. The data set covers all deaths occurring in Scotland and is collected weekly. For more information, see the NRS – Deaths Data[9] webpage.

Population data

Data controller:	NRS
A record represents:	A death
Frequency of collection:	Weekly
Number of annual records:	N = approximately 55,000
Geography coverage:	Scotland
Population coverage:	All deaths in Scotland

Study data

Data period:	2002 to 2016 inclusive
Number of records:	N = 834,939
Population coverage:	All Scotland-resident deaths

Variables

Year:	Year of registration of death
Age:	Age at death
Sex:	Male, female, unknown
SIMD:	SIMD quintile of data zone of residence:
	SIMD 2004 for 2002–2004 records

[9] www.ndc.scot.nhs.uk/National-Datasets/data.asp?ID=3&SubID=13

	SIMD 2006 for 2005–2006 records
	SIMD 2009 for 2007–2009 records
	SIMD 2012 for 2010–2013 records
	SIMD 2016 for 2014–2016 records
LA:	Local authority of residence

9.2.3 Inpatients and day cases (SMR01)

Continuous inpatient stays in hospital, derived from data collected on discharges from non-obstetric and non-psychiatric hospitals in Scotland. The specialty of geriatric long stay is excluded. A day case is a patient who has an elective admission to a specialty for clinical care, and sees a professional and requires supervised recovery in the place of treatment. The patient is not expected to, and does not, remain overnight. An inpatient is a patient who occupies, or is expected to occupy, an available staffed bed in a hospital for one or more nights. Inpatients also include all those admitted as an emergency or urgent case. For more information, see the General Acute Inpatient and Day Case (SMR01)[10] webpage.

Probability matching methods have been used to link together individual SMR01 hospital episodes for each patient, thereby creating ‘linked’ patient histories. Within these patient histories, SMR01 episodes are grouped according to whether they form part of a continuous spell of treatment (whether or not this involves transfer between specialties, consultants, hospitals or Health Boards).

Population data

Data controller:	NHS National Services Scotland (NSS)
A record represents:	An inpatient or day case episode
Frequency of collection:	Continuously
Number of annual records:	N = approximately 1,400,000
Geography coverage:	All residents in Scotland who receive care

[10] www.ndc.scot.nhs.uk/National-Datasets/data.asp?ID=1&SubID=5

	in hospital and general acute specialities
Population coverage:	All inpatients and day cases in Scotland

Study data

Data period:	2001 to 2016 inclusive
Number of records:	N = 3,491 for main extract
	N = 15,816 for local authority extract.
Population coverage:	All Scotland-resident inpatients and day cases

Variables

Year:	Year of discharge from hospital
Age:	Age of patient on admission. Five-year age groups 0–4, 5–9, 10–15, 16–19, 20–24, etc. to 90+ in extract without local authority identifier. Reduced age groups (0–15, 16–69 and 70+) in the extract with the local authority identifier.
Sex:	Male, female, unknown
SIMD:	SIMD quintile of data zone of residence:
	SIMD 2004 for 2001–2003 records;
	SIMD 2006 for 2004–2006 records;
	SIMD 2009 for 2007–2009 records;
	SIMD 2012 for 2010–2013 records;

	SIMD 2016 for 2014–2016 records.
LA:	Local authority of residence (this extract had reduced age groups: 0–15, 16–69, 70+)

9.2.4 Mental health inpatients and day cases (SMR04)

The mental health inpatient and day case data set (SMR04) collects episode-level data on patients who are receiving care at psychiatric hospitals at the point of both admission and discharge. The majority of mental health episodes will be dealt with first by GPs and then by community health workers. Only the most acute cases will appear in SMR04. For more information, see the Mental Health Inpatient and Day Case[11] webpage. SMR04 completeness[12] varies across Health Boards.

Probability matching methods have been used to link together individual hospital episodes for each patient, thereby creating 'linked' patient histories. Within these patient histories, episodes are grouped according to whether they form part of a continuous spell of treatment.

Population data

Data controller:	NHS National Services Scotland (NSS)
A record represents:	A mental health inpatient or day case episode
Frequency of collection:	Continuously
Number of annual records:	N = approximately 21,000
Geography coverage:	Everyone admitted to psychiatric hospitals in Scotland.
Population coverage:	All inpatients and day cases

[11] www.ndc.scot.nhs.uk/National-Datasets/data.asp?ID=1&SubID=7
[12] www.isdscotland.org/products-and-Services/Data-Support-and-Monitoring/SMR-Completeness/

Study data

Data period:	2001 to 2016 inclusive
Number of records:	N = 2,901 for main extract N = 10,759 for local authority extract.
Population coverage:	All Scotland-resident inpatients and day cases

Variables

Year:	Year of discharge from hospital
Age:	Age of patient on admission. 5-year age groups 0–4, 5–9, 10–15, 16–19, etc. to 90+ in extract without local authority identifier. Reduced age groups (0–15, 16–69 and 70+) in the extract with the local authority identifier.
Sex:	Male, female, unknown
SIMD:	SIMD quintile of data zone of residence: SIMD 2004 for 2001–2003 records; SIMD 2006 for 2004–2006 records; SIMD 2009 for 2007–2009 records; SIMD 2012 for 2010–2013 records; SIMD 2016 for 2014–2016 records.
LA:	Local authority of residence (this extract had reduced age groups: 0–15, 16–69, 70+)

9.2.5 National life tables, Scotland (NRS)

National life tables, which are produced annually for the United Kingdom and its constituent countries, provide period expectation of life statistics. Period life expectancy is the average number of additional years a person can be expected to live for if he or she experiences the age-specific mortality rates of the given area and time period for the rest of his or her life.

For more information, see the NRS – Life Expectancy at Scotland Level – Scottish National Life Tables[13] webpage.

Population data

Data controller:	NRS
A record represents:	Life expectancy by age and sex
Number of annual records:	202
Geography coverage:	Scotland
Population coverage:	All Scottish residents

Study data

Data period:	2014 to 2016 inclusive
Number of records:	202
Population coverage:	All Scottish residents

Variables

Age:	Age (single year up to 100)
Sex:	Male, female

[13] www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/life-expectancy/life-expectancy-at-scotland-level/scottish-national-life-tables

9.3 Local authority matching table

The most similar 2011 local authorities were identified by ONS as part of the Area Classification for local authorities[14].

Name	Most similar local authority (2011)
Aberdeen City	Dundee City
Aberdeenshire	Angus
Angus	Scottish Borders
Argyll and Bute	Highland
City of Edinburgh	Glasgow City
Clackmannanshire	Falkirk
Dumfries and Galloway	Scottish Borders
Dundee City	Glasgow City
East Ayrshire	North Ayrshire
East Dunbartonshire	East Renfrewshire
East Lothian	Midlothian
East Renfrewshire	East Dunbartonshire
Falkirk	South Lanarkshire
Fife	Clackmannanshire
Glasgow City	Dundee City
Highland	Perth and Kinross
Inverclyde	Renfrewshire
Midlothian	East Lothian
Moray	Angus
Eilean Siar	Orkney Islands
North Ayrshire	East Ayrshire
North Lanarkshire	South Lanarkshire
Orkney Islands	Shetland Islands
Perth and Kinross	Highland
Renfrewshire	South Lanarkshire
Scottish Borders	Angus
Shetland Islands	Orkney Islands
South Ayrshire	Angus
South Lanarkshire	Falkirk
Stirling	Fife
West Dunbartonshire	Renfrewshire
West Lothian	Falkirk

[14] More information is available from: www.ons.gov.uk/methodology/geography/geographicalproducts/areaclassifications/2011areaclassifications/datasets

9.4 Intervention effect data for the income-based policies

Table 10: Percentage change in equivalised household income (before housing costs) under each income-based intervention, by SIMD 2016 quintile.

Income-based intervention	Q1	Q2	Q3	Q4	Q5
Attendance Allowance +10%	0.031	0.067	0.024	0.025	0.027
Attendance Allowance +50%	0.156	0.335	0.118	0.127	0.137
Benefit uptake +1%	0.236	0.051	0.000	0.018	0.000
Carer's Allowance +10%	0.012	0.010	0.005	0.000	0.001
Carer's Allowance +50%	0.066	0.060	0.026	0.003	0.004
Citizen’s Basic Income	1.777	1.110	0.991	-0.282	-2.549
Citizen’s Basic Income Plus	3.330	2.264	1.166	-0.579	-3.027
Council Tax increase	-0.017	-0.072	-0.144	-0.222	-0.401
Devolved benefits +10%	0.501	0.386	0.268	0.136	0.092
Devolved benefits +50%	2.511	1.941	1.344	0.682	0.461
DLA/PIP +10%	0.415	0.248	0.192	0.075	0.033
DLA/PIP +50%	2.074	1.242	0.960	0.376	0.165
Income Tax additional rate +5p	-0.079	-0.009	-0.046	-0.043	-0.137
Income Tax basic rate +5p	-1.539	-2.127	-2.411	-2.811	-2.949
Income Tax basic rate -1p	0.308	0.426	0.482	0.562	0.590
Income Tax rates +1p	-0.358	-0.482	-0.598	-0.694	-0.806
Income Tax rates -1p	0.358	0.483	0.598	0.694	0.806
Industrial Injuries Disability Benefit +10%	0.006	0.014	0.011	0.006	0.000
Industrial Injuries Disability Benefit +50%	0.028	0.071	0.053	0.031	0.000
Living Wage	3.089	2.113	2.111	1.829	0.943
Local Income Tax	2.120	1.997	2.065	2.122	1.967
Means-tested benefits +10%	1.765	1.019	0.508	0.323	0.170
Means-tested benefits +50%	8.637	5.059	2.483	1.591	0.850
Personal Allowance -£1,000	-0.669	-0.761	-0.798	-0.860	-0.816
Personal Allowance +£1,000	0.638	0.695	0.759	0.817	0.793
Severe Disability Allowance +10%	0.004	0.010	0.000	0.002	0.000
Severe Disability Allowance +50%	0.020	0.048	0.000	0.008	0.000
Winter Fuel Allowance +10%	0.034	0.037	0.037	0.028	0.031
Winter Fuel Allowance +50%	0.168	0.186	0.187	0.138	0.156

Table 11. Mortality IRRs for the income-based interventions, by SIMD 2016 quintile (Q1 most deprived, Q5 least deprived).

Income-based intervention	Q1	Q2	Q3	Q4	Q5
Attendance Allowance +10%	0.9996	0.9992	0.9997	0.9997	0.9997
Attendance Allowance +50%	0.9982	0.9962	0.9987	0.9986	0.9984
Benefit uptake +1%	0.9973	0.9994	1.0000	0.9998	1.0000
Carer's Allowance +10%	0.9999	0.9999	0.9999	1.0000	1.0000
Carer's Allowance +50%	0.9992	0.9993	0.9997	1.0000	1.0000
Citizen's Basic Income	0.9801	0.9875	0.9888	1.0032	1.0298
Citizen's Basic Income Plus	0.9634	0.9748	0.9869	1.0066	1.0356
Council Tax increase	1.0002	1.0008	1.0016	1.0025	1.0046
Devolved benefits +10%	0.9943	0.9956	0.9970	0.9985	0.9990
Devolved benefits +50%	0.9722	0.9784	0.9849	0.9923	0.9948
DLA/PIP +10%	0.9953	0.9972	0.9978	0.9991	0.9996
DLA/PIP +50%	0.9769	0.9861	0.9892	0.9957	0.9981
Income Tax additional rate +5p	1.0009	1.0001	1.0005	1.0005	1.0016
Income Tax basic rate +5p	1.0178	1.0248	1.0282	1.0330	1.0347
Income Tax basic rate -1p	0.9965	0.9952	0.9945	0.9936	0.9933
Income Tax rates +1p	1.0041	1.0055	1.0069	1.0080	1.0093
Income Tax rates -1p	0.9959	0.9945	0.9932	0.9922	0.9909
Indust. Injuries Disability Benefit +10%	0.9999	0.9998	0.9999	0.9999	1.0000
Indust. Injuries Disability Benefit +50%	0.9997	0.9992	0.9994	0.9997	1.0000
Living Wage	0.9660	0.9765	0.9765	0.9796	0.9894
Local Income Tax	0.9764	0.9777	0.9770	0.9764	0.9781
Means-tested benefits +10%	0.9803	0.9885	0.9942	0.9963	0.9981
Means-tested benefits +50%	0.9100	0.9454	0.9725	0.9822	0.9904
Personal Allowance -£1,000	1.0077	1.0087	1.0092	1.0099	1.0094
Personal Allowance +£1,000	0.9928	0.9922	0.9914	0.9908	0.9911
Severe Disability Allowance +10%	1.0000	0.9999	1.0000	1.0000	1.0000
Severe Disability Allowance +50%	0.9998	0.9995	1.0000	0.9999	1.0000
Winter Fuel Allowance +10%	0.9996	0.9996	0.9996	0.9997	0.9996
Winter Fuel Allowance +50%	0.9981	0.9979	0.9979	0.9984	0.9982

Table 12. Hospitalisation IRRs for the income-based interventions, by SIMD 2016 quintile (Q1 most deprived, Q5 least deprived).

Income-based intervention	Q1	Q2	Q3	Q4	Q5
Attendance Allowance +10%	0.9997	0.9993	0.9998	0.9998	0.9997
Attendance Allowance +50%	0.9985	0.9967	0.9988	0.9988	0.9987
Benefit uptake +1%	0.9977	0.9995	1.0000	0.9998	1.0000
Carer's Allowance +10%	0.9999	0.9999	1.0000	1.0000	1.0000
Carer's Allowance +50%	0.9994	0.9994	0.9997	1.0000	1.0000
Citizen’s Basic Income	0.9829	0.9893	0.9904	1.0028	1.0256
Citizen’s Basic Income Plus	0.9685	0.9784	0.9887	1.0057	1.0305
Council Tax increase	1.0002	1.0007	1.0014	1.0022	1.0039
Devolved benefits +10%	0.9951	0.9962	0.9974	0.9987	0.9991
Devolved benefits +50%	0.9761	0.9814	0.9870	0.9934	0.9955
DLA/PIP +10%	0.9960	0.9976	0.9981	0.9993	0.9997
DLA/PIP +50%	0.9801	0.9880	0.9907	0.9963	0.9984
Income Tax additional rate +5p	1.0008	1.0001	1.0004	1.0004	1.0013
Income Tax basic rate +5p	1.0153	1.0212	1.0241	1.0283	1.0297
Income Tax basic rate -1p	0.9970	0.9959	0.9953	0.9945	0.9943
Income Tax rates +1p	1.0035	1.0047	1.0059	1.0068	1.0079
Income Tax rates -1p	0.9965	0.9953	0.9942	0.9933	0.9922
Indust. Injuries Disability Benefit +10%	0.9999	0.9999	0.9999	0.9999	1.0000
Indust. Injuries Disability Benefit +50%	0.9997	0.9993	0.9995	0.9997	1.0000
Living Wage	0.9707	0.9798	0.9798	0.9824	0.9909
Local Income Tax	0.9797	0.9809	0.9802	0.9797	0.9811
Means-tested benefits +10%	0.9831	0.9901	0.9951	0.9969	0.9983
Means-tested benefits +50%	0.9223	0.9529	0.9763	0.9847	0.9918
Personal Allowance -£1,000	1.0066	1.0075	1.0079	1.0085	1.0080
Personal Allowance +£1,000	0.9938	0.9933	0.9926	0.9921	0.9923
Severe Disability Allowance +10%	1.0000	0.9999	1.0000	1.0000	1.0000
Severe Disability Allowance +50%	0.9998	0.9995	1.0000	0.9999	1.0000
Winter Fuel Allowance +10%	0.9997	0.9996	0.9996	0.9997	0.9997
Winter Fuel Allowance +50%	0.9984	0.9982	0.9982	0.9987	0.9985

9.5 R code for calculating mortality and hospitalisation rate coefficients

File name: PROG1.R

```
## PROG1.R
## R code for calculating mortality and hospitalisation rate coefficients by mean age,
## year, sex and SIMD quintile.  An interaction term for age and gender improved
## the fit a  lot for hospitalisation and a little for mortality. No other interactions
## improved the fit. Uses parametric survival models (i.e. not Cox). Decided to use
## exponential distribution as this fits as well as Weibull and is simpler.

# This R code, when run, will produce
# 1. An Rdata file with the coefficients
# 2. A .csv file with the coefficients
# The required inputs are
# 1. A .csv file with historic mortality rates in this format:
# (column headings “year”, “sex” (‘Female’ or ‘Male’), “simd5”
# (1 to 5), “agegroup” (for reference, not used), “meanage”, and “rate” (per 1000))
# 2. A .csv file with the historic hospitalisation rates in the same format

# The following R packages are needed.
# If not already installed need to uncomment this line.
# install.packages (c("survival", "ggplot2"))
library (survival)
library (ggplot2)
library (reshape2)

# Set working directory - where .csv files are stored and where R will save the output
setwd()

# Read files
mort <- read.csv (file = "historic_mortality_rates_2002to2016.csv", as.is = TRUE)

# Transform data
MortHospClean <- function (mydata, type, simd.present = TRUE) {names(mydata) <-
c("year", "sex", "simd", "agegroup", "meanage", "rate")

# Change SIMD to factor, not much change in fit, but easier to set 3 to reference
  mydata$simd <- factor (mydata$simd)
  mydata$simd <- relevel (mydata$simd, 3)

# Select age range desired (16-79 for the purposes of this modelling)
  mydata <- subset (mydata, meanage >=15 & meanage<80)

# make event variable for model to run
  mydata$event <- 1

# convert rate into per person year, not per 1000 person years
```

```
  if (type == "mort") mydata$rate <- mydata$rate /1000
  if (type == "hosp") mydata$rate <- mydata$rate /1000
  mydata
}

# apply function to transform each dataset
mort <- MortHospClean (mort, type = "mort")
hosp <- MortHospClean (hosp, type = "hosp")

# Run regression model based on event rates for mortality and hospitalisation

# Exponential distribution
model.surv.e <- survreg (Surv(time = rate, event) ~ meanage + simd + sex + year +
sex:meanage, dist = "exponential",data = mort)
model.surv.e.hosp <- survreg (Surv(time = rate, event) ~ meanage + simd + sex +
year + sex:meanage, dist = "exponential",data = hosp)

# Weibull distribution
model.surv.w <- update (model.surv.e, dist = "weibull")
model.surv.w.hosp <- update (model.surv.e.hosp, dist = "weibull")

# Show model results
summary(model.surv.e)
summary(model.surv.w)
summary(model.surv.e.hosp)
summary(model.surv.w.hosp)

# Produce predicted rates from the model for the plots used to examine the fit
mort$weib <- predict (model.surv.w)
mort$expo <- predict (model.surv.e)
hosp$weib <- predict (model.surv.w.hosp)
hosp$expo <- predict (model.surv.e.hosp)

# Create plots of rates and predicted rates for men and women
# Red lines are for an exponential distribution, blue for Weibull
plot.surv.men <- ggplot (subset (mort, sex == "Male"), aes (x = meanage, y = rate)) +
geom_point() +
facet_grid (simd~year) +
geom_line (aes(x = meanage, y = expo), colour = "red") +
geom_line (aes(x = meanage, y = weib), colour = "blue") +
ggtitle ("Men, mortality")
plot.surv.women <- ggplot (subset (mort, sex == "Female"), aes (x = meanage, y =
rate)) + geom_point() +
facet_grid (simd~year) +
geom_line (aes(x = meanage, y = expo), colour = "red") +
geom_line (aes(x = meanage, y = weib), colour = "blue")+
ggtitle ("Women, mortality")
plot.surv.men.hosp <- ggplot (subset (hosp, sex == "Male"), aes (x = meanage, y =
rate)) + geom_point() +
facet_grid (simd~year) +
```

```
geom_line (aes(x = meanage, y = expo), colour = "red") +
geom_line (aes(x = meanage, y = weib), colour = "blue") +
ggtitle ("Men, hospitalisation")
plot.surv.women.hosp <- ggplot (subset (hosp, sex == "Female"), aes (x = meanage,
y = rate)) + geom_point() +
facet_grid (simd~year) +
geom_line (aes(x = meanage, y = expo), colour = "red") +
geom_line (aes(x = meanage, y = weib), colour = "blue")+
ggtitle ("Women, hospitalisation")

# Save plots as a PDF with today's date
mydate <- format (Sys.Date(), "%Y%m%d")
filename <- paste ("..\\syntax\\PROG1 output\\Graphs of hosp and mort data, run on
", mydate, ".pdf", sep = "")
pdf (filename)
plot.surv.men + theme_gray (base_size =8)
plot.surv.women + theme_gray (base_size =8)
plot.surv.men.hosp + theme_gray (base_size =8)
plot.surv.women.hosp + theme_gray (base_size =8)

# Create coefficients table and save as .csv file and .Rdata objects
mortality.coefficients <- coef (model.surv.e)
hospitalisation.coefficients <- coef(model.surv.e.hosp)

all.coefficients <- rbind (mortality.coefficients, hospitalisation.coefficients)
filename <- paste ("..\\syntax\\PROG1 output\\Coeffs from hosp and mort models,
run on ", mydate, ".csv", sep = "")
write.csv (all.coefficients, file = filename)
filename <- paste ("..\\syntax\\PROG1 output\\Coeffs from hosp and mort models,
run on ", mydate, ".Rdata", sep = "")
save (mortality.coefficients, hospitalisation.coefficients, file = filename)
```

9.6 R code to calculate formula for IRRs over time

File name: PROG2.R

```
#PROG2
# R code to create formulas describing rate ratios for death
# and hospitalisation. This code uses Nonlinear Least Squares
# to produce a function describing the change in IRR. This
# approach constrains the rate ratio to lie between 0 and 1
# If the rate ratio is zero, you need to take its inverse to
# calculate the formula, and then invert the function when
# running it in the VBA toolkit (invert_rr = 1).This form of
# the non-linear model is a sigmoid function with two
# parameters and a single  # predictor: time.This function is
# paramaterised in terms of the gain and threshold.
# The threshold is the point on the x-axis which corresponds
# to y = 0.5. The gain is how steeply the curve moves through
# that point. You may need to supply reasonable values as
# starting points for the gain and threshold if
# the plots show that the estimates don't fit the values well

# Inputs
# a .csv file with time and IRRs for hospitalisation and death
# column headings “year” (1 to 20), “mort”, and “hosp”
# starting values for the gain and threshold, if model won’t
# fit with the defaults

# Outputs
# model coefficients (a .csv file)
# plots of the rate ratio and the rate ratio described as a
# function and two example plots. Set working directory –
# where .csv files are stored and where R will save the output
setwd()

# Read in the data
intervention <- read.csv ("irrs.csv")
intervention.name <- "intervention1_IRRs"

# Now model the intervention effect change over time:
# Sigmoid function with two parameters
# Different starting values for gain and threshold may be
# required if the models don't work.
# Use trial and error.
mort <- nls(mort ~ 1 / (1 + exp(-gain * (year - threshold))), data=intervention,
start=list(gain=1, threshold = -1))
intervention$rr.mort.predicted <- predict(mort)

hosp <- nls(hosp ~ 1 / (1 + exp(-gain * (year - threshold))), data=intervention,
start=list(gain=0.2, threshold = -5))
```

```
intervention$rr.hosp.predicted <- predict(hosp)

# Plot points to formula
pdf (paste (intervention.name, ".pdf", sep = ""))
par (mfrow = c(2,2))
plot (1:21, intervention$rr.mort, ylim = c(0,1), main = "Mortality rate ratio", xlab =
"Time (years)", ylab = "Rate ratio")
lines (1:21, predict(mort))
plot (1:21, intervention$rr.hosp, ylim = c(0,1), main = "Hospitalisation rate ratio", xlab
= "Time (years)", ylab = "Rate ratio")
lines (1:21, predict(hosp))

# Produce example plots
rr <- function (time, gain, threshold) {1 / (1 + exp(-gain * (time-threshold)))}
plot (0:21, rr(0:21,1, 10), ylim = c(0,1), main = "eg: gain = 1, thresholds = 5, 10 & 15",
xlab = "Time (years)", ylab = "Rate ratio", type = "l")
lines (0:21, rr(0:21,1, 5))
lines (0:21, rr(0:21,1, 15))
plot (0:21, rr(0:21,0.1, 10), ylim = c(0,1), main = "eg: threshold = 10, gain = 0.1, 0.2
and 0.5", xlab = "Time (years)", ylab = "Rate ratio", type = "l")
lines (0:21, rr(0:21,0.2, 10))
lines (0:21, rr(0:21,0.5, 10))
dev.off()

# save coefficients
rr.hosp.coef <- coef (hosp)
rr.mort.coef <- coef (mort)
write.csv (rbind (rr.mort.coef, rr.hosp.coef), file = paste(intervention.name, ".csv", ""))
write.csv (intervention, file = paste(intervention.name, "_predictions.csv", ""))
```

9.7 Change in IRRs over time

Table 13. Change in all-cause hospitalisation IRRs over time for relevant interventions (derived from evidence), and the gain and threshold parameters used to model IRR change over time in the Triple I model.

Year	ABI	Weight mgt	CCBT	Self-help	Group PA	Smoking (M)	Smoking (F)	Tob. tax (M)	Tob. tax (F)	Job provision
1	0.9545	0.9787	0.9246	0.7787	0.8456	0.9896	0.9861	0.9950	0.9933	0.9524
2	0.9610	0.9831	0.9308	0.7971	0.8584	0.9900	0.9867	0.9965	0.9953	0.9709
3	0.9675	0.9876	0.9371	0.8156	0.8713	0.9905	0.9873	0.9965	0.9953	0.9615
4	0.9740	0.9921	0.9434	0.8340	0.8842	0.9909	0.9879	0.9965	0.9953	0.9709
5	0.9805	0.9967	0.9497	0.8525	0.8971	0.9913	0.9885	0.9965	0.9953	0.9724
6	0.9870	1.0014	0.9560	0.8710	0.9100	0.9918	0.9891	0.9965	0.9953	0.9740
7	0.9935	1.0061	0.9623	0.8894	0.9228	0.9922	0.9897	0.9965	0.9953	0.9756
8	1.0000	1.0000	0.9686	0.9079	0.9357	0.9927	0.9903	0.9965	0.9953	0.9772
9	1.0000	1.0000	0.9749	0.9263	0.9486	0.9927	0.9903	0.9965	0.9953	0.9788
10	1.0000	1.0000	0.9812	0.9448	0.9615	0.9927	0.9903	0.9965	0.9953	0.9804
11	1.0000	1.0000	0.9875	0.9633	0.9744	0.9927	0.9903	0.9965	0.9953	0.9785
12	1.0000	1.0000	0.9938	0.9817	0.9872	0.9927	0.9903	0.9965	0.9953	0.9766
13	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9747
14	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9728
15	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
16	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
17	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
18	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
19	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
20	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927	0.9903	0.9965	0.9953	0.9709
Gain	0.2985	0.4690	0.1794	0.1970	0.1885	0.0177	0.0177	0.0057	0.0057	0.0131
Thresh	-8.8512	-6.9522	-12.2678	-4.6727	-7.3122	-262.6903	-245.6250	-980.6395	-928.5810	-260.9657

CCBT: computerised CBT; F, female; M, male; PA, physical activity.

Table 14. Change in all-cause mortality IRRs over time for relevant interventions (derived from evidence), and the gain and threshold parameters used to model IRR change over time in the Triple I model.

Year	Pedom	PA brief	ABI	Weight mgt	CCBT	Self-help	Group PA	Smoking (M)	Smoking (F)	Tob. Tax (M)	Tob. Tax (F)	Job prov.
1	0.9570	0.9544	0.9562	0.8610	0.9599	0.8764	0.9162	0.9861	0.9791	0.9933	0.9899	0.5587
2	0.9659	0.9652	0.9624	0.8884	0.9632	0.8867	0.9232	0.9867	0.9800	0.9953	0.9929	0.6944
3	0.9739	0.9745	0.9687	0.9169	0.9666	0.8971	0.9302	0.9873	0.9809	0.9953	0.9929	0.7299
4	0.9808	0.9812	0.9749	0.9466	0.9699	0.9074	0.9372	0.9879	0.9818	0.9953	0.9929	0.7407
5	0.9867	0.9870	0.9812	0.9775	0.9733	0.9177	0.9442	0.9885	0.9827	0.9953	0.9929	0.7576
6	0.9915	0.9917	0.9875	1.0097	0.9766	0.9280	0.9511	0.9891	0.9836	0.9953	0.9929	0.7752
7	0.9952	0.9953	0.9937	1.0433	0.9800	0.9383	0.9581	0.9897	0.9845	0.9953	0.9929	0.7937
8	0.9979	0.9979	1.0000	1.0000	0.9833	0.9486	0.9651	0.9903	0.9854	0.9953	0.9929	0.8130
9	0.9995	0.9995	1.0000	1.0000	0.9867	0.9589	0.9721	0.9903	0.9854	0.9953	0.9929	0.8333
10	1.0000	1.0000	1.0000	1.0000	0.9900	0.9692	0.9791	0.9903	0.9854	0.9953	0.9929	0.8547
11	1.0000	1.0000	1.0000	1.0000	0.9933	0.9795	0.9861	0.9903	0.9854	0.9953	0.9929	0.8621
12	1.0000	1.0000	1.0000	1.0000	0.9967	0.9898	0.9931	0.9903	0.9854	0.9953	0.9929	0.8696
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8772
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8850
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8929
16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8945
17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8961
18	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8977
19	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.8993
20	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9903	0.9854	0.9953	0.9929	0.9009
Gain	0.3367	0.3533	0.2982	0.4988	0.1756	0.1848	0.1803	0.0177	0.0178	0.0057	0.0057	0.1086
Thresh	-8.0434	-7.4937	-8.9912	-2.4196	-16.3837	-8.8953	-11.5637	-245.6245	-221.2746	-928.6092	-854.7397	-4.8301

CCBT: computerised CBT; F, female; M, male; PA, physical activity

9.8 Intervention costs

Table 15. Costs for the individual-level interventions.

Intervention	Cost per individual	Source	Explanation
Pedometer-based intervention	£7	Harris et al. (2018)	Cost of a pedometer intervention administered by post. Inflation-adjusted to 2015/16 using HCHS index
Physical activity brief intervention	£7	PSSRU (2016)	Staff costs, based on Band 5 nurse delivering 10-minute intervention
ABI	£39	Scottish Government Local Delivery Plan (2018)	Cost for a GP delivering a 10-minute ABI, costed using PSSRU (2016)
Lifestyle weight management services	£75	Fuller et al. (2013)	Mean weighted cost for delivery in primary care setting (15%) and commercial setting (85%), inflated to 2015/16 using HCHS index
Computerised CBT (for depression)	£34	NICE (2009), NHS24's Scottish Centre for Telehealth and Telecare (personal communication), and PSSRU (2016)	NICE (2009) provide estimates of staff time (midpoint 25 mins of Band 4 nurse), which we costed using PSSRU (2016). Software costs were obtained from NHS24 and adjusted to 2015/16 using HCHS index
Individual guided self-help (for depression)	£140	NICE (2009) and PSSRU (2016)	NICE (2009) provide estimates of staff time (midpoint 164 mins of Band 6 nurse), which we costed using PSSRU (2016)
Group physical activity (for depression)	£256	NICE (2009) and PSSRU (2016)	NICE (2009) provide estimates of staff time (midpoint 180 mins of Band 5 nurse), which we costed using PSSRU (2016)
Smoking cessation services	£104	Ormston et al. (2012)	Costs for a non-quit4u programme adjusted to 2015/16 using HCHS
Job provision (notional intervention)	£4,626	Beatty et al. (2011)	Estimation of the annual net cost per job created in a large-scale government job creation scheme (wages, National Insurance plus employability support minus savings in benefits and extra tax revenue). Inflated using 2015/16 HCHS index

Table 16. Costs for the population-level interventions (negative cost = revenue or saving).

Intervention	Cost per Scotland-wide intervention (£ million)	Source	Explanation	Local area estimates
Tobacco taxation +10%	-£71 m per annum	HMRC (2018) and ONS (2018)	HMRC revenue from tobacco tax in UK was £9,092 million in 2016. A 5.6% reduction in tobacco products consumption (predicted from a 10% increase in taxation) would reduce this to £8,523 million. Based on Scotland's share of the UK population this would equate to £706 million revenue in Scotland. 10% increase in tax would mean £71 million increased revenue per annum	Estimated for illustrative purposes only. Calculated based on the proportion of smokers in the area, out of the Scottish total
20 mph speed limits	£35 m one-off cost	Edinburgh Council (personal communication), NRS, Ordnance Survey	Costs for the 20 mph scheme in Edinburgh were obtained from Edinburgh Council for 2016/17 and 2015/16 and were deflated to 2015/2016 using the HCHS inflation index. The resulting cost in 2015/16 terms was £2,727,458 for 1,204 km of roads (includes staff time, construction and awareness raising). This £2,265 per km would scale to an estimated £35 million for the 15,531 km of local and minor roads in urban settlements in Scotland	We calculated the length of local and minor roads in urban settlements for each area, and scaled the cost per km accordingly
Income-based interventions	See Table 17	EUROMOD	The implication of each income-based intervention for government expenditure on benefits and revenue from taxes and National Insurance contributions was derived from the EUROMOD output. The costs/savings are presented net of government spending in the absence of the intervention. Additional notes are given below, where relevant	An illustrative indication of the costs/savings for each local area was calculated on a % share of adult population basis

Table 17. Annual costs for the income-based interventions (N.B. negative cost = revenue or saving)

Intervention	Cost per Scotland-wide intervention (£ million per annum)
Attendance Allowance +10%	£20
Attendance Allowance +50%	£101
Benefit uptake +1%[a]	£36
Carer's Allowance +10%	£4
Carer's Allowance +50%	£23
Citizen's Basic Income	£442
Citizen's Basic Income Plus	£535
Council Tax increase	-£135
Devolved benefits +10%[b]	£154
Devolved benefits +50%[b]	£773
DLA/PIP +10%	£106
DLA/PIP +50%	£529
Income Tax additional rate +5p	-£51
Income Tax basic rate +5p	-£1,697
Income Tax basic rate -1p	£340
Income Tax rates +1p	-£429
Income Tax rates -1p	£429
Indust. Injuries Disability Benefit +10%	£4
Indust. Injuries Disability Benefit +50%	£22
Living Wage[c]	£1,264
Local Income Tax	£1,288
Means-tested benefits +10%	£442
Means-tested benefits +50%	£2,173
Personal Allowance -£1,000	-£541
Personal Allowance +£1,000	£513
Severe Disability Allowance +10%	£2
Severe Disability Allowance +50%	£9
Winter Fuel Allowance +10%	£18
Winter Fuel Allowance +50%	£89

[a] Benefit uptake +1%: The government cost includes additional benefit payments but excludes the cost of implementing the intervention (e.g. income-maximisation advice services), therefore, should be treated as an under-estimate.
[b] The costs for increasing devolved benefits are lower than estimated by DWP/Scottish Government. This is most likely because most devolved benefits are not simulated by EUROMOD, hence were increased manually.
[c] Costs for implementing the real Living Wage include a £2,148 m increased wage bill that will be borne by employers as well as by government.

9.9 VBA code for the bespoke Excel functions needed to run Triple I

```
'# This VBA code creates the extra bespoke functions needed to run the
'# Triple I model. The functions are called from Calculations tab of the
'# spreadsheet, and take input values based on the selections the user has
'# made on the Options tab.

'# Inputs ----
''''''''''''''''
'# Constants that are hard-coded into this VBA code:
'# Mortality and hospitalisation rate parameters (from PROG1.R)
'# Intervention rate ratio parameters (from PROG2.R)

'# Values that are provided by the spreadsheet:
'# Subgroup values from spreadsheet:
'# age, sex, SIMD quintile, life expectancy, population, number exposed,
'# number treated.  Intervention values from spreadsheet: name, start year,
'# years of follow up.

'# Outputs ----
'''''''''''''''''
'# Counts of deaths (Cumulative Incidence, or CI), hospitalisations, Years
'# of Life Lost (YLL),
'# and premature mortality for the policy and
'# baseline scenarios.All of the output figures are rounded to 10 decimal
'# places, as an attempt to produce figures that match those calculated
'# outside of Excel, using R.

''''''code starts here
Option Explicit

'#### Constants ----
'# 1. Parameters for the VBA function mortality_rate()
''''''''''''''''''''''''''''''''''''''''''''''''''''''
'# These coefficients are used by the function to estimate the mortality
'# rate for the age-sex-SIMD subgroup, at a specified number of years into
'# the follow up. Coeffs were estimated by the R program PROG1.R, using
'# NRS's historic mortality rates.

Const Intercept As Double = 38.36744292
Const age_coef As Double = 0.085054332
Const simd1 As Double = 0.569156193
Const simd2 As Double = 0.212506415
Const simd3 As Double = 0
Const simd4 As Double = -0.231707254
Const simd5 As Double = -0.538707646
Const gender_female = 0
Const gender_male = 1.049519375
```

```
Const year_coef = -0.024095154
Const age_gender_male = -0.009556622
Const age_gender_female = 0

'# 2. Parameters for the VBA function hosp_rate()
''''''''''''''''''''''''''''''''''''''''''''''''''''

'# These coefficients are used by the function to estimate the
'# hospitalisation rate for the age-sex-SIMD subgroup, at a specified
'# number of years into the follow up.
'# The coeffs were estimated by the R program PROG1.R, using ISD's historic
'# hospitalisation data (SMR01 and SMR04)

Const Intercept_h As Double = -5.61123982
Const age_coef_h As Double = 0.02515369
Const simd1_h As Double = 0.352635931
Const simd2_h As Double = 0.145517834
Const simd3_h As Double = 0
Const simd4_h As Double = -0.125522986
Const simd5_h As Double = -0.242687357
Const gender_female_h = 0
Const gender_male_h = -0.581646606
Const year_coef_h = 0.001409703
Const age_gender_male_h = 0.010341497
Const age_gender_female_h = 0

'# 3. Exposure Rate Ratios (ERR)
'''''''''''''''''''''''''''''''''

'# The ERR is the risk of all-cause mortality or hospitalisation in the
'# exposed population (i.e., Population at Risk)compared with the unexposed
'# population. N.B. This intervention has sex-specific ERRs for
'# hospitalisation.

Const exposure_rate_ratio_mortality As Double = 1.79
Const exposure_rate_ratio_hosp_m As Double = 1.49
Const exposure_rate_ratio_hosp_f As Double = 1.31

'# 4. Parameters for the Intervention Rate Ratio (IRR) function
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

'# The change in the intervention effect over time, based on the best
'# available evidence, has been modelled in R by fitting a sigmoid function
'# (non-linear least squares) with two parameters and a single predictor,
'# time. The code used is PROG2.R and the function is IRR = 1 / (1 + exp(-
'# gain * (year – threshold)).
'# The threshold is the point on the x-axis which corresponds to y = 0.5
'# (which can of course lie outside the range of values we are interested
'# in).  The gain is how steeply the curve moves through that point. The
'# gain and threshold coefficients from this model are hard-coded
'# here for each intervention, and then used in the rr() and rr_h()
'# functions:
```

```
Const weight_mort_gain = 0.340886866
Const weight_hosp_gain = 0.316449439
Const weight_mort_threshold = -3.02870986
Const weight_hosp_threshold = -9.816454992

'# The IRR calculations in rr() and rr_h() require RR to be inverted, using
'# these constants. If the intervention is harmful, i.e. IRR>1, these
'# should be changed to 1 (default -1) for mortality:
Const invert_rr = -1
'# for hospitalisation:
Const invert_rr_h = -1

'# mortality_rate()
''''''''''''''''''''''
'# The VBA function mortality_rate() estimates the mortality rate for the
'# age-sex-SIMD subgroup, at a specified number of years into follow up.

Function mortality_rate(time As Double, age_start As Double, sex As String,
simdquintile As Integer, year_start As Integer) As Double
Dim gender As Double
Dim gender_inter As Double
Dim simd As Double

If sex = "female" Then gender = gender_female
If sex = "female" Then gender_inter = age_gender_female
If sex = "male" Then gender = gender_male
If sex = "male" Then gender_inter = age_gender_male
If simdquintile = 1 Then simd = simd1
If simdquintile = 2 Then simd = simd2
If simdquintile = 3 Then simd = simd3
If simdquintile = 4 Then simd = simd4
If simdquintile = 5 Then simd = simd5

mortality_rate = Round(Exp(Intercept + simd + gender + age_coef * (age_start +
time) + year_coef * (year_start + time) + gender_inter * (age_start + time)), 10)
End Function

'# hosp_rate()
''''''''''''''''''''''
'# The VBA function hosp_rate() estimates the hospitalisation rate for the
'# age-sex-SIMD subgroup, at a specified number of years into follow up.

Function hosp_rate(time As Double, age_start As Double, sex As String, simdquintile
As Integer, year_start As Integer) As Double
Dim gender As Double
Dim gender_inter As Double
Dim simd As Double

If sex = "female" Then gender = gender_female_h
If sex = "female" Then gender_inter = age_gender_female_h
```

```
If sex = "male" Then gender = gender_male_h
If sex = "male" Then gender_inter = age_gender_male_h
If simdquintile = 1 Then simd = simd1_h
If simdquintile = 2 Then simd = simd2_h
If simdquintile = 3 Then simd = simd3_h
If simdquintile = 4 Then simd = simd4_h
If simdquintile = 5 Then simd = simd5_h

hosp_rate = Round(Exp(Intercept_h + simd + gender + age_coef_h * (age_start +
time) + year_coef_h * (year_start + time) + gender_inter * (age_start + time)), 10)
End Function

'# rr()
''''''''''''''''''''

'# The VBA function rr() calculates the mortality Intervention Rate Ratio
'# for the specified intervention at a given length of follow-up.  It uses
'# the coefficients (gain and threshold) that were calculated by the
'# program PROG2.R and hard-coded into this VBA code, above.

Function rr(time As Double, intervention As String)
rr = 1 / (1 + Exp(-weight_mort_gain * (time - weight_mort_threshold)))
rr = Round(rr ^ (-invert_rr), 10)
End Function

'# rr_h()
''''''''''''''''''''

'# The VBA function rr_h() calculates the hospitalisation Intervention Rate
'# Ratio for the specified intervention at a given length of follow-up.  It
'# uses the coefficients (gain and threshold) that were calculated by the
'# program PROG2.R and hard-coded into this VBA code

Function rr_h(time As Double, intervention As String)
rr_h = 1 / (1 + Exp(-weight_hosp_gain * (time - weight_hosp_threshold)))
rr_h = Round(rr_h ^ (-invert_rr_h), 10)
End Function

'# mortality_rate_rr()
''''''''''''''''''''''

'# The VBA function mortality_rate_rr() estimates the mortality rate for
'# the age-sex-SIMD subgroup if 'treated', at a specified number of years
'# into the follow up.  mortality rate = rate for subgroup * IRR

Function mortality_rate_rr(time As Double, age_start As Double, sex As String,
simdquintile As Integer, year_start As Integer, intervention As String) As Double
mortality_rate_rr = Round(mortality_rate(time, age_start, sex, simdquintile,
year_start) * rr(time, intervention), 10)
End Function

'# hosp_rate_rr()
''''''''''''''''''''''
```

```
'# The VBA function hosp_rate_rr() estimates the hospitalisation rate for
'# the age-sex-SIMD subgroup if 'treated', at a specified number of years
'# into the follow up.
'# hospitalisation rate = rate for subgroup * IRR

Function hosp_rate_rr(time As Double, age_start As Double, sex As String,
simdquintile As Integer, year_start As Integer, intervention As String) As Double
hosp_rate_rr = Round(hosp_rate(time, age_start, sex, simdquintile, year_start) *
rr_h(time, intervention), 10)
End Function

'# new_ci()
''''''''''''''''''''''''
'# The VBA function new_ci() calculates the cumulative incidence rate (CI)
'# of deaths for the age-sex-SIMD subgroup, after n years of follow up.  It
'# takes the subgroup characteristics to calculate the rates, and the
'# populations (total, exposed, and treated_each_year) to apply the rates
'# to. It makes 4 separate calculations which are summed at the end:
'#  1. CI in the unexposed population
'#  2. CI in the exposed but untreated population
'#  3. CI in the exposed but treated population IF THEY HAD NOT BEEN TREATED
'#  4. CI in the exposed but treated population
'# It calls the next two functions - IntegrateF() and
'# cumulativeincidenceF() - to integrate
'# under the relevant mortality rate curve for the subgroup, and then
'# transform the result to give the CI.

Function new_ci(time As Double, age_start As Double, sex As String, simdquintile
As Integer, year_start As Integer, _
            treated_each_year As Integer, n_years_treatment As Integer, total As
Double, exposed As Double, intervention As String, Optional CI_output As String =
"Total CI") As Variant
Dim integrand_unexposed
Dim integrand_untreated
Dim integrand_tx_base
Dim integrand_treated
Dim cumulative_incidence_unexposed
Dim cumulative_incidence_untreated
Dim cumulative_incidence_tx_base
Dim cumulative_incidence_treated
Dim i As Double
Dim j As Double
Dim ci As Double
Dim tmparray(1 To 3) As Variant

'# 1. CI in the unexposed population.
'# Produces a 1 column wide table with the number of new cases, number of
'# rows correspond to length of follow-up plus 1Input is the mortality rate
'# in the unexposed (mortality rate overall * rate ratio at time zero).
'# Loops through integrating the mortality rate function
```

```
'# and transforming (CI = 1- exp(integrand)) in order to calculate the
'# proportion of new cases at each point in follow up. Multiplies this
'# proportion by the number unexposed at baseline to get the unexposed CI.

integrand_unexposed = IntegrateF(1, time, age_start, sex, simdquintile, year_start,
"mortality_rate_unex", total, exposed)
cumulative_incidence_unexposed = cumulativeincidenceF(integrand_unexposed) *
(total - exposed)

'# 2. CI in the exposed but untreated population
'# This calculates the CI at each time point using the mortality rate and
'# the number exposed but untreated.

integrand_untreated = IntegrateF(1, time, age_start, sex, simdquintile, year_start,
"mortality_rate", total, exposed)
cumulative_incidence_untreated = cumulativeincidenceF(integrand_untreated) *
(exposed - treated_each_year * n_years_treatment)

'# 3. CI in the exposed but treated population IF THEY HAD NOT BEEN TREATED
'# (i.e., the baseline scenario)

integrand_tx_base = integrand_untreated
cumulative_incidence_tx_base = cumulativeincidenceF(integrand_tx_base) *
treated_each_year * n_years_treatment

'# 4. CI in the exposed but treated population
'# As with loops 1, 2 and 3 this code calculates the CI at each time point
'# corresponding to each year of follow-up. It was written to do this for n
'# groups, where n is the number of years at which treatments were applied,
'# but this functionality is not used in Triple I currently: instead only
'# one year of treatment is given. This means there is only one group:
'# the whole treated population.

For i = 1 To n_years_treatment
   If i > time Then j = time
   If i <= time Then j = i
   integrand_untreated = IntegrateF(1, j, age_start, sex, simdquintile, year_start,
"mortality_rate", total, exposed)
   integrand_treated = IntegrateF(j, time, age_start, sex, simdquintile, year_start,
"mortality_rate_rr", total, exposed, intervention)
   ci = cumulativeincidenceF(integrand_untreated + integrand_treated) *
treated_each_year
   cumulative_incidence_treated = cumulative_incidence_treated + ci
Next i

'# The optional extra argument CI_output controls what output is given by
'# the function. The default is "Total CI": the sum of CI for unexposed,
'# exposed+untreated, and treated.
'# "Total CI" covers baseline and intervention cases, because the treated
'# population are included in the exposed+untreated population in the
```

'# baseline calculation. ("Total CI base" is not used currently, but would
'# give the same result at baseline).

If CI_output = "Total CI" Then new_ci = Round(cumulative_incidence_unexposed + cumulative_incidence_untreated + cumulative_incidence_treated, 10)
If CI_output = "unexposed" Then new_ci = Round(cumulative_incidence_unexposed, 10)
If CI_output = "untreated" Then new_ci = Round(cumulative_incidence_untreated, 10)
If CI_output = "treated" Then new_ci = Round(cumulative_incidence_treated, 10)

'# If CI_output is "Each CI" the CIs for unexposed, exposed+untreated,
'# exposed+treated and exposed+treated (if not treated) are provided as an
'# array that can be used by the hosp_count() function:

tmparray(1) = cumulative_incidence_unexposed
tmparray(2) = cumulative_incidence_untreated
tmparray(3) = cumulative_incidence_treated
If CI_output = "Each CI" Then new_ci = tmparray
End Function

'# IntegrateF()
''''''''''''''''''''''
'# The IntegrateF() function is used to calculate the area under the
'# relevant mortality curve for each subgroup.Excel doesn't have a
'# built-in integrate function, so this is done from first principles.
'# It calculates the area under the curve y(x) between x=a and x=b using
'# Simpson's Rule, with n intervals (n = even)

Function IntegrateF(a As Double, b As Double, age_start As Double, _
sex As String, simdquintile As Integer, year_start As Integer, _
mortality_function As String, total As Double, exposed As Double, Optional intervention As String, Optional N As Integer = 10) As Double

'# Local variables

Dim h As Double, sum As Double, term As Double
Dim x As Double
Dim i As Double
Dim Simpson As Double
Dim prevalence_exposed As Double

'# Calculate prevalence of exposure

prevalence_exposed = exposed / total

'# Do error checking

If N = 0 Or N Mod 2 = 1 Then
Simpson = 0#

```
MsgBox "Sorry # of intervals has to be > 0 and even"
Exit Function
End If
h = (b - a) / N
x = a
sum = 0#
For i = 1 To N Step 2
If mortality_function = "mortality_rate" Then term = _
     (mortality_rate(x, age_start, sex, simdquintile, year_start) + _
  4 * mortality_rate(x + h, age_start, sex, simdquintile, year_start) + _
     mortality_rate(x + 2 * h, age_start, sex, simdquintile, year_start)) _
     * exposure_rate_ratio_mortality / (prevalence_exposed *
exposure_rate_ratio_mortality + 1 - prevalence_exposed)
If mortality_function = "mortality_rate_rr" Then term = _
     (mortality_rate_rr(x, age_start, sex, simdquintile, year_start, intervention) + _
  4 * mortality_rate_rr(x + h, age_start, sex, simdquintile, year_start, intervention) + _
     mortality_rate_rr(x + 2 * h, age_start, sex, simdquintile, year_start, intervention))
_
     * exposure_rate_ratio_mortality / (prevalence_exposed *
exposure_rate_ratio_mortality + 1 - prevalence_exposed)
If mortality_function = "mortality_rate_unex" Then term = (1 /
exposure_rate_ratio_mortality) * _
     (mortality_rate(x, age_start, sex, simdquintile, year_start) + _
  4 * mortality_rate(x + h, age_start, sex, simdquintile, year_start) + _
     mortality_rate(x + 2 * h, age_start, sex, simdquintile, year_start)) _
     * exposure_rate_ratio_mortality / (prevalence_exposed *
exposure_rate_ratio_mortality + 1 - prevalence_exposed)
sum = sum + term
x = x + 2 * h
Next i
Simpson = sum * h / 3
IntegrateF = Round(Simpson, 10)
End Function

'# cumulativeincidenceF()
''''''''''''''''''''''''

'# The cumulativeincidenceF() function performs the transformation of the
'# result of IntegrateF()to give the CI count.

Function cumulativeincidenceF(integrand) As Double
cumulativeincidenceF = Round(1 - Exp(-integrand), 10)
End Function

'# prem_mort()
''''''''''''''''''''

'# The function prem_mort() calculates the number of premature deaths.
'# For each subgroup it runs the new_ci() function as long as the age at
'# that point in the follow up period is still less than 75.
```

```
Function prem_mort(time As Double, age_start As Double, sex As String, simdquintile As Integer, year_start As Integer, _
            treated_each_year As Integer, n_years_treatment As Integer, total As Double, exposed As Double, intervention As String) As Double
Dim i As Double
Dim ci As Double
Dim ci_last As Double
Dim new_deaths As Double

time = time - 1
ci_last = 0
new_deaths = 0

For i = 1 To time

   If i + age_start < 75 Then ci = new_ci(i + 1, age_start, sex, simdquintile, year_start, treated_each_year, n_years_treatment, total, exposed, intervention)
      new_deaths = (ci - ci_last)
      ci_last = ci
   If i + age_start >= 75 Then new_deaths = 0
   prem_mort = Round(prem_mort + new_deaths, 10)
Next i

End Function

'# new_yllv2()
''''''''''''''''''''''''''
'# The new_yllv2() function takes the CI for the subgroup each year and
'# calculates the Years of Life Lost it represents, based on the life-
'# expectancy for the subgroup.YLL are calculated as (lifeexp - age at
'# death) x number dying each year.

Function new_yllv2(ylltime As Double, age_start As Double, life_exp As Double, sex As String, simdquintile As Integer, year_start As Integer, _
            treated_each_year As Integer, n_years_treatment As Integer, total As Double, exposed As Double, intervention As String) As Double

Dim i As Double
Dim ci As Double
Dim ci_last As Double
Dim yll As Double

ylltime = ylltime - 1
ci_last = 0

For i = 1 To ylltime
   If i + age_start >= life_exp Then
      ci = 0
   ElseIf i + age_start < life_exp Then
```

```
        ci = new_ci(i + 1, age_start, sex, simdquintile, year_start, treated_each_year,
n_years_treatment, total, exposed, intervention)
        yll = (ci - ci_last) * (life_exp - age_start - i)
        new_yllv2 = Round(new_yllv2 + yll, 10)
        ci_last = ci
    End If
Next i

End Function

'# hosp_count()
''''''''''''''''''''''''''
'# The hosp_count() function calculates hospitalisation counts.
'# As for YLL this loops through the cumulative incidence function,
'# removing the deaths from the population, and calculating
'# hospitalisations for the remainder.The function calculates the person
'# time each year of follow-up and multiplies this by the appropriate
'# hospitalisation rate (unexposed, exposed or treated)

Function hosp_count(hosptime As Double, age_start As Double, sex As String,
simdquintile As Integer, year_start As Integer, _
            treated_each_year As Integer, n_years_treatment As Integer, total As
Double, exposed As Double, intervention As String) As Double
Dim i As Double
Dim ci_each() As Variant
Dim ci_untreated As Double
Dim ci_untreated_last As Double
Dim hosp_untreated As Double
Dim ci_treated As Double
Dim ci_treated_last As Double
Dim hosp_treated As Double
Dim ci_unexposed As Double
Dim ci_unexposed_last As Double
Dim hosp_unexposed As Double
Dim unexposed_N As Double
Dim treated_N As Double
Dim untreated_N As Double

Dim prevalence_exposed_hosp As Double
Dim exposure_rate_ratio_hosp As Double

If sex = "female" Then exposure_rate_ratio_hosp = exposure_rate_ratio_hosp_f
If sex = "male" Then exposure_rate_ratio_hosp = exposure_rate_ratio_hosp_m

'# Define prevalence of exposure
prevalence_exposed_hosp = exposed / total

hosptime = hosptime - 1
ci_unexposed_last = 0
ci_untreated_last = 0
```

```
ci_treated_last = 0

unexposed_N = total - exposed
treated_N = treated_each_year * n_years_treatment
untreated_N = total - unexposed_N - treated_N

For i = 1 To hosptime
ci_each = new_ci(i, age_start, sex, simdquintile, year_start, treated_each_year,
n_years_treatment, total, exposed, intervention, "Each CI")
ci_unexposed = ci_each(1)
ci_untreated = ci_each(2)
ci_treated = ci_each(3)
hosp_untreated = (untreated_N - ci_untreated) * hosp_rate(i, age_start, sex,
simdquintile, year_start) _
      * exposure_rate_ratio_hosp / (prevalence_exposed_hosp *
exposure_rate_ratio_hosp + 1 - prevalence_exposed_hosp)

hosp_treated = (treated_N - ci_treated) * hosp_rate_rr(i, age_start, sex, simdquintile,
year_start, intervention) _
      * exposure_rate_ratio_hosp / (prevalence_exposed_hosp *
exposure_rate_ratio_hosp + 1 - prevalence_exposed_hosp)

hosp_unexposed = (unexposed_N - ci_unexposed) * (1 / exposure_rate_ratio_hosp)
* hosp_rate(i, age_start, sex, simdquintile, year_start) _
      * exposure_rate_ratio_hosp / (prevalence_exposed_hosp *
exposure_rate_ratio_hosp + 1 - prevalence_exposed_hosp)

hosp_count = Round(hosp_count + hosp_unexposed + hosp_untreated +
hosp_treated, 10)
ci_unexposed_last = ci_unexposed
ci_untreated_last = ci_untreated
ci_treated_last = ci_treated
Next i
End Function
```

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