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Recent adverse mortality trends in Scotland: comparison with other high-income countries.

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Abstract

Objective

Gains in life expectancy have faltered in several high-income countries in recent years. We aim to compare life expectancy trends in Scotland to those seen internationally, and to assess the timing of any recent changes in mortality trends for Scotland.

Setting

Austria, Croatia, Czech Republic, Denmark, England & Wales, Estonia, France, Germany, Hungary, Iceland, Israel, Japan, Korea, Latvia, Lithuania, Netherlands, Northern Ireland, Poland, Scotland, Slovakia, Spain, Sweden, Switzerland, USA.

Methods

We used life expectancy data from the Human Mortality Database (HMD) to calculate the mean annual life expectancy change for 24 high-income countries over five-year periods from 1992 to 2016, and the change for Scotland for five-year periods from 1857 to 2016. One- and two-break segmented regression models were applied to mortality data from National Records of Scotland (NRS) to identify turning points in age-standardised mortality trends between 1990 and 2018.

Results

In 2012-2016 life expectancies in Scotland increased by 2.5 weeks/year for females and 4.5 weeks/year for males, the smallest gains of any period since the early 1970s. The improvements in life expectancy in 2012-2016 were smallest among females (<2.0 weeks/year) in Northern Ireland, Iceland, England & Wales and the USA and among males (<5.0 weeks/year) in Iceland, USA, England & Wales and Scotland. Japan, Korea, and countries of Eastern Europe have seen substantial gains in the same period. The best estimate of when mortality rates changed to a slower rate of improvement in Scotland was the year to 2012 Q4 for males and the year to 2014 Q2 for females.

Conclusion

Life expectancy improvement has stalled across many, but not all, high income countries. The recent change in the mortality trend in Scotland occurred within the period 2012-2014. Further research is required to understand these trends, but governments must also take timely action on plausible contributors.

Key Words

Mortality, Life expectancy, Scotland, Europe, International, trend, austerity, influenza.

Article summary

Strengths and limitations of this study

- The use of five-year time periods for comparison of life expectancy changes reduces the influence of year-to-year variation on observations.
- Examining long-term trends addresses concerns that recent life expectancy stalling may be over-emphasised due to notably large gains in the immediately preceding period.
- The international comparison was limited to the 24 high-income countries for which data were readily available for the relevant period.
- Analysis of trend data will always be sensitive to the period selected, however segmented regression of the full period of mortality rates available offers an objective method of identifying the timing of a change in trend.

Background

Mortality rates have steadily declined, and life expectancy has improved, in most high-income countries since 1945.[1,2] There have been previous exceptions to this general trend, including the countries of Eastern Europe during the 1990s.[1,3] Recently there have been a series of reports suggesting that mortality improvements are now faltering, or even reversing, for the USA, the UK, and much of continental Europe, since around 2011.[4-6]

Contextualising current mortality trends within those that have been observed previously and internationally can support a proportionate public health response, and identify comparator countries or periods to assist future investigation of causal hypotheses. International comparison of changes in life expectancy across a single year (2014 to 2015) found that life expectancy declined in 8 out of 18 high-income countries, including the UK.[4] However, the short-run trends in mortality data, even at national level, can vary substantially from year-to-year and observations may be therefore by sensitive to the comparison period.[7] Comparison of the most recent six years to the preceding six years found that, of 20 countries, the UK had had the largest life expectancy slow-down for females, and the second largest for males.[5] This however, does not allow identification of which period was exceptional: the previous gains or the current slow-down.

Among the UK countries Scotland has the lowest life expectancy, with a period life expectancy at birth in 2015-2017 which was 2.0 years lower for women, and 2.5 years lower for men than that observed in England.[8] Analysis by the UK Office for National Statistics (ONS) found that a slowdown in mortality rates has been seen in all four UK countries in 2011-2016 compared to 2006-2011, but that Scotland experienced the least stalling for women, and second least after Northern Ireland for men.[6]

Several hypotheses have been proposed to explain recent changes in life expectancy trends. Cohort effects, whereby a particular generation is at a higher risk of mortality, may be important if that generation is now reaching an age where it contributes more to overall mortality and life expectancy.[2,9] Other possibilities are that there is an interaction between period effects (such as policy changes or infectious disease epidemics) and vulnerabilities within a cohort such that mortality for that group increases. This has been observed for specific causes of death in Scotland and the USA (suicide, drug-related deaths and alcohol).[10-13]

There has been an apparent polarisation of the debate regarding causes of recent adverse mortality trends, between explanations emphasising influenza, and those concerned with the impacts of austerity.[14-18] It may be that this split is in part attributable to studies seeking the answers to different questions (for example the causes of high numbers of deaths in short periods of time versus stalling of overall life expectancy over longer periods) and in variable comparator, or baseline, periods employed. Causal investigation would be strengthened by clear description of the nature, scale and timing of the phenomenon we are seeking to explain.

This study aims to describe the nature, scale and timing of changes in mortality in Scotland, and to compare these to those seen internationally, as an early step in understanding their causes.

Methods

We report our results in accordance with the RECORD guideline.[19]

Data

We used population data from the Human Mortality Database (HMD)[20] for life expectancy analyses. Segmented regression analysis of age-standardised mortality rates used data held by National Records of Scotland (NRS). All analyses were undertaken for males and females separately.

Life expectancy: average annual change in five-year periods

Period life expectancy figures for Scotland for each single year between 1855 and 2016 were extracted. For international comparisons, data were obtained for all high-income countries within the HMD which provided data for 2016 at the time of extraction[1]. The mean annual change in life expectancy (in weeks) for five-year periods running back from 2016 was calculated for each country. A sensitivity analysis using rolling five-year time periods rather than set periods from 2016 backwards was also undertaken.

Age-standardised mortality rates: segmented regression

We calculated directly age-standardised mortality rates per 100,000 population for rolling four-quarter periods for Scotland using the 2013 European Standard Population for the entire time period (Q1 1990 to Q2 2018). Population estimates were calculated for each four-quarter period by interpolating the mid-year estimates. Data points are labelled by their final quarter, so quarter 1 (Q1) 2016 represents the mortality rate for 2015 Q2, Q3 and Q4 combined with 2016 Q1. Quarterly-rolling rates were used in order to increase the number of data points available to the model.
In order to identify the point in the time series at which a change in trend occurred, we undertook segmented regression in R using the 'segmented' package.[21,22] We used the Davies test for the existence and statistical significance of a breakpoint. We used the segmented test, which treats the whole time series as continuous, to identify the breakpoint and standard error. The results of the segmented test were interpreted as identifying the quarterly data point within which the breakpoint fell. In this way a result of 2014.374 falls within quarter 2 of 2014, and the data which correspond to this quarter represent the 'year' quarter 3 2013 to quarter 2 2014, hence the year to 2014 Q2 is interpreted as the best estimate of when a change in trend occurred. Ninety-five percent confidence intervals for the breakpoint were calculated from the standard error of this estimate. We used the segmented test to examine one and two break point models and compared model fit using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values. Segmented regression models were produced separately for all males, all females and for males and females divided into under 75 year and 75+ year age groups.

Patient and public involvement

This research was done without direct patient or public involvement.

[1] 24 of 42 HMD countries included. Excluded countries: No data for 2016: Australia, Belgium, Canada, Chile, Finland, Greece, Ireland, Italy, Luxembourg, New Zealand, Norway, Portugal, Slovenia, Taiwan, and Ukraine. Not high-income: Belarus, Bulgaria, and Russia.

Results

Life expectancy trends

Period life expectancy at birth for men and women in Scotland increased from 44 years for women and 41 years for men in 1855 to 81 years for women and 77 years for men in 2016, based on single-year estimates. Throughout this period women had longer life expectancies than men. The trend up to around 1945 was substantially more unstable than in later years, but there was a general improvement, especially after 1890. From 1950 the degree of year-to-year variability reduced and there was a slower, steady improvement.

The mean annual change in life expectancy observed in Scotland in five-year periods (1857 and 2016) shows that the largest gains were made in the periods following declines in life expectancy (e.g. 1942-1946) (Figure 1). From 1997-2011 each period saw steady gains for females (range 9.8-11.0 weeks/year) and males (range 14.1-17.3 week/year). In the period 2012-2016, only small mean life expectancy improvements were observed: 2.5 weeks/year for females and 4.5 weeks/year for males. This represents the smallest average annual increase for women since 1937-41, and for men since 1972-76. A sensitivity analysis (**Error! Reference source not found.**) using rolling five-year periods identifies similar periods of slow life expectancy gain, showing results are not dependent on the selection of particular start and finish years.

To identify the nations and time periods with the greatest change in life expectancy trends over the last three decades, the mean annual changes in life expectancy (in weeks) for all 24 high-income countries with HMD data available to 2016 are shown in Figures 2 and 3, for females and males respectively. Nearly all countries saw mean increases in life expectancy across all five-year time periods, with the exceptions among females being: Northern Ireland (2012-2016), Iceland (1997-2001) Latvia (1992-1996), and Lithuania (2002-2006), and among males: Iceland and USA (2012-2016), Latvia (1992-1996) and Lithuania (1992-1996 and 2002-2006).

For females, the range of mean life expectancy change in 2012-2016 was -1.3 to 14.5 weeks/year (interquartile range 3.3 to 10.0 weeks/year). Nine countries saw mean gains of less than five weeks/year: Northern Ireland (-1.2 weeks/year), Iceland (0.1 weeks/year), England & Wales (1.1 weeks/year), USA (1.9 weeks/year), Scotland (2.5 weeks/year), the Netherlands (2.7 weeks/year), France (3.4 weeks/year) and Sweden (4.4 weeks/year), and Germany (4.6 weeks/year). Seven countries had mean gains of 10 weeks per year or more: Poland (10.0 weeks/year), Denmark (10.0 weeks/year), Croatia (10.0 weeks/year), Czech Republic (10.5 weeks/year), Hungary (11.1 weeks/year), Japan (13.3 weeks/year) and Korea (14.5 weeks/year). Life expectancy gain was smaller in 2012-2016 than the preceding 5 years for all countries except the Czech Republic, Hungary and Japan (Figure 2).

Amongst males, the range of mean life expectancy change in 2012-2016 was -1.7 to 20.6 weeks/year (interquartile range 7.8 to 14.0 weeks/year). Four countries had mean gains of less than five weeks/year: Iceland (-1.7 weeks/year), USA (-0.4 weeks/year), England & Wales (4.0 weeks/year), and Scotland (4.5 weeks/year). Fourteen countries had gains of 10 weeks/year or more: Spain (10.5 weeks/year), Austria (11.1 weeks/year), Croatia (11.9 weeks/year), Switzerland (12.9 weeks/year) Latvia (12.9 weeks/year), Denmark (13.0 weeks/year), Poland (13.7 weeks/year), Czech Republic (13.8 weeks/year), Hungary (14.7 weeks/year), Lithuania (14.9 weeks/year), Slovakia (15.5 weeks/year), Japan (16.1 weeks/year), Estonia (19.7 weeks/year) and Korea (20.6 weeks/year). The increases for the 2012-2016 were smaller than in 2007-2011 for all countries except Japan and Korea (Figure 3).

Figure 1 – Mean annual change in period life expectancy at birth (weeks) for five-year periods, men and women, Scotland (civilian population), 1857-2016

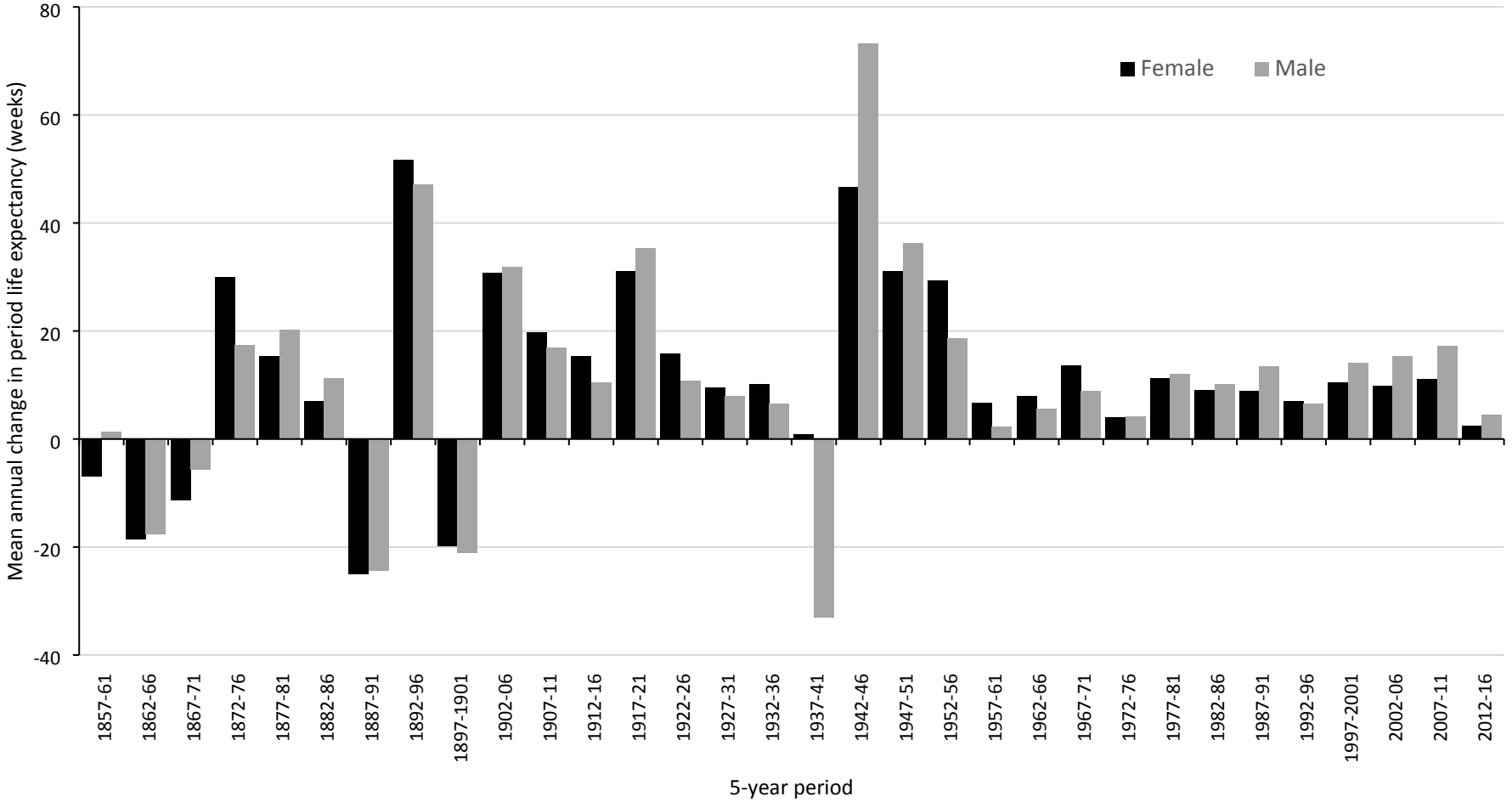


Figure 2 - Mean annual change in female life expectancy at birth (weeks), for five-year periods 1991-2016, by country.
*no data available for Croatia and Korea for periods prior to 2002.

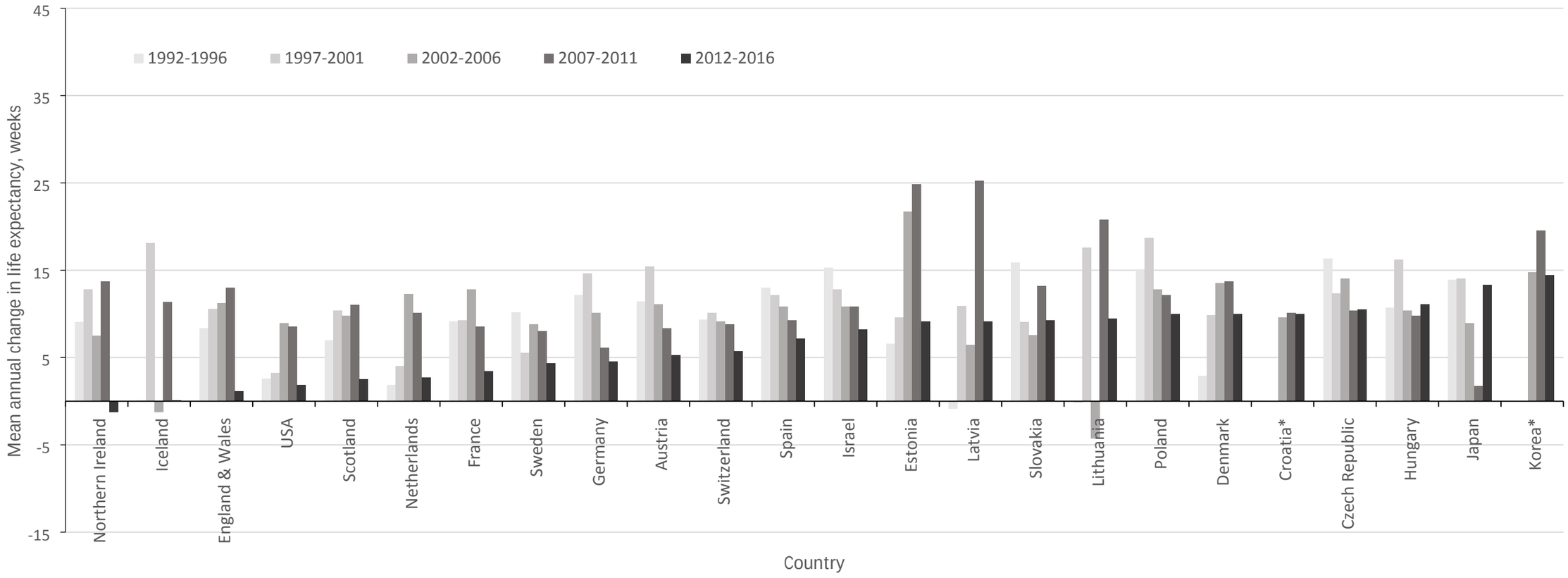
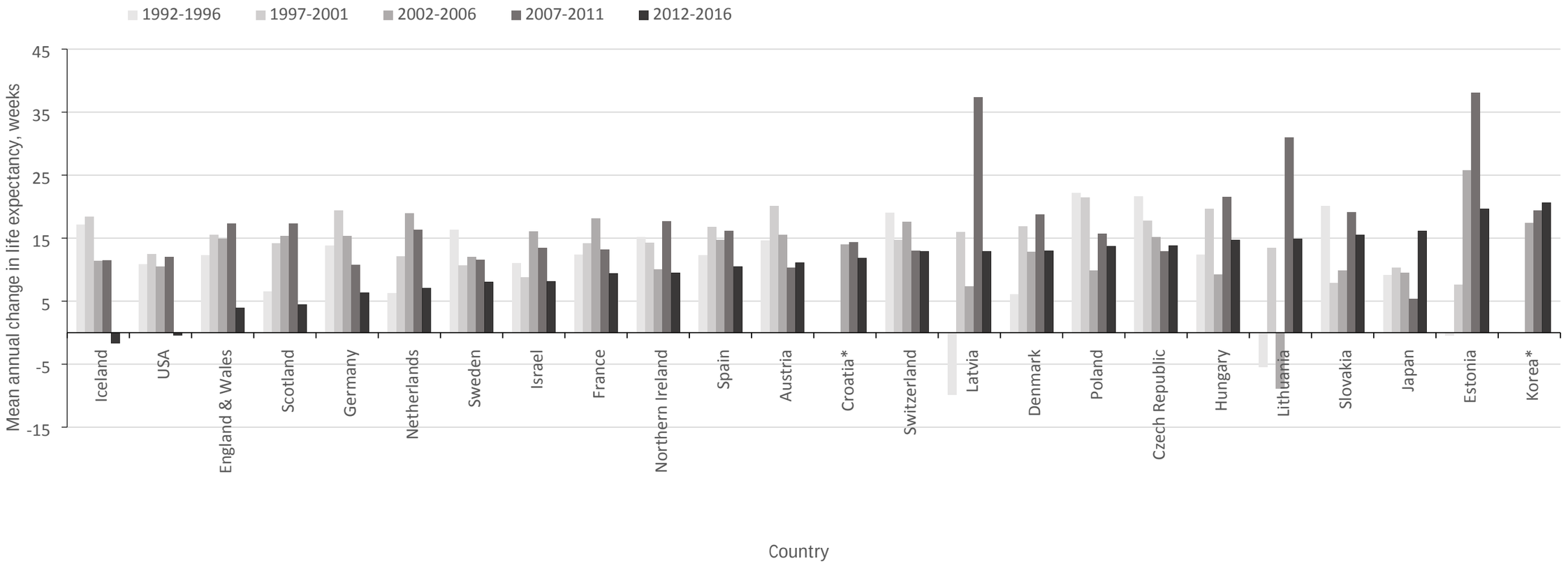


Figure 3 - Mean annual change in male life expectancy at birth (weeks), for five-year periods 1991-2016, by country.
*no data available for Croatia and Korea for periods prior to 2002.



Segmented regression

Figure 4 shows the rolling four-quarter age standardised mortality rates (ASMRs), by sex, for Scotland for all ages. Over the period (1990 Q1 – 2018 Q2), the ASMR per 100,000 population fell from 2,114 to 1,355 for males, and from 1,386 to 1,025 for females. Males had a higher mortality rate than females throughout the series, although this gap narrowed over time. The steadiest period of decline in mortality rates appeared to be from 2004 to around 2011, with the periods before and after this showing variation between slow improvements, worsening of mortality rates, and faster improvements. The mortality rates for those aged 75+ years showed greater variability than those in the younger age group.

The Davies test for the existence of a change in the slope identified a statistically significant change ($p<0.01$) for males and females, and both age groups tested. For all groups the breakpoint identified by the Davies test fell within the period 2012-2014 (see Table 1). The segmented model provides a more precise approach to estimation of the timing of the breakpoint. The date estimates from the one-break segmented model corresponded to those identified by the Davies test for all groups, to within 0.2 years. One and two-break models were run for all groups; both AIC and BIC were lower for the two-break models, indicating that these are a better fit, hence the results below report the two-break model findings.

The two-break model for all ages identified the first breakpoint in the year to 1993 Q4 for both males (95% confidence interval (CI): year to 1992 Q4 - year to 1994 Q4) and females (95% CI: year to 1992 Q1 – year to 1995 Q2). A second breakpoint for males was identified in the year to 2012 Q4 (95% CI: year to 2012 Q1 – year to 2013 Q3), and for females in the year to 2014 Q2 (95% CI: year to 2013 Q2 – year to 2015 Q2). The change in trend indicated by these breakpoints is shown in Figure 4; the break in 1993 indicates a change from a period of slower mortality improvement to a period of faster improvement and the later breaks in 2012 and 2014 (males and females respectively) indicate a change to much slower gains.

Among those aged under 75 years, the results of the two-break model suggested that the later change in trend occurred approximately 18 months earlier in males (year to 2012 Q4) than in females (year to 2014 Q2), with the 95% confidence intervals for the estimates not overlapping (see Table 1). For those aged 75+ years the estimate for males (year to 2012 Q3) was one year later than for females (year to 2011 Q3), but the 95% confidence intervals for the estimates overlap.

Among males, the estimate of the later breakpoint of the two-break model was similar for those aged under 75 years and 75+ years (year to 2012 Q4 for both groups). For females the later breakpoint occurred nearly 3 years later in those aged under 75 years (year to 2014 Q2) than those aged 75+ years (year to 2011 Q3), with the 95% confidence intervals not overlapping.

Figure 4 – Age-standardised rolling four-quarterly mortality rates, with segmented regression models fitted, Scotland, 1990-2018

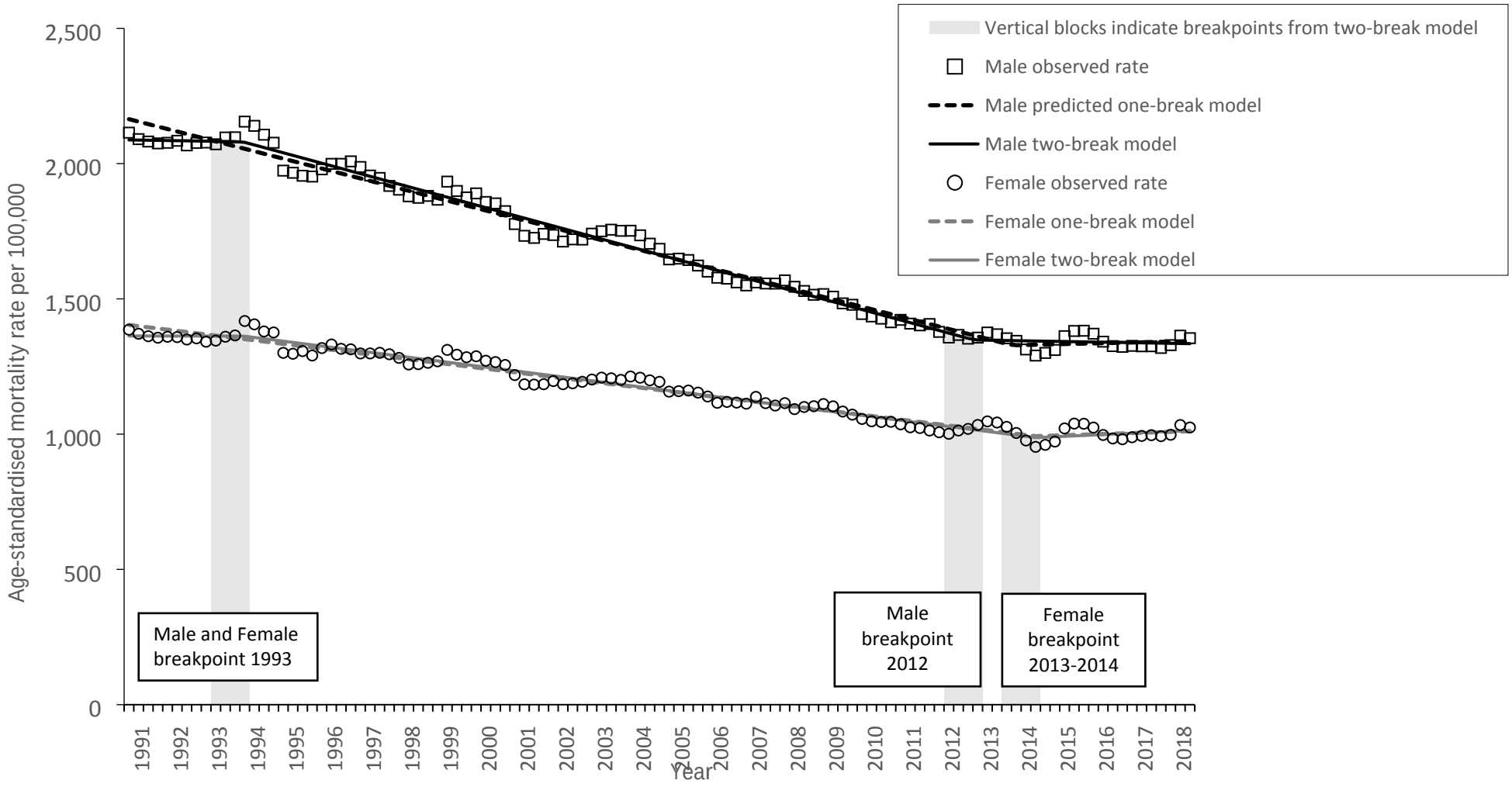


Table 1: Summary of results of segmented regression by population group and model/test

Population group	Model/test	Breakpoint	Lower 95% confidence interval	Upper 95% confidence interval	P-value	Additional breakpoint	Lower 95% confidence interval	Upper 95% confidence interval	AIC	BIC
Male all age	Davies test	2013.7			<0.00001					
Male all age	Segmented: one break	2013.8	2012.9	2014.6					1151	1164
Male all age	Segmented: two break	2012.8	2012.0	2013.6		1993.8	1992.8	1994.9	1140	1097
Female all age	Davies test	2014.4			<0.00001					
Female all age	Segmented: one break	2014.3	2013.3	2015.5					1083	1159
Female all age	Segmented: two break	2014.4	2013.4	2015.4		1993.9	1992.2	1995.5	1063	1082
Male <75 yrs	Davies test	2013.5			<0.00001					
Male <75 yrs	Segmented: one break	2013.5	2012.8	2014.1					874	888
Male <75 yrs	Segmented: two break	2013.0	2012.5	2013.5		1994.1	1993.3	1995.0	835	735
Female <75 yrs	Davies test	2012.5			<0.00001					
Female <75 yrs	Segmented: one break	2012.5	2011.9	2013.2					722	854
Female <75 yrs	Segmented: two break	2014.4	2013.7	2015.1		2005.9	2003.0	2008.7	709	728
Male 75+yrs	Davies test	2014.2			<0.0001					
Male 75+yrs	Segmented: one break	2014.1	2013.0	2015.2					1578	1592
Male 75+yrs	Segmented: two break	2012.7	2011.5	2013.9		1993.6	1992.3	1994.9	1561	1580
Female 75+yrs	Davies test	2014.4			0.0087					
Female 75+yrs	Segmented: one break	2014.6	2012.5	2016.6					1536	1549
Female 75+yrs	Segmented: two break	2011.7	2010.2	2013.3		2004.3	2002.0	2006.7	1520	1539

Discussion

Principal findings

The increase in life expectancy in Scotland since 1855 has occurred at different rates over time. Over the first one hundred years examined here, there were periods of rapid increase, but also notable declines. Since 1957, however, there has been a pattern of smaller, steadier increases in life expectancy for both males and females. The life expectancy gains between 2012 and 2016 are amongst the smallest seen in this later period, with average increases of only 2.5 weeks/year for women and 4.5 weeks/year for men.

Of the 24 high-income countries for which data were available, nearly all had smaller life expectancy gains in 2012-2016 than in the immediately preceding period. Japan and Korea are notable exceptions, and in Japan there was a substantial slow-down in life expectancy gains in the period 2007-2011, followed by a resumption of gains at the level previously seen. Among the countries with a stalling of life expectancy gains in 2012-2016 there is large variation in the mean change observed, and in the scale of the difference between periods. Iceland, the USA, England & Wales, Scotland, and, for females, Northern Ireland, had the smallest gains in 2012-2016 and the most marked stalling. In general, the countries of Western Europe saw smaller gains in 2012-2016, with some degree of slow-down, compared to countries of Eastern Europe, where steadier gains have been maintained. Denmark is notable for having maintained mean life expectancy gains of around 10 weeks/year among females across the period 1997-2016, and even greater gains among males.

The two-break segmented regression model suggests that mortality trends changed to a pattern of more rapid improvement for both males and females in the year to 1993 Q4. In the year to 2012 Q4 for males, and 2014 Q2 for females, the trend in mortality rates changes again, with an increase thereafter. For all the models and groups tested, a negative turning point in mortality rates was consistently identified within the period 2011 to 2015.

Strengths and weaknesses

Using life expectancy and age-standardised mortality rates ensures that the analyses in this paper are not prone to confounding by changes in the age structure of the population. We used all-cause mortality rates, thus avoiding difficulties due to competing causes of death and coding uncertainties. We performed sensitivity analyses on the periodisation of the average gain in life expectancy comparisons to identify the potential for the findings to be affected by the selection of a particular start date for the analyses.

The use of single-year life expectancy estimates from the HMD allowed international comparison; it should be noted that these data differ slightly from life expectancy estimates published by NRS using 3-yearly rolling averages. The international analysis is limited to the range of countries for which data were available through the HMD at the time of extraction. We were only able to conduct segmented regression employing four-quarter rolling mortality rates for Scotland, as we did not have access to equivalent data for other countries. We acknowledge that the confidence intervals presented for segmented regression may underestimate the true uncertainty, as the nature of the rolling quarterly mortality rate estimates means that the data points aren't discrete.

Whilst other studies have focused changes in mortality between single years (particularly 2014 to 2015), we were explicit in seeking to describe the longer-term

mortality trends, and therefore employed five-year time periods for comparison to reduce the influence of year-to-year variation on observations. By extending life expectancy gain comparisons back over a longer time period we have sought to address concerns that the stalling of life expectancy in the most recent period may be over-emphasised due to notably large gains in the immediately preceding period.

How this fits

Our overall findings are consistent with those of others, and the recent stalling of life expectancy gains across many high-income countries is now well recognised.[4-7] Other analyses have emphasised the recent reduction in mortality improvements relative to those seen in the immediately preceding period.[5] We have shown that relatively large life expectancy gains were seen for both males and females in Scotland in the preceding 15 years (1997-2011), but that even before this gains as small as those seen recently have not been observed since at least the early 1970s. Comparison of mortality trends within the UK suggests that the stalling seen in Scotland may not be as severe as that seen in England and Wales.[6] Our findings confirm this, but allow us to place this difference within a wider international context which shows that the changes seen in Scotland are still more severe than those observed in many other high-income countries. The timing of a change in overall mortality trends found in this analysis is broadly consistent with that observed in England, where a breakpoint for females was found in the year to 2014 Q2, and the year to 2012 Q1 for males.[23] Some differences are seen when data are age-stratified, with an earlier breakpoint observed in England for males <75 years and females 75+ years.

Meaning – explanations and implications

Various hypotheses have been proposed to explain these trends, in particular the period effects of influenza and of economic austerity, and cohort effects, such as the impact on mortality risk of population cohorts with a high prevalence of obesity. It seems likely that factors common to all of the countries displaying similar trends, and absent in countries without the change in trend, are causal. It is also likely that several factors acting together are relevant to explaining the trends, whether that is some aspect of the context (such as the underlying political economy within a country) or two specific factors interacting. Many of the hypotheses proposed thus far are not mutually exclusive, but that does not mean that all the factors suggested are causal or have the same importance. It is possible that influenza and political economy explanations are both causal, with interactions between population vulnerability, social and health care pressures, and influenza.

The global financial crisis of 2008 led to a marked economic recession in many countries, and given that unemployment and income are important determinants of health,[24] the potential for the crisis to adversely impact on mortality was highlighted early.[25] However, the evidence around the impact of economic recession on health and mortality of populations, rather than individuals, is complex and contested.[26] The response to this financial crisis, across many countries, was to implement a range of austerity policies whereby public spending was reduced in the pursuit of balanced budgets. As a result many public services experienced substantial reductions in their budgets and public sector wages and income transfers to lower income groups were frequently reduced in real terms. There is evidence that this impacted on a range of health outcomes, but not always consistently or negatively.[27-31]

Unanswered questions and further research

Further descriptive work is required on the contribution of different causes of death, age-specific components and inequalities to the trends in Scotland. Work to

understand the theoretical interaction of different hypothesised causes, and to test these theories is urgently required. In the meantime, governments at all levels should seek to provide public services according to need and sufficient social protection for all of their populations as key determinants of health. Providing effective vaccination programmes against influenza and sufficient health and social care capacity to deal with surges in demand is also required.

Conclusion

Between 2012 and 2016 the rate of improvement in mortality markedly slowed across many high-income countries, and particularly in England & Wales, the USA, Scotland, Iceland and Northern Ireland. For this period in Scotland, the increases were only 2.5 weeks/year for women and 4.5 weeks for men. The timing of the change in mortality trend in Scotland for all ages is best estimated for men in the year to 2012 Q4 and for women in the year to 2014 Q2. Further research is required to test the range of theories for the causes of these trends, but in the meantime, governments should take action to ensure effective public services, adequate incomes, health and social care services and influenza vaccination programmes are in place.

Competing interests

The authors declare that they have no competing interests. No funding was received for this work.

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Author statement

GM drafted the manuscript. LF and JM undertook the analyses. JR and MK provided data for the segmented regression analysis. All authors made substantial contributions to editing the manuscript and approved the final draft.

Ethics

No new data were collected in this study and there was no public or patient involvement. We used mortality data made available to us by National Records of Scotland and adhered to our standard procedures to protect against disclosure.

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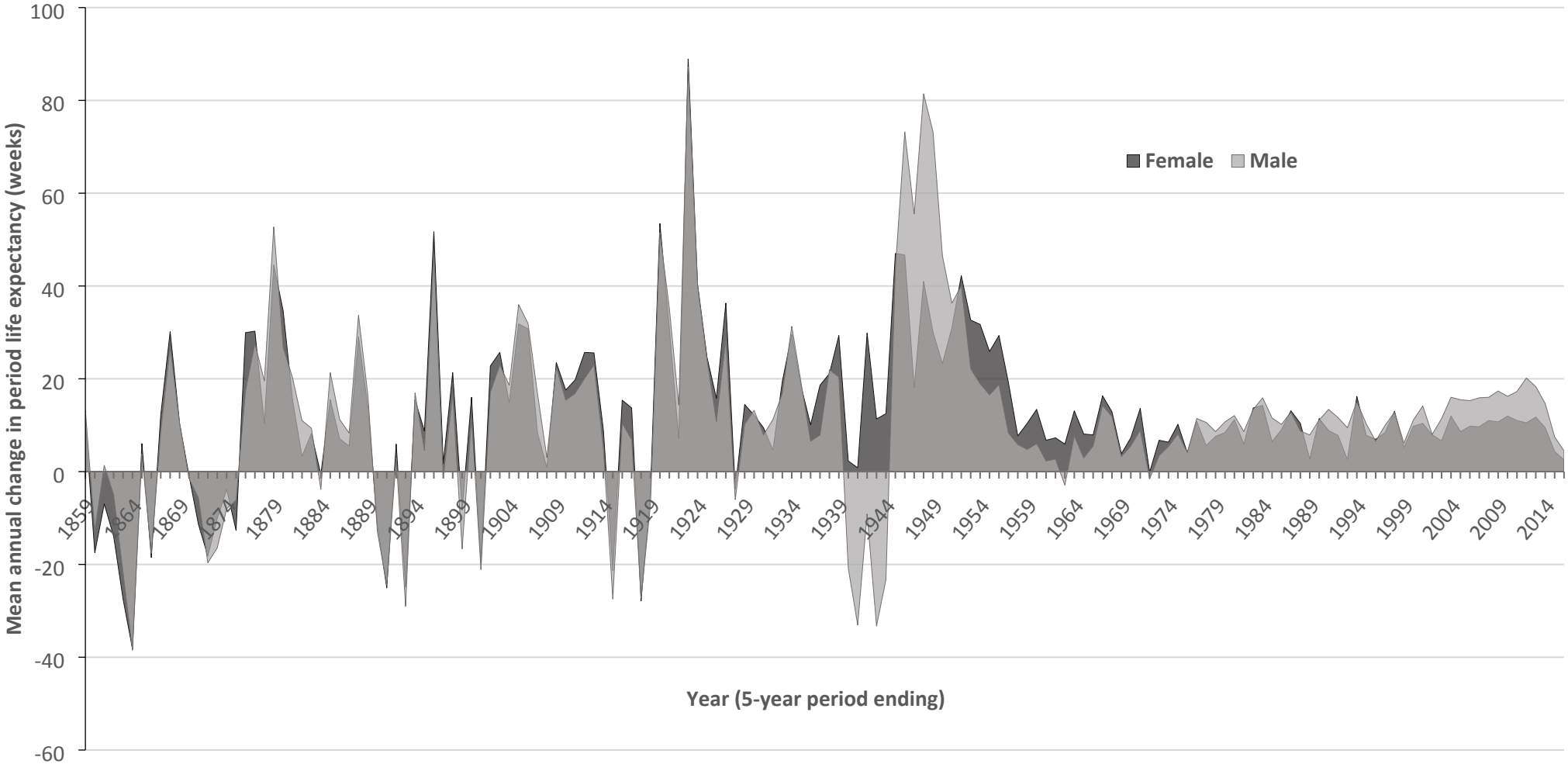
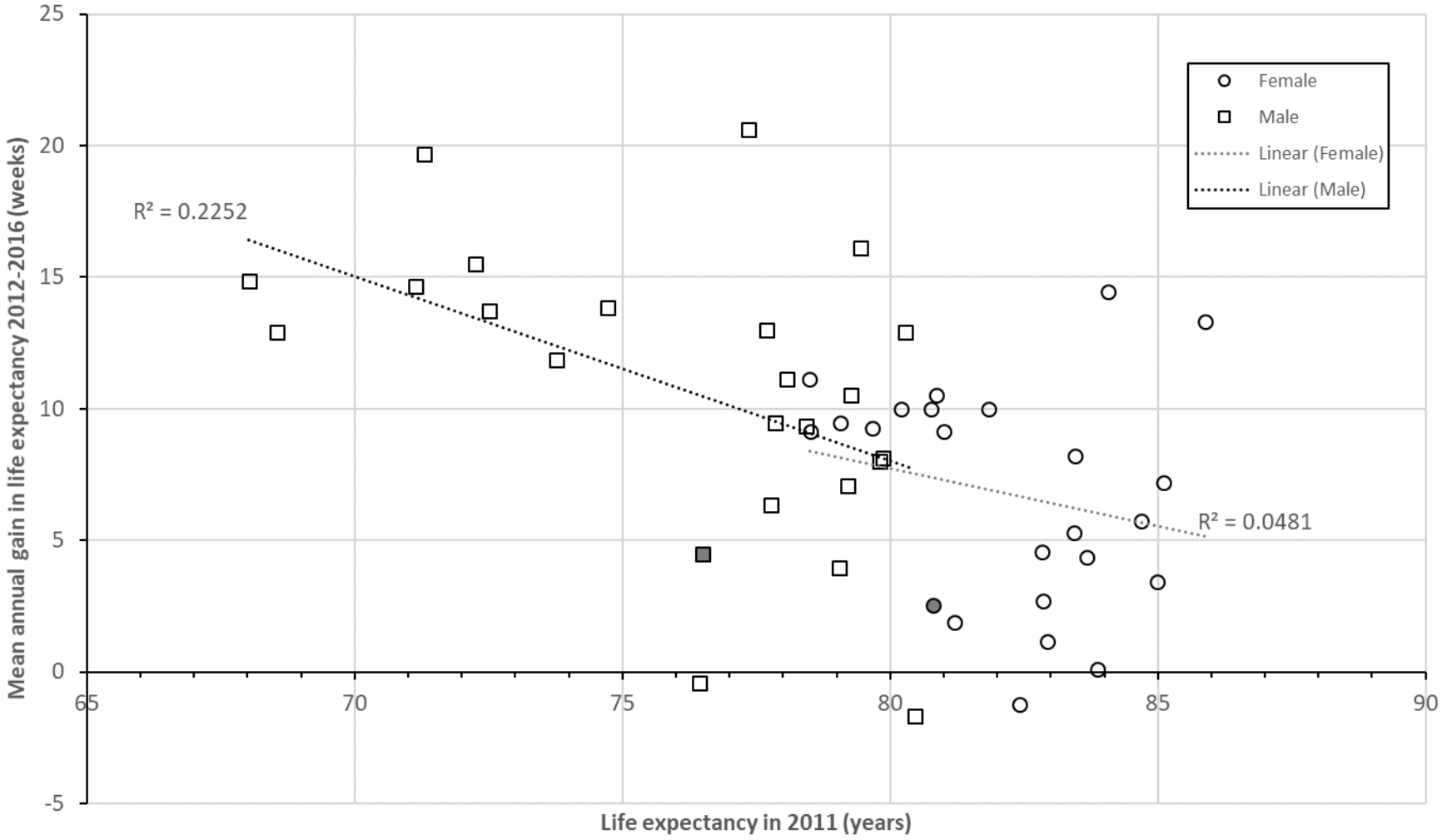
Appendix figure 1: Mean annual average change in life expectancy (civilian population) for 5-year rolling periods, Scotland, males and females, 1859-2016. Data source: Human Mortality Database.



Appendix figure 2: Relationship between life expectancy in 2011, and mean annual gain in life expectancy 2012-2016, for 24 high-income countries: Austria, Croatia, Czech Republic, Denmark, England & Wales, Estonia, France, Germany, Hungary, Iceland, Israel, Japan, Korea, Latvia, Lithuania, Netherlands, Northern Ireland, Poland, Scotland (indicated by shaded markers), Slovakia, Spain, Sweden, Switzerland, USA.



The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract Abstract N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Introduction		
Objectives	3	State specific objectives, including any prespecified hypotheses	Introduction		
Methods					
Study Design	4	Present key elements of study design early in the paper	Abstract, methods		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Abstract, methods		

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	Methods	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Methods	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	N/A
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Methods, Results, supplemental appendix		

Bias	9	Describe any efforts to address potential sources of bias	Methods, Supplemental appendix		
Study size	10	Explain how the study size was arrived at	Methods		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Methods		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	Methods, Supplemental appendix		
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Methods

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	None
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)	Population-wide data, age-standardised, stratified by sex.		
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure	Results		

		category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Results		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Supplemental appendix		
Discussion					
Key results	18	Summarise key results with reference to study objectives	Discussion		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Discussion	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	N/A
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	Discussion		

		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	End of paper		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Publicly accessible data, other data will be uploaded to Dryad

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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Recent adverse mortality trends in Scotland: comparison with other high-income countries.

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Recent adverse mortality trends in Scotland: comparison with other high-income countries.

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Abstract

Objective

Gains in life expectancy have faltered in several high-income countries in recent years. Scotland has consistently had a lower life expectancy than many other high-income countries over the past 70 years. We aim to compare life expectancy trends in Scotland to those seen internationally, and to assess the timing and importance of any recent changes in mortality trends for Scotland.

Setting

Austria, Croatia, Czech Republic, Denmark, England & Wales, Estonia, France, Germany, Hungary, Iceland, Israel, Japan, Korea, Latvia, Lithuania, Netherlands, Northern Ireland, Poland, Scotland, Slovakia, Spain, Sweden, Switzerland, USA.

Methods

We used life expectancy data from the Human Mortality Database (HMD) to calculate the mean annual life expectancy change for 24 high-income countries over five-year periods from 1992 to 2016. Linear regression was used to assess the association between life expectancy in 2011 and mean life expectancy change over the subsequent five years. One- and two-break segmented regression models were used to test the timing of mortality rate changes in Scotland between 1990 and 2018.

Results

Mean improvements in life expectancy in 2012-2016 were smallest among females (<2.0 weeks/year) in Northern Ireland, Iceland, England & Wales and the USA and among males (<5.0 weeks/year) in Iceland, USA, England & Wales and Scotland. Japan, Korea, and countries of Eastern Europe had substantial gains in life expectancy over the same period. The best estimate of when mortality rates changed to a slower rate of improvement in Scotland was the year to 2012 quarter 4 for males and the year to 2014 quarter 2 for females.

Conclusion

Life expectancy improvement has stalled across many, but not all, high income countries. The recent change in the mortality trend in Scotland occurred within the period 2012-2014. Further research is required to understand these trends, but governments must also take timely action on plausible contributors.

Key Words

Mortality, Life expectancy, Scotland, Europe, International, trend, austerity, influenza.

Article summary

Strengths and limitations of this study

- The use of five-year time periods for comparison of life expectancy changes reduces the influence of year-to-year variation on observations.
- Examining long-term trends addresses concerns that recent life expectancy stalling may be over-emphasised due to notably large gains in the immediately preceding period.
- The international comparison was limited to the 24 high-income countries for which data were readily available for the relevant period.
- Analysis of trend data will always be sensitive to the period selected, however segmented regression of the full period of mortality rates available offers an objective method of identifying the timing of a change in trend.

Background

Mortality rates have steadily declined, and life expectancy has improved, in most high-income countries since 1945. [1], [2]There have been exceptions to this trend, including in countries of Eastern Europe where there were slower improvements from the 1960s and dramatic declines in the 1990s.[1], [3] Recent reports indicate that mortality improvements have been faltering, or reversing, in the USA, the UK, and much of continental Europe, since around 2011.[4]–[7]

Since 1950, life expectancy trends in Scotland have followed a trajectory between slower improvements in Eastern Europe and faster improvements in Western Europe.1 Scotland has relatively wide socioeconomic health inequalities and additional premature mortality beyond that expected for the level of deprivation.[8] Among the UK countries, Scotland has the lowest life expectancy; 2.0 years lower for women, and 2.5 years lower for men than England in 2015-2017.[9] The causes of the higher mortality and wider health inequalities in Scotland have been summarised as historical vulnerability combined with the changed politics from the 1980s onwards.[8] Existing analyses suggest that Scotland has experienced a smaller stalling in life expectancy gains than England and Wales, since 2011, but the scale of this difference, in an international context, is not clear.[7]

International comparison of changes in life expectancy across a single year (2014 to 2015) found that life expectancy declined in 11 and 12 of 18 high income countries, for men and women respectively, including the UK.[4] However, the short-run trends in mortality data, even at national level, can vary substantially and observations may therefore be sensitive to the comparison period.[10] Comparison of the most recent six years to the preceding six years found that, of 20 countries, the UK experienced the largest life expectancy slow-down for females, and the second largest for males.[5] This, however, does not allow identification of which period was exceptional: the previous gains or the current slow-down.

Describing the patterning of recent mortality trends can help understanding of the scale of the problem and identify comparator countries or periods to assist future investigation of causal hypotheses. There has been an apparent polarisation of the debate regarding causes of recent adverse mortality trends, between explanations emphasising influenza, and those concerned with the impacts of austerity.[11]–[14] This split may, in part, be attributable to studies seeking the answers to different questions (for example the causes of high numbers of deaths in short periods of time versus stalling of overall life expectancy over longer periods) and in variable comparator, or baseline, periods employed. Cohort effects and interactions between period effects (such as policy changes or infectious disease epidemics) and vulnerabilities within a cohort may also play a role. [2][15] Such interactions have been observed for drug-related deaths and those due to suicide and alcohol in Scotland and the USA.[16], [17] Causal investigation would be strengthened by clear description of the nature, scale and timing of the phenomenon we are seeking to explain.

This study aims to describe the nature, scale and timing of changes in mortality in Scotland, and to compare these to those seen internationally, as an early step in understanding their causes.

Methods

We report our results in accordance with the RECORD guideline.[18]

Life expectancy: average annual change in five-year periods

Data on period life expectancy at birth were obtained from the Human Mortality Database (HMD).[19] All high-income countries for which there were data available up to 2016 were included.[a] The mean annual change in life expectancy (in weeks) for five-year periods running back from 2016 to 1992 was calculated for each country (a longer time-series was also undertaken for Scotland alone). Two sensitivity analyses

[a] 24 of 42 HMD countries included. Excluded countries: No data for 2016: Australia, Belgium, Canada, Chile, Finland, Greece, Ireland, Italy, Luxembourg, New Zealand, Norway, Portugal, Slovenia, Taiwan, and Ukraine. Not high-income: Belarus, Bulgaria, and Russia.

were undertaken. First, we recalculated using rolling five-year time periods rather than set periods from 2016 backwards. Second, we excluded 2015 from the mean change in the last time period (making it 2012-2014 plus 2016). We assessed the relationship between life expectancy in 2011 and mean life expectancy gain in the following 5 year using linear regression. All analyses were undertaken for males and females separately.

Age-standardised mortality rates: segmented regression

Directly age-standardised mortality rates per 100,000 population for rolling four-quarter periods for Scotland were calculated (using the 2013 European Standard Population; upper age group 90+ years) from quarter 1 1990 to quarter 2 2018) from mortality data held by National Records of Scotland (NRS). The 1990 start date was adopted as an acceptable application of the ESP 2013, and to permit comparison with analyses from England.[20] Population estimates were calculated for each four-quarter period by interpolating the mid-year estimates. Data points are labelled by their final quarter, so quarter 1 (Q1) 2016 represents the mortality rate for 2015 Q2, Q3 and Q4 combined with 2016 Q1. Quarterly-rolling rates were used in order to increase the number of data points available to the model.

Segmented regression was undertaken in R using the 'segmented' package.[21], [22] The Davies test assessed the existence and statistical significance of a breakpoint, and the segmented test was used to identify the breakpoint and standard error. The results of the segmented test were interpreted as identifying the quarterly data point within which the breakpoint fell. In this way a result of 2014.374 falls within quarter 2 of 2014, and the data which correspond to this quarter represent the 'year' quarter 3 2013 to quarter 2 2014, hence the year to 2014 Q2 is interpreted as the best estimate of when a change in trend occurred. One and two breakpoint models were compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values. Analyses were undertaken separately for males and females and for under 75 year and 75+ year age groups for both sexes, in keeping with the use of the under 75 year age group to calculate premature mortality in the UK.

Patient and public involvement

This research was done without direct patient or public involvement.

Results

Life expectancy trends – 24 high-income countries

The mean annual changes in life expectancy (in weeks), for all 24 high-income countries with HMD data available to 2016, are shown in Figures 1 and 2, for females and males respectively (data are shown in supplemental table 1). The countries are ordered on the size of mean life expectancy change in the most recent period. Nearly all countries saw mean increases in life expectancy across all five-year time periods, with the exceptions being: Northern Ireland (2012-2016), Iceland (1997-2001) Latvia (1992-1996), and Lithuania (2002-2006) among females; and Iceland and USA (2012-2016), Latvia (1992-1996) and Lithuania (1992-1996 and 2002-2006) among males.

For the period 2012-2016 the range of mean life expectancy changes was -1.3 weeks/year to +14.5 weeks/year for females (interquartile range [IQR]: 3.3 to 10.0 weeks/year), and -1.7 to 20.6 weeks/year (IQR 7.8 to 14.0 weeks/year) for males. Mean gains of less than five weeks/year were seen in 9 countries for females, and 4 countries for males. Gains of 10 weeks/year or more were seen in 4 countries for females, and 14 countries for males. For both sexes, the mean annual increases were smaller in 2012-2016 than over 2007-2011 for nearly all countries, with Japan a notable exception for both sexes. When 2015 is excluded from the latest time period the stalling effect is less marked, although the scale of impact of this year varies, and for some countries, notably the USA this exclusion had little effect (supplemental figures 1 and 2).

In Scotland over the period 2012-2016 mean life expectancy improvements of 2.5 weeks/year for females and 4.5 weeks/year for males were observed. This represents the smallest average annual increase for women since 1937-41, and for men since 1972-76 (see supplemental figure 3). A sensitivity analysis (supplemental figure 4) using rolling five-year periods identifies similar periods of slow life expectancy gain, showing results are not dependent on the selection of particular start and finish years.

The relationship between starting life expectancy in 2011 and subsequent mean annual change in life expectancy (in weeks) from 2012-2016 is shown in figure 3, for males and females separately, and for each of the countries considered. This indicates that subsequent life expectancy gains tended to be slightly smaller in countries that had higher life expectancies in 2011, but this relationship is very weak, especially for females, where the R-squared value is 0.05.

Figure 1 - Mean annual change in female life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

Figure 2 - Mean annual change in male life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

Figure 3 - Life expectancy in 2011 (years) and mean change in life expectancy 2012-2016 (weeks), for 24 high income countries, by sex.

Segmented regression - Scotland

Rolling, four-quarter, age standardised mortality rates (ASMRs), by sex, for Scotland for all ages from 1990 Q1 to 2018 Q2, are shown in figure 4. Over the whole period the ASMR per 100,000 population fell from 2,114 to 1,355 for males, and from 1,386 to 1,025 for females. The steadiest period of decline in mortality rates appeared to be from 2004 to around 2011, with the periods before and after this showing greater variation.

As shown in table 1, the Davies test identified a statistically significant change in trend ($p<0.01$) for males and females, and both age groups. For all groups the breakpoint identified by the Davies test fell within the period 2012-2014. The date estimates from the one-break segmented model corresponded to those identified by the Davies test for all groups, to within 0.2 years. One and two-break models were run for all groups; both AIC and BIC were lower for all two-break models, indicating that these are a better fit.

The two-break model for all ages indicated a first breakpoint as the year to 1993 Q4 for both males (95% confidence interval (CI): year to 1992 Q4 - year to 1994 Q4) and females (95% CI: year to 1992 Q1 – year to 1995 Q2). A second breakpoint for males was identified as the year to 2012 Q4 (95% CI: year to 2012 Q1 – year to 2013 Q3), and for females as the year to 2014 Q2 (95% CI: year to 2013 Q2 – year to 2015 Q2). The models are shown in figure 4; the break in 1993 indicates a change from a period of slower mortality improvement to a period of faster improvement and the later breaks in 2012 (males) and 2014 (females) indicate a change to much slower gains.

Among all age groups a later breakpoint changing to slower improvements was identified within the period year to 2012 Q4 and year to 2014 Q2, with the earliest being males aged under 75 years, and the latest females aged under 75 years. Full age-group results are shown in table 1.

Figure 4 – Age-standardised rolling four-quarterly mortality rates for men and women in Scotland, with segmented regression models fitted, 1990-2018.

Table 1: Summary of results of segmented regression by population group and model/test

Population group	Model/test	Breakpoint	Lower 95% confidence interval	Upper 95% confidence interval	P-value	Additional breakpoint	L c in
Male all age	Davies test	2013.7			<0.00001		
Male all age	Segmented: one break	2013.8	2012.9	2014.6			
Male all age	Segmented: two break	2012.8	2012.0	2013.6		1993.8	
Female all age	Davies test	2014.4			<0.00001		
Female all age	Segmented: one break	2014.3	2013.3	2015.5			
Female all age	Segmented: two break	2014.4	2013.4	2015.4		1993.9	
Male <75 yrs	Davies test	2013.5			<0.00001		
Male <75 yrs	Segmented: one break	2013.5	2012.8	2014.1			
Male <75 yrs	Segmented: two break	2013.0	2012.5	2013.5		1994.1	
Female <75 yrs	Davies test	2012.5			<0.00001		
Female <75 yrs	Segmented: one break	2012.5	2011.9	2013.2			
Female <75 yrs	Segmented: two break	2014.4	2013.7	2015.1		2005.9	
Male 75+yrs	Davies test	2014.2			<0.0001		
Male 75+yrs	Segmented: one break	2014.1	2013.0	2015.2			
Male 75+yrs	Segmented: two break	2012.7	2011.5	2013.9		1993.6	
Female 75+yrs	Davies test	2014.4			0.0087		
Female 75+yrs	Segmented: one break	2014.6	2012.5	2016.6			
Female 75+yrs	Segmented: two break	2011.7	2010.2	2013.3		2004.3	

Discussion

Principal findings

Of the 24 high-income countries for which data were available, nearly all had smaller life expectancy gains in 2012-2016 than in the preceding 5-year period. Japan and Korea are notable exceptions; in Japan there was a substantial slow-down in life expectancy gains in the period 2007-2011 (almost certainly explained by the 18,000 direct deaths from the 2011 earthquake and tsunami)[23], followed by a resumption of gains at the level previously seen.

Among the countries with a stalling of life expectancy gains in 2012-2016 there is large variation in the mean change observed, and in the scale of the difference between periods. Iceland, the USA, England & Wales, Scotland, and, for females, Northern Ireland, had the smallest gains in 2012-2016 and the most marked stalling. In general, the countries of Western Europe saw smaller gains in 2012-2016, with some degree of slow-down, compared to countries of Eastern Europe, where steadier gains have been maintained. Denmark is notable for having maintained mean life expectancy gains of around 10 weeks/year among females across the period 1997-2016, and even greater gains among males. In Scotland the life expectancy gains between 2012 and 2016 are amongst the smallest seen since the 1970s.

Scotland has had marked stalling in spite of a comparatively low life expectancy in 2011, and there is a generally weak relationship between life expectancy and mean life expectancy gains internationally. This suggests that recent adverse mortality trends are not due to any 'natural' long-term tendency for life expectancy gains to slow down in high-income countries.

The two-break segmented regression model of Scottish mortality rates, indicates that mortality trends changed to a pattern of more rapid improvement for both males and females in the year to 1993 Q4. In the year to 2012 Q4 for males, and 2014 Q2 for females, the trend in mortality rates changes again, with an increase in mortality thereafter. For all the models and groups tested, a negative turning point in mortality rates was consistently identified within the period 2011 to 2015.

Strengths and weaknesses

Using life expectancy and age-standardised mortality rates ensured that our analyses were not prone to confounding by changes in the age structure of the population. We used all-cause mortality rates, thus avoiding difficulties due to competing causes of death and coding uncertainties. We performed sensitivity analyses on the periodisation of the average gain in life expectancy comparisons to identify the potential for the findings to be affected by the selection of a particular start date for the analyses.

Whilst other studies have focused on changes in mortality between single years (particularly 2014 to 2015), we were explicit in seeking to describe the longer-term mortality trends, and therefore employed five-year time periods for comparison to reduce the influence of year-to-year variation on observations. By extending life expectancy gain comparisons back over a longer time period we have sought to address concerns that the stalling of life expectancy in the most recent period may be over-emphasised due to notably large gains in the immediately preceding period. Our results using a longer time period show that such concerns are unfounded.

The use of life expectancy estimates from the HMD allowed international comparison; for Scotland these single-year data differ slightly from life expectancy estimates of NRS which use 3-year averages. The international analysis is limited to the range of countries for which data were available through the HMD. We adopted the broad inclusion criteria of data availability and income level, in order to avoid any selection bias, and did not group or ascribe mortality characteristics to countries in advance of analysis. Thus several countries of Eastern Europe were included, which experienced a well-described decline and then recovery in life expectancy from the early 1990s.[24] It is possible that some of the recent faster improvements in Eastern Europe may be due to 'catch-up' following the ending of a negative exposure, however it is also instructive to find that these countries seem to be less affected by the recent stalling.

The segmented regression analysis was limited to Scotland, as we did not have access to equivalent mortality data for other countries. We acknowledge that the confidence intervals presented for segmented regression may underestimate the true uncertainty, as the nature of the rolling quarterly mortality rates means that the data points aren't discrete.

How this fits

Our overall findings are consistent with those of others, and the recent stalling of life expectancy gains across many high-income countries is now well recognised. [4] [5] [6] Other analyses have emphasised the reduction in mortality improvements relative to those seen in the immediately preceding period.[4], [5] We have shown that relatively large life expectancy gains were seen for both males and females in Scotland in the preceding 15 years (1997-2011), but that even before this gains as small as those seen recently have not been observed since at least the early 1970s. Comparison of mortality trends within the UK suggests that the stalling seen in Scotland is not as severe as that seen in England and Wales.[7] Our findings confirm this, but allow us to place this difference within a wider international context which shows that the changes seen in Scotland are still more severe than those observed in many other high-income countries, and are particularly concerning given the higher starting levels of mortality. The timing of a change in overall mortality trends found in this analysis is broadly consistent with that observed in England, where a breakpoint for females was found in the year to 2014 Q2, and the year to 2012 Q1 for males.[20]

The recent slowdown in improving life expectancies in Scotland follows from decades of relative health disadvantage in Scotland compared with other affluent countries. A comparison of age-specific mortality rates over time in Scotland compared with England & Wales found a growing disadvantage in mortality in younger working age since the 1980s, disproportionately affecting males, as well as persistent disadvantages at older ages, disproportionately affecting females.[25] Increased rates and inequalities in suicide and drug-related deaths have been observed in young adults, and patterns of cause-specific death by age and year indicative of a cohort effect, with elevated hazards for cohorts who entered the labour market after the 'neoliberal' labour market reforms of the 1980s than for earlier cohorts, suggesting political economy as an underlying explanatory factor.[26] High rates of alcohol-related deaths, and steep socioeconomic gradients, also emerged over the 1990s and 2000s, affecting slightly older working ages. Scotland also has relatively high rates of deaths from circulatory disease in older ages, though trends in ischaemic heart disease have been improving since the early 1990s.[27]

The greatest contributions to the recent changes in life expectancy are due to worsening rates of drug-related deaths, sharp slowdowns in improvements in

circulatory diseases, and rising rates of deaths attributed to dementias and Alzheimer's Disease.[28]

Meaning – explanations and implications
Various hypotheses have been proposed to explain recent adverse trends, in particular the period effects of influenza and of economic austerity, and cohort effects, such as the mortality risk of cohorts with a high prevalence of obesity. Many of these hypotheses are not mutually exclusive, but that does not mean that all the factors suggested are causal or have the same importance. It is possible that influenza and political economy explanations are both causal, with interactions between population vulnerability, social and health care pressures, and influenza. It seems likely that factors common to all of the countries displaying similar trends, and absent in countries without the change in trend, are causal, and also likely that several factors acting together are relevant to explaining the trends.

The global financial crisis of 2008 led to a marked economic recession in many countries, and given that unemployment and income are important determinants of health,[29] the potential for the crisis to adversely impact on mortality was highlighted early.[30] However, the evidence around the impact of economic recession on health and mortality of populations, rather than individuals, is complex and contested.[31] The response to the financial crisis, across many countries, was to implement a range of austerity policies whereby public spending was reduced in the pursuit of balanced budgets. As a result many public services experienced substantial reductions in their budgets and public sector wages and income transfers to lower income groups were frequently reduced in real terms. There is good evidence now available that this impacted negatively on mortality rates and self-rated health.[32]–[34]

It seems less plausible that the trends can be explained as a natural limit to life expectancy or by a new stage of health transition since there is continued improvement in some of the countries with the highest life expectancy (e.g. Japan) and amongst those within countries who already have the longest life expectancy.[35]

Unanswered questions and further research
Further descriptive work is required on the contribution of different causes of death, age-specific components and inequalities to the trends in Scotland. We also need to understand the degree to which the relatively rapid improvements across the UK during the late 1990s and 2000s were unusual. Work to understand the theoretical interaction of different hypothesised causes, and to test these theories is urgently required.

Conclusion

Between 2012 and 2016 the rate of improvement in mortality markedly slowed across many high-income countries, and particularly in England & Wales, the USA, Scotland, Iceland and Northern Ireland. The timing of the change in mortality trend in Scotland for all ages is estimated for men in the year to 2012 Q4 and for women in the year to 2014 Q2. Further research is required to test the range of theories for the causes of these trends, but in the meantime, governments at all levels should take action to ensure effective public services, adequate incomes, health and social care services and influenza vaccination programmes are in place.

Competing interests

The authors declare that they have no competing interests. No funding was received for this work.

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Contributorship statement
LF and GM conceived the idea for this study. LF and JM undertook the analyses. JR and MK provided data for the segmented regression analysis. GM drafted the manuscript. CF and GW, along will all other authors made substantial contributions to interpretation of results and editing the manuscript, and all approved the final draft.

Data availability statement
Life expectancy data used for these analyses are publicly available via the Human Mortality Database at https://www.mortality.org/. Quarterly-rolling age-standardised mortality rates used for the segmented regression are available on request from lynda.fenton@nhs.net.

Ethics
No new data were collected in this study and there was no public or patient involvement. We used mortality data made available to us by National Records of Scotland and adhered to our standard procedures to protect against disclosure.

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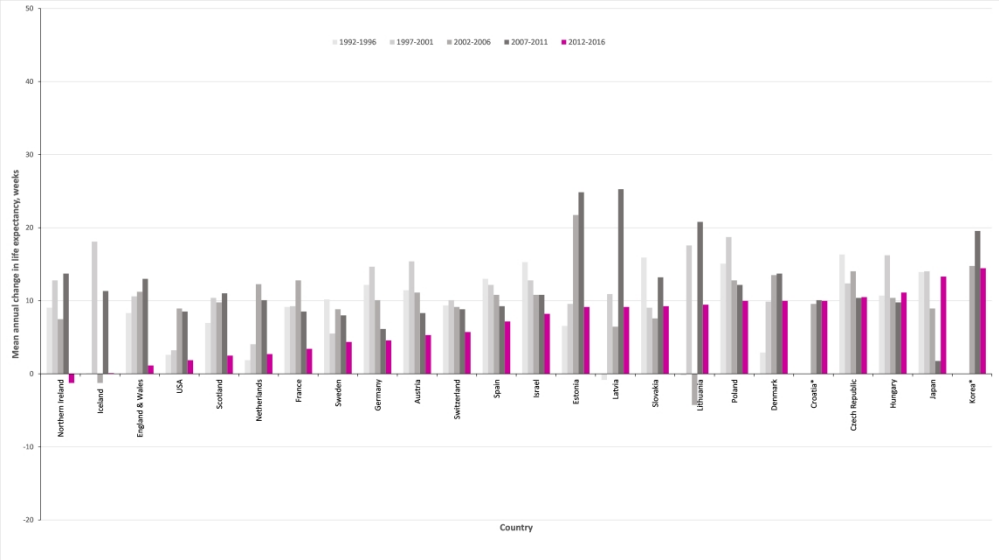

Figure 1 - Mean annual change in female life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

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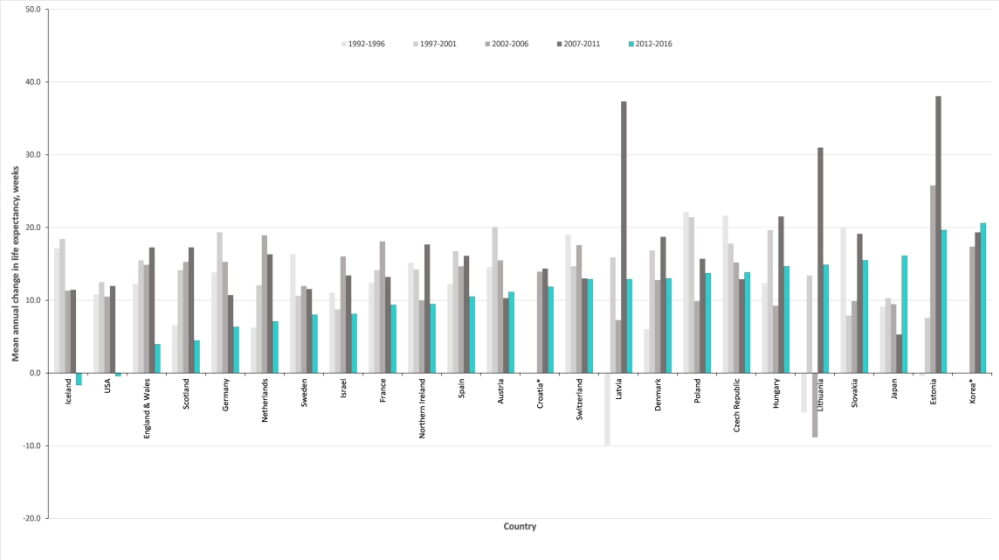

Figure 2 - Mean annual change in male life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

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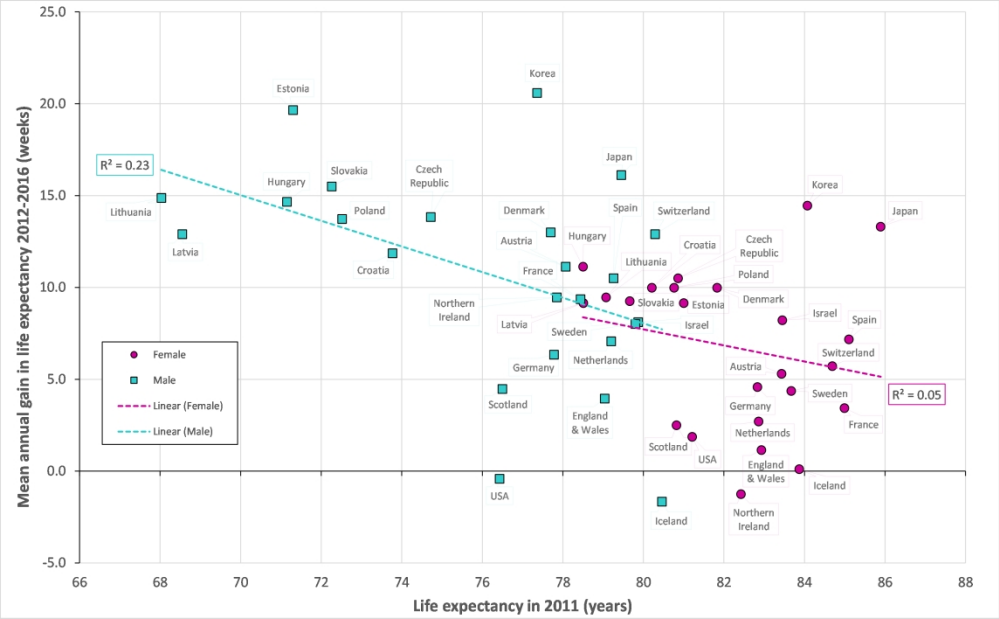


Figure 3: Life expectancy in 2011 (years) and mean change in life expectancy 2012-2016 (weeks), for 24 high income countries, by sex.

284x175mm (300 x 300 DPI)

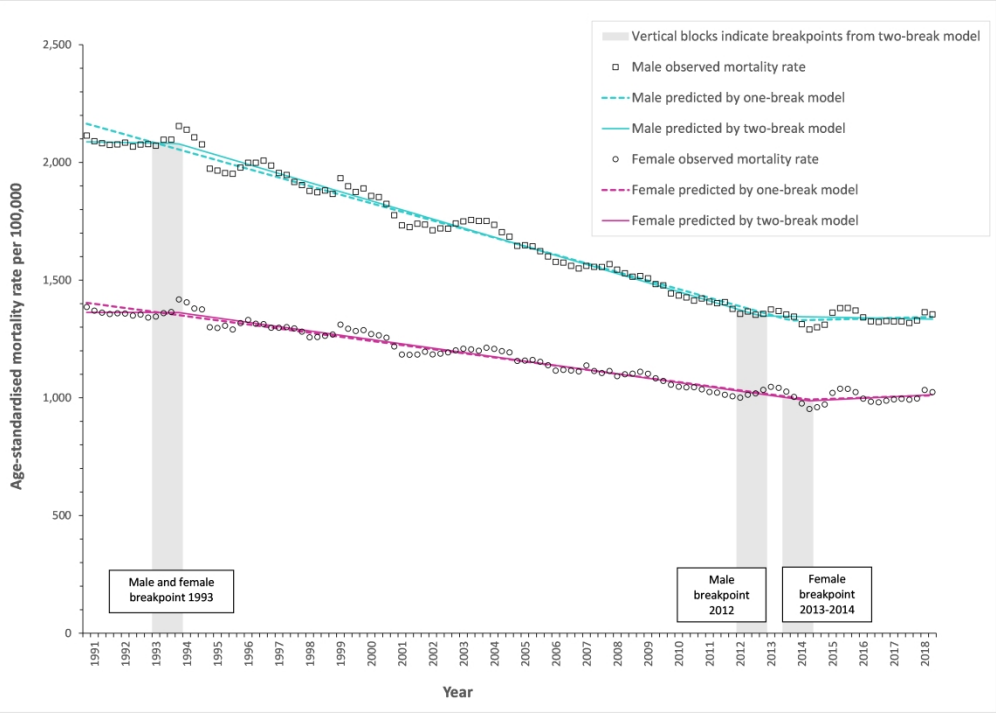
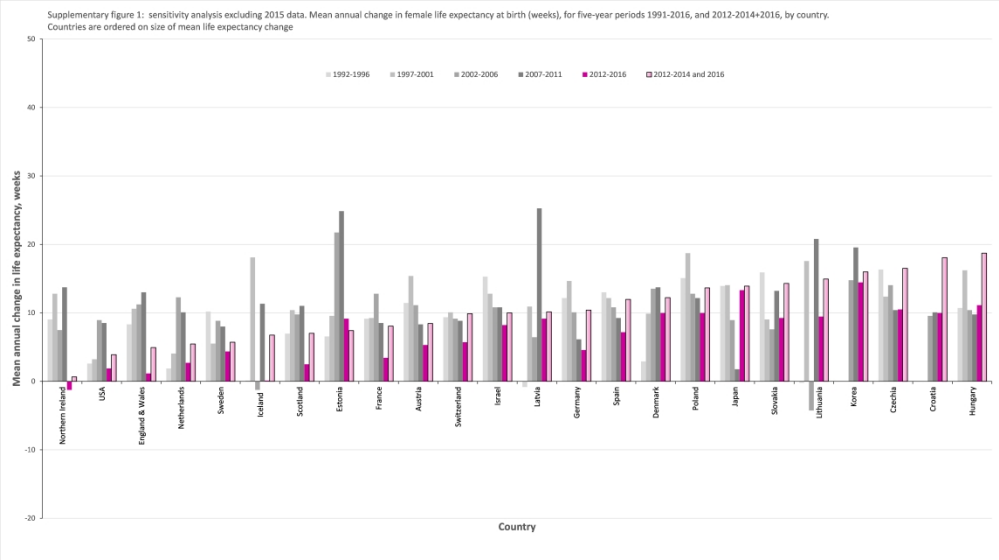


Figure 4: Age-standardised rolling four-quarterly mortality rates for men and women in Scotland, with segmented regression models fitted, 1990-2018.

336x239mm (300 x 300 DPI)



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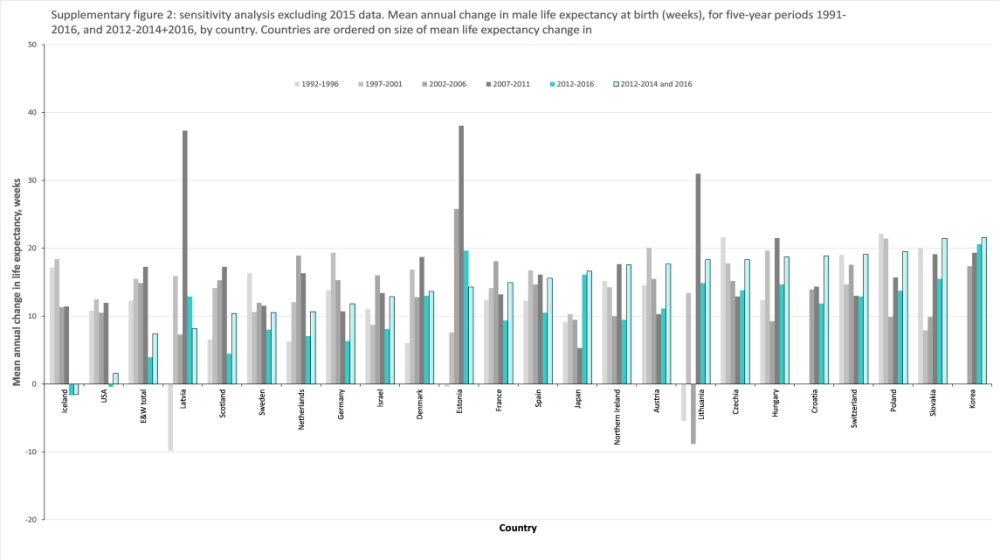

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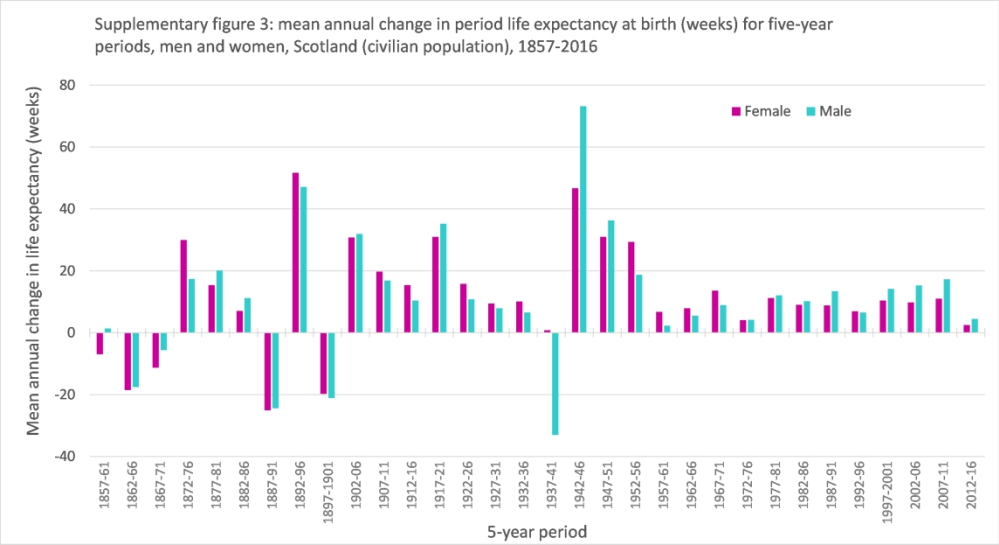

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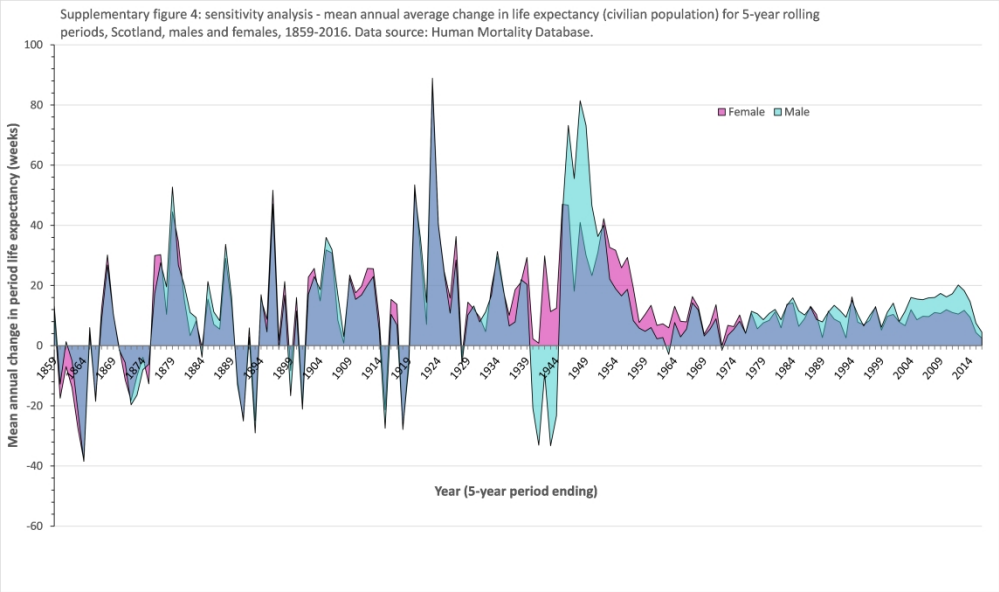

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Supplementary table 1: mean annual change in life expectancy at birth (weeks), for five-year periods 1992-2016, for females and males, by country.

Female					
Country	**1992-1996**	**1997-2001**	**2002-2006**	**2007-2011**	**2012-2016**
Northern Ireland	9.0	12.8	7.5	13.7	-1.2
Iceland	0.1	18.1	-1.2	11.3	0.1
England & Wales	8.3	10.6	11.2	13.0	1.1
USA	2.6	3.2	8.9	8.5	1.9
Scotland	7.0	10.4	9.8	11.0	2.5
Netherlands	1.9	4.1	12.3	10.1	2.7
France	9.2	9.3	12.8	8.5	3.4
Sweden	10.2	5.5	8.8	8.0	4.4
Germany	12.2	14.7	10.1	6.1	4.6
Austria	11.4	15.4	11.1	8.3	5.3
Switzerland	9.4	10.1	9.2	8.8	5.7
Spain	13.0	12.2	10.8	9.3	7.2
Israel	15.3	12.8	10.8	10.8	8.2
Estonia	6.6	9.6	21.7	24.9	9.2
Latvia	-0.8	10.9	6.4	25.3	9.2
Slovakia	15.9	9.0	7.6	13.2	9.3
Lithuania	-0.2	17.6	-4.3	20.8	9.5
Poland	15.1	18.7	12.8	12.2	10.0
Denmark	2.9	9.9	13.5	13.7	10.0
Croatia*	0.0	0.0	9.6	10.1	10.0
Czech Republic	16.3	12.4	14.0	10.4	10.5
Hungary	10.7	16.2	10.4	9.8	11.1
Japan	13.9	14.0	8.9	1.8	13.3
Korea*	0.0	0.0	14.8	19.6	14.5
Male					
Iceland	17.2	18.4	11.3	11.4	-1.7
USA	10.8	12.5	10.5	12.0	-0.4
England & Wales	12.3	15.5	14.9	17.3	4.0
Scotland	6.6	14.1	15.3	17.3	4.5
Germany	13.8	19.3	15.3	10.7	6.3
Netherlands	6.2	12.1	18.9	16.3	7.1
Sweden	16.3	10.6	12.0	11.5	8.0
Israel	11.0	8.7	16.0	13.4	8.1
France	12.4	14.1	18.1	13.2	9.4
Northern Ireland	15.2	14.2	10.0	17.7	9.5
Spain	12.3	16.7	14.7	16.1	10.5
Austria	14.6	20.1	15.5	10.3	11.1
Croatia*	0.0	0.0	13.9	14.4	11.9
Switzerland	19.0	14.7	17.6	13.0	12.9
Latvia	-9.9	15.9	7.3	37.3	12.9
Denmark	6.0	16.8	12.8	18.7	13.0
Poland	22.2	21.4	9.9	15.7	13.7
Czech Republic	21.6	17.8	15.2	12.9	13.8
Hungary	12.4	19.7	9.3	21.5	14.7
Lithuania	-5.4	13.4	-8.8	31.0	14.9
Slovakia	20.1	7.9	9.9	19.1	15.5
Japan	9.2	10.3	9.5	5.3	16.1
Estonia	-0.4	7.6	25.8	38.1	19.7

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract; methods – p.2 Abstract; setting – p.2 N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Background		Background; paragraphs 1, 2, 4 - p.4
Objectives	3	State specific objectives, including any prespecified hypotheses	Background		Background; paragraph 5 – p.4
Methods					
Study Design	4	Present key elements of study design early in the paper	Abstract, methods		Abstract: methods – p.2 Methods – p.4-5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Abstract, methods		Abstract: setting, methods –p.2 Methods – p.4-5

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	Methods	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Methods	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	N/A
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Methods, Results, supplemental appendix		Methods p.4-5

Bias	9	Describe any efforts to address potential sources of bias	Methods, Supplemental appendix		Methods p.4-5 Discussion; strengths and weaknesses - p. 10-11 Sensitivity analysis – supplemental files 2, 3, 5
Study size	10	Explain how the study size was arrived at	Methods		Methods p.4-5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Methods		Methods p.4-5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	Methods, Supplemental appendix		Methods p.4-5

Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods p.4-5 None
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods p.4-5
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest	Population-wide data, age-standardised, stratified by sex.		n/a – no individual participants

		(c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	Results		Figures 1, 2, 7 Supplemental table 1 Figure 8
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Results		Table 2
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Supplemental appendix		Supplemental files 2, 3, 4, 5
Discussion					
Key results	18	Summarise key results with reference to study objectives	Discussion		Discussion; principal findings – p.10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision.	Discussion	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the	Discussion; strengths and

		Discuss both direction and magnitude of any potential bias		specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	weaknesses – p.10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Discussion		Discussion; meaning – p.12
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion		Discussion; how this fits – p.11
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	End of paper		p.13
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Publicly accessible data via HMD, other data (calculated mortality rates) will be uploaded to Dryad

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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Recent adverse mortality trends in Scotland: comparison with other high-income countries.

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Abstract

Objective

Gains in life expectancy have faltered in several high-income countries in recent years. Scotland has consistently had a lower life expectancy than many other high-income countries over the past 70 years. We aim to compare life expectancy trends in Scotland to those seen internationally, and to assess the timing and importance of any recent changes in mortality trends for Scotland.

Setting

Austria, Croatia, Czech Republic, Denmark, England & Wales, Estonia, France, Germany, Hungary, Iceland, Israel, Japan, Korea, Latvia, Lithuania, Netherlands, Northern Ireland, Poland, Scotland, Slovakia, Spain, Sweden, Switzerland, USA.

Methods

We used life expectancy data from the Human Mortality Database (HMD) to calculate the mean annual life expectancy change for 24 high-income countries over five-year periods from 1992 to 2016. Linear regression was used to assess the association between life expectancy in 2011 and mean life expectancy change over the subsequent five years. One- and two-break segmented regression models were used to test the timing of mortality rate changes in Scotland between 1990 and 2018.

Results

Mean improvements in life expectancy in 2012-2016 were smallest among females (<2.0 weeks/year) in Northern Ireland, Iceland, England & Wales and the USA and among males (<5.0 weeks/year) in Iceland, USA, England & Wales and Scotland. Japan, Korea, and countries of Eastern Europe had substantial gains in life expectancy over the same period. The best estimate of when mortality rates changed to a slower rate of improvement in Scotland was the year to 2012 quarter 4 for males and the year to 2014 quarter 2 for females.

Conclusion

Life expectancy improvement has stalled across many, but not all, high income countries. The recent change in the mortality trend in Scotland occurred within the period 2012-2014. Further research is required to understand these trends, but governments must also take timely action on plausible contributors.

Key Words

Mortality, Life expectancy, Scotland, Europe, International, trend, austerity, influenza.

Article summary

Strengths and limitations of this study

- The use of five-year time periods for comparison of life expectancy changes reduces the influence of year-to-year variation on observations.
- Examining long-term trends addresses concerns that recent life expectancy stalling may be over-emphasised due to notably large gains in the immediately preceding period.
- The international comparison was limited to the 24 high-income countries for which data were readily available for the relevant period.
- Segmented regression provides a means of identifying the timing of a change in the trend.

Background

Mortality rates have steadily declined, and life expectancy has improved, in most high-income countries since 1945.[1,2] There have been exceptions to this trend, for example in Russia and the Baltic states where life expectancy declined steadily from the 1960s, and then fell more dramatically in the 1990s.[1,3] Recent reports indicate that mortality improvements have been faltering, or reversing, in the USA, the UK, and much of continental Europe, since around 2011.[4–7]

Since 1950, life expectancy trends in Scotland have followed a trajectory between slower improvements in Eastern Europe and faster improvements in Western Europe.[1] Scotland has relatively wide socioeconomic health inequalities and additional premature mortality beyond that expected for the level of deprivation.[8] Among the UK countries, Scotland has the lowest life expectancy; 2.0 years lower for women, and 2.5 years lower for men than England in 2015-2017.[9] The causes of the higher mortality and wider health inequalities in Scotland have been summarised as historical vulnerability combined with the changed politics from the 1980s onwards.[8] Existing analyses suggest that Scotland has experienced a smaller stalling in life expectancy gains than England and Wales, since 2011, but the scale of this difference, in an international context, is not clear.[7]

International comparison of changes in life expectancy across a single year (2014 to 2015) found that life expectancy declined in 11 and 12 of 18 high income countries, for men and women respectively, including the UK.[4] However, the short-run trends in mortality data, even at national level, can vary substantially and observations may therefore be sensitive to the comparison period.[10] Comparison of the most recent six years to the preceding six years found that, of 20 countries, the UK experienced the largest life expectancy slow-down for females, and the second largest for males.[5] This, however, does not allow identification of which period was exceptional: the previous gains or the current slow-down.

Describing the patterning of recent mortality trends can help understanding of the scale of the problem and identify comparator countries or periods to assist future investigation of causal hypotheses. There has been an apparent polarisation of the debate regarding causes of recent adverse mortality trends, between explanations emphasising influenza, and those concerned with the impacts of austerity.[11–14] This split may, in part, be attributable to studies seeking the answers to different questions (for example the causes of high numbers of deaths in short periods of time versus stalling of overall life expectancy over longer periods) and in variable comparator, or baseline, periods employed. Cohort effects and interactions between period effects (such as policy changes or infectious disease epidemics) and vulnerabilities within a cohort may also play a role. [2,15] Such interactions have been observed for drug-related deaths and those due to suicide and alcohol in Scotland and the USA.[16,17] Causal investigation would be strengthened by clear description of the nature, scale and timing of the phenomenon we are seeking to explain.

This study aims to describe the nature, scale and timing of changes in mortality in Scotland, and to compare these to those seen internationally, as an early step in understanding their causes.

Methods

We report our results in accordance with the RECORD guideline.[18]

Life expectancy: average annual change in five-year periods

Data on period life expectancy at birth were obtained from the Human Mortality Database (HMD).[19] All high-income countries for which there were data available up to 2016 were included.[a] The mean annual change in life expectancy (in weeks) for five-year periods running back from 2016 to 1992 was calculated for each country (a longer time-series was also undertaken for Scotland alone). Two sensitivity analyses

[a] 24 of 42 HMD countries included. Excluded countries: No data for 2016: Australia, Belgium, Canada, Chile, Finland, Greece, Ireland, Italy, Luxembourg, New Zealand, Norway, Portugal, Slovenia, Taiwan, and Ukraine. Not high-income: Belarus, Bulgaria, and Russia.

were undertaken. First, we recalculated using rolling five-year time periods rather than set periods from 2016 backwards. Second, we excluded 2015 from the mean change in the last time period (making it 2012-2014 plus 2016). We assessed the relationship between life expectancy in 2011 and mean life expectancy gain in the following 5 year using linear regression. All analyses were undertaken for males and females separately.

Age-standardised mortality rates: segmented regression

Directly age-standardised mortality rates per 100,000 population for rolling four-quarter periods for Scotland were calculated (using the 2013 European Standard Population(ESP); upper age group 90+ years) from quarter 1 1990 to quarter 2 2018) from mortality data held by National Records of Scotland (NRS). The 1990 start date was adopted as an acceptable application of the ESP 2013, and to permit comparison with analyses from England.[20] Population estimates were calculated for each four-quarter period by interpolating the mid-year estimates. Data points are labelled by their final quarter, so quarter 1 (Q1) 2016 represents the mortality rate for 2015 Q2, Q3 and Q4 combined with 2016 Q1. Quarterly-rolling rates were used in order to increase the number of data points available to the model.

Segmented regression was undertaken in R using the 'segmented' package.[21,22] The Davies test assessed the existence and statistical significance of a breakpoint, and the segmented test was used to identify the breakpoint and standard error. The results of the segmented test were interpreted as identifying the quarterly data point within which the breakpoint fell. In this way a result of 2014.374 falls within quarter 2 of 2014, and the data which correspond to this quarter represent the 'year' quarter 3 2013 to quarter 2 2014, hence the year to 2014 Q2 is interpreted as the best estimate of when a change in trend occurred. One and two breakpoint models were compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values. Analyses were undertaken separately for males and females and for under 75 year and 75+ year age groups for both sexes, in keeping with the use of the under 75 year age group to calculate premature mortality in the UK.

Patient and public involvement

This research was done without direct patient or public involvement.

Results

Life expectancy trends – 24 high-income countries

The mean annual changes in life expectancy (in weeks), for all 24 high-income countries with HMD data available to 2016, are shown in Figures 1 and 2, for females and males respectively (data are shown in supplemental table 1). The countries are ordered on the size of mean life expectancy change in the most recent period. Nearly all countries saw mean increases in life expectancy across all five-year time periods, with the exceptions being: Northern Ireland (2012-2016), Iceland (1997-2001) Latvia (1992-1996), and Lithuania (2002-2006) among females; and Iceland and USA (2012-2016), Latvia (1992-1996) and Lithuania (1992-1996 and 2002-2006) among males.

For the period 2012-2016 the range of mean life expectancy changes was -1.3 weeks/year to +14.5 weeks/year for females (interquartile range [IQR]: 3.3 to 10.0 weeks/year), and -1.7 to 20.6 weeks/year (IQR 7.8 to 14.0 weeks/year) for males. Mean gains of less than five weeks/year were seen in 9 countries for females, and 4 countries for males. Gains of 10 weeks/year or more were seen in 4 countries for females, and 14 countries for males. For both sexes, the mean annual increases were smaller in 2012-2016 than over 2007-2011 for nearly all countries, with Japan a notable exception for both sexes. When 2015 is excluded from the latest time period the stalling effect is less marked, although the scale of impact of this year varies, and for some countries, notably the USA this exclusion had little effect (supplemental figures 1 and 2).

In Scotland over the period 2012-2016 mean life expectancy improvements of 2.5 weeks/year for females and 4.5 weeks/year for males were observed. This represents the smallest average annual increase for women since 1937-41, and for men since 1972-76 (see supplemental figure 3). A sensitivity analysis (supplemental figure 4) using rolling five-year periods identifies similar periods of slow life expectancy gain, showing results are not dependent on the selection of particular start and finish years.

The relationship between starting life expectancy in 2011 and subsequent mean annual change in life expectancy (in weeks) from 2012-2016 is shown in figure 3, for males and females separately, and for each of the countries considered. This indicates that subsequent life expectancy gains tended to be slightly smaller in countries that had higher life expectancies in 2011, but this relationship is very weak, especially for females, where the R-squared value is 0.05.

Figure 1 - Mean annual change in female life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

Figure 2 - Mean annual change in male life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

Figure 3 - Life expectancy in 2011 (years) and mean change in life expectancy 2012-2016 (weeks), for 24 high income countries, by sex.

Segmented regression - Scotland

Rolling, four-quarter, age standardised mortality rates (ASMRs), by sex, for Scotland for all ages from 1990 Q1 to 2018 Q2, are shown in figure 4. Over the whole period the ASMR per 100,000 population fell from 2,114 to 1,355 for males, and from 1,386 to 1,025 for females. The steadiest period of decline in mortality rates appeared to be from 2004 to around 2011, with the periods before and after this showing greater variation.

As shown in table 1, the Davies test identified a statistically significant change in trend ($p<0.01$) for males and females, and both age groups. For all groups the breakpoint identified by the Davies test fell within the period 2012-2014. The date estimates from the one-break segmented model corresponded to those identified by the Davies test for all groups, to within 0.2 years. One and two-break models were run for all groups; both AIC and BIC were lower for all two-break models, indicating that these are a better fit.

The two-break model for all ages indicated a first breakpoint as the year to 1993 Q4 for both males (95% confidence interval (CI): year to 1992 Q4 - year to 1994 Q4) and females (95% CI: year to 1992 Q1 – year to 1995 Q2). A second breakpoint for males was identified as the year to 2012 Q4 (95% CI: year to 2012 Q1 – year to 2013 Q3), and for females as the year to 2014 Q2 (95% CI: year to 2013 Q2 – year to 2015 Q2). The models are shown in figure 4; the break in 1993 indicates a change from a period of slower mortality improvement to a period of faster improvement and the later breaks in 2012 (males) and 2014 (females) indicate a change to much slower gains.

Among all age groups a later breakpoint changing to slower improvements was identified within the period year to 2012 Q4 and year to 2014 Q2, with the earliest being males aged under 75 years, and the latest females aged under 75 years. Full age-group results are shown in table 1.

Figure 4 – Age-standardised rolling four-quarterly mortality rates for men and women in Scotland, with segmented regression models fitted, 1990-2018.

Table 1: Summary of results of segmented regression by population group and model/test

Population group	Model/test	Breakpoint	Lower 95% confidence interval	Upper 95% confidence interval	P-value	Additional breakpoint	Lower 95% confidence interval	Upper 95% confidence interval	AIC	BIC
Male all age	Davies test	2013.7			<0.00001					
Male all age	Segmented: one break	2013.8	2012.9	2014.6					1151	1164
Male all age	Segmented: two break	2012.8	2012.0	2013.6		1993.8	1992.8	1994.9	1140	1097
Female all age	Davies test	2014.4			<0.00001					
Female all age	Segmented: one break	2014.3	2013.3	2015.5					1083	1159
Female all age	Segmented: two break	2014.4	2013.4	2015.4		1993.9	1992.2	1995.5	1063	1082
Male <75 yrs	Davies test	2013.5			<0.00001					
Male <75 yrs	Segmented: one break	2013.5	2012.8	2014.1					874	888
Male <75 yrs	Segmented: two break	2013.0	2012.5	2013.5		1994.1	1993.3	1995.0	835	735
Female <75 yrs	Davies test	2012.5			<0.00001					
Female <75 yrs	Segmented: one break	2012.5	2011.9	2013.2					722	854
Female <75 yrs	Segmented: two break	2014.4	2013.7	2015.1		2005.9	2003.0	2008.7	709	728
Male 75+yrs	Davies test	2014.2			<0.0001					
Male 75+yrs	Segmented: one break	2014.1	2013.0	2015.2					1578	1592
Male 75+yrs	Segmented: two break	2012.7	2011.5	2013.9		1993.6	1992.3	1994.9	1561	1580
Female 75+yrs	Davies test	2014.4			0.0087					
Female 75+yrs	Segmented: one break	2014.6	2012.5	2016.6					1536	1549
Female 75+yrs	Segmented: two break	2011.7	2010.2	2013.3		2004.3	2002.0	2006.7	1520	1539

Discussion

Principal findings

Of the 24 high-income countries for which data were available, nearly all had smaller life expectancy gains in 2012-2016 than in the preceding 5-year period. Japan and Korea are notable exceptions; in Japan there was a substantial slow-down in life expectancy gains in the period 2007-2011 (almost certainly explained by the 18,000 direct deaths from the 2011 earthquake and tsunami)[23], followed by a resumption of gains at the level previously seen.

Among the countries with a stalling of life expectancy gains in 2012-2016 there is large variation in the mean change observed, and in the scale of the difference between periods. Iceland, the USA, England & Wales, Scotland, and, for females, Northern Ireland, had the smallest gains in 2012-2016 and the most marked stalling. In general, the countries of Western Europe saw smaller gains in 2012-2016, with some degree of slow-down, compared to countries of Eastern Europe, where steadier gains have been maintained. Denmark is notable for having maintained mean life expectancy gains of around 10 weeks/year among females across the period 1997-2016, and even greater gains among males. In Scotland the life expectancy gains between 2012 and 2016 are amongst the smallest seen since the 1970s.

Scotland has had marked stalling in spite of a comparatively low life expectancy in 2011, and there is a generally weak relationship between life expectancy and mean life expectancy gains internationally. This suggests that recent adverse mortality trends are not due to any 'natural' long-term tendency for life expectancy gains to slow down in high-income countries.

The two-break segmented regression model of Scottish mortality rates, indicates that mortality trends changed to a pattern of more rapid improvement for both males and females in the year to 1993 Q4. In the year to 2012 Q4 for males, and the year to 2014 Q2 for females, the trend in mortality rates changes again, with an increase in mortality thereafter. For all the models and groups tested, a negative turning point in mortality rates was consistently identified within the period 2011 to 2015.

Strengths and weaknesses

Using life expectancy and age-standardised mortality rates ensured that our analyses were not prone to confounding by changes in the age structure of the population. We used all-cause mortality rates, thus avoiding difficulties due to competing causes of death and coding uncertainties. We performed sensitivity analyses on the periodisation of the average gain in life expectancy comparisons to identify the potential for the findings to be affected by the selection of a particular start date for the analyses.

Whilst other studies have focused on changes in mortality between single years (particularly 2014 to 2015), we were explicit in seeking to describe the longer-term mortality trends, and therefore employed five-year time periods for comparison to reduce the influence of year-to-year variation on observations. By extending life expectancy gain comparisons back over a longer time period we have sought to address concerns that the stalling of life expectancy in the most recent period may be over-emphasised due to notably large gains in the immediately preceding period. Our results using a longer time period show that such concerns are unfounded.

The use of life expectancy estimates from the HMD allowed international comparison; for Scotland these single-year data differ slightly from life expectancy estimates of NRS which use 3-year averages. The international analysis is limited to the range of countries for which data were available through the HMD. We adopted the broad inclusion criteria of data availability and income level, in order to avoid any selection bias, and did not group or ascribe mortality characteristics to countries in advance of analysis. Thus several countries of Eastern Europe were included, which experienced a well-described decline and then recovery in life expectancy from the early 1990s.[24] It is possible that some of the recent faster improvements in Eastern Europe may be due to 'catch-up' following the ending of a negative exposure, however it is also instructive to find that these countries seem to be less affected by the recent stalling.

The segmented regression analysis was limited to Scotland, as we did not have access to equivalent mortality data for other countries. We acknowledge that the confidence intervals presented for segmented regression may underestimate the true uncertainty, as the nature of the rolling quarterly mortality rates means that the data points aren't discrete.

How this fits

Our overall findings are consistent with those of others, and the recent stalling of life expectancy gains across many high-income countries is now well recognised. [4,5] [6] Other analyses have emphasised the reduction in mortality improvements relative to those seen in the immediately preceding period.[4,5] We have shown that relatively large life expectancy gains were seen for both males and females in Scotland in the preceding 15 years (1997-2011), but that even before this gains as small as those seen recently have not been observed since at least the early 1970s. Comparison of mortality trends within the UK suggests that the stalling seen in Scotland is not as severe as that seen in England and Wales.[7] Our findings confirm this, but allow us to place this difference within a wider international context which shows that the changes seen in Scotland are still more severe than those observed in many other high-income countries, and are particularly concerning given the higher starting levels of mortality. The timing of a change in overall mortality trends found in this analysis is broadly consistent with that observed in England, where a breakpoint for females was found in the year to 2014 Q2, and the year to 2012 Q1 for males.[20]

The recent slowdown in improving life expectancies in Scotland follows decades of relative health disadvantage in Scotland compared with other affluent countries. A comparison of age-specific mortality rates over time in Scotland compared with England & Wales found a growing disadvantage in mortality in younger working age since the 1980s, disproportionately affecting males, as well as persistent disadvantages at older ages, disproportionately affecting females.[25] Increased rates and inequalities in suicide and drug-related deaths have been observed in young adults, and patterns of cause-specific death by age and year indicative of a cohort effect, with elevated hazards for cohorts who entered the labour market after the 'neoliberal' labour market reforms of the 1980s than for earlier cohorts, suggesting political economy as an underlying explanatory factor.[26] High rates of alcohol-related deaths, and steep socioeconomic gradients, also emerged over the 1990s and 2000s, affecting slightly older working ages. Scotland also has relatively high rates of deaths from circulatory disease in older ages, though trends in ischaemic heart disease have been improving since the early 1990s.[27]

The greatest contributions to the recent changes in life expectancy are due to worsening rates of drug-related deaths, sharp slowdowns in improvements in

circulatory diseases, and rising rates of deaths attributed to dementias and Alzheimer's Disease.[28]

Meaning – explanations and implications
Various hypotheses have been proposed to explain recent adverse trends, in particular the period effects of influenza and of economic austerity, and cohort effects, such as the mortality risk of cohorts with a high prevalence of obesity. Many of these hypotheses are not mutually exclusive, but that does not mean that all the factors suggested are causal or have the same importance. It is possible that influenza and political economy explanations are both causal, with interactions between population vulnerability, social and health care pressures, and influenza. It seems likely that factors common to all of the countries displaying similar trends, and absent in countries without the change in trend, are causal, and also likely that several factors acting together are relevant to explaining the trends.

The global financial crisis of 2008 led to a marked economic recession in many countries, and given that unemployment and income are important determinants of health,[29] the potential for the crisis to adversely impact on mortality was highlighted early.[30] However, the evidence around the impact of economic recession on health and mortality of populations, rather than individuals, is complex and contested.[31] The response to the financial crisis, across many countries, was to implement a range of austerity policies whereby public spending was reduced in the pursuit of balanced budgets. As a result many public services experienced substantial reductions in their budgets and public sector wages and income transfers to lower income groups were frequently reduced in real terms. There is good evidence now available that this impacted negatively on mortality rates and self-rated health.[32–34] It seems less plausible that the trends can be explained as a natural limit to life expectancy, since there is continued improvement in some of the countries with the highest life expectancies, such as Japan.[35]

Unanswered questions and further research
Further descriptive work is required on the contribution of different causes of death, age-specific components and inequalities to the trends in Scotland. We also need to understand the degree to which the relatively rapid improvements across the UK during the late 1990s and 2000s were unusual. Work to understand the theoretical interaction of different hypothesised causes, and to test these theories is urgently required.

Conclusion

Between 2012 and 2016 the rate of improvement in mortality markedly slowed across many high-income countries, and particularly in England & Wales, the USA, Scotland, Iceland and Northern Ireland. The timing of the change in mortality trend in Scotland for all ages is estimated for men in the year to 2012 Q4 and for women in the year to 2014 Q2. Further research is required to test the range of theories for the causes of these trends, but in the meantime, governments at all levels should take action to ensure effective public services, adequate incomes, health and social care services and influenza vaccination programmes are in place.

Competing interests

The authors declare that they have no competing interests. No funding was received for this work.

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Contributorship statement
LF and GM conceived the idea for this study. LF and JM undertook the analyses. JR and MK provided data for the segmented regression analysis. GM drafted the manuscript. CF and GW, along will all other authors made substantial contributions to interpretation of results and editing the manuscript, and all approved the final draft.

Data availability statement
Life expectancy data used for these analyses are publicly available via the Human Mortality Database at https://www.mortality.org/. Quarterly-rolling age-standardised mortality rates used for the segmented regression are available on request from lynda.fenton@nhs.net.

Extra data can be accessed via the Dryad data repository at http://datadryad.org/ with the doi: 10.5061/dryad.hc627cj

Ethics
No new data were collected in this study and there was no public or patient involvement. We used mortality data made available to us by National Records of Scotland and adhered to our standard procedures to protect against disclosure.

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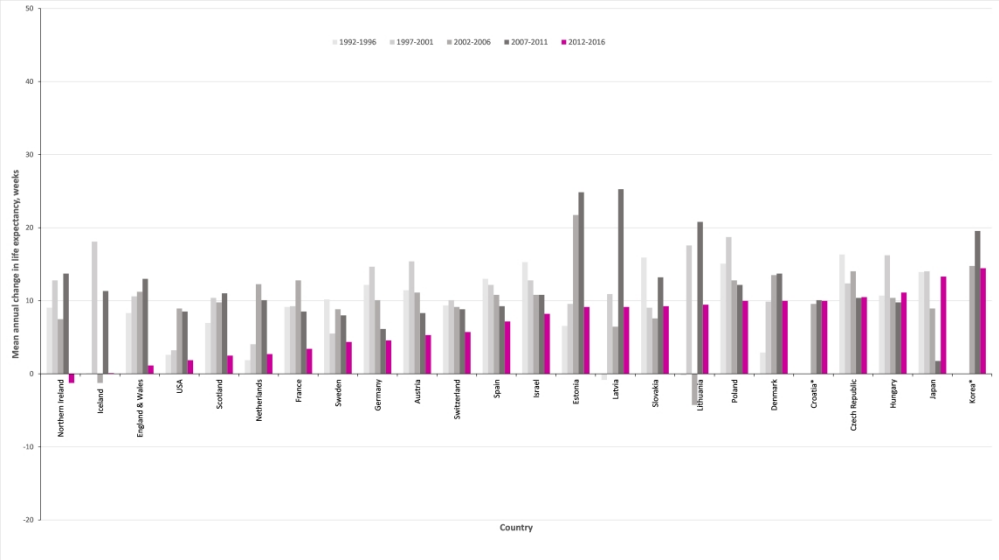

Figure 1 - Mean annual change in female life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

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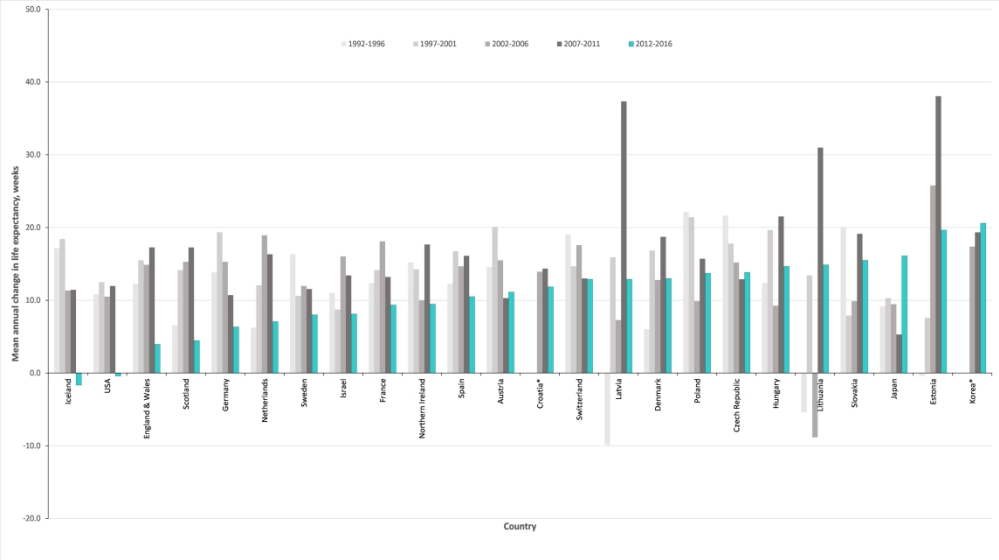

Figure 2 - Mean annual change in male life expectancy at birth (weeks), for five-year periods 1991-2016, by country. Countries are ordered on size of mean life expectancy change in the most recent period (2012-2016).

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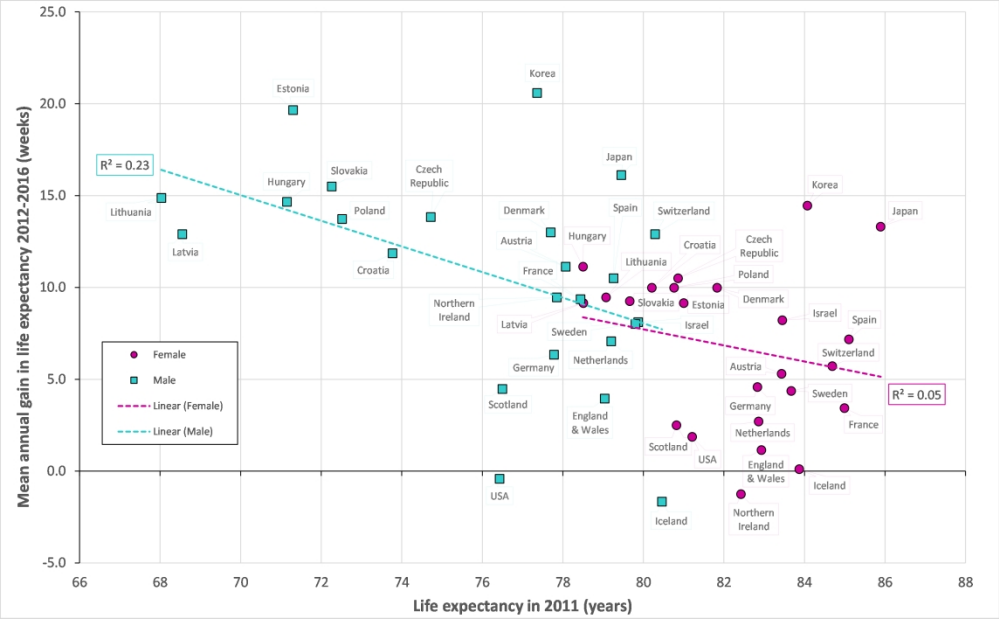

Figure 3: Life expectancy in 2011 (years) and mean change in life expectancy 2012-2016 (weeks), for 24 high income countries, by sex.

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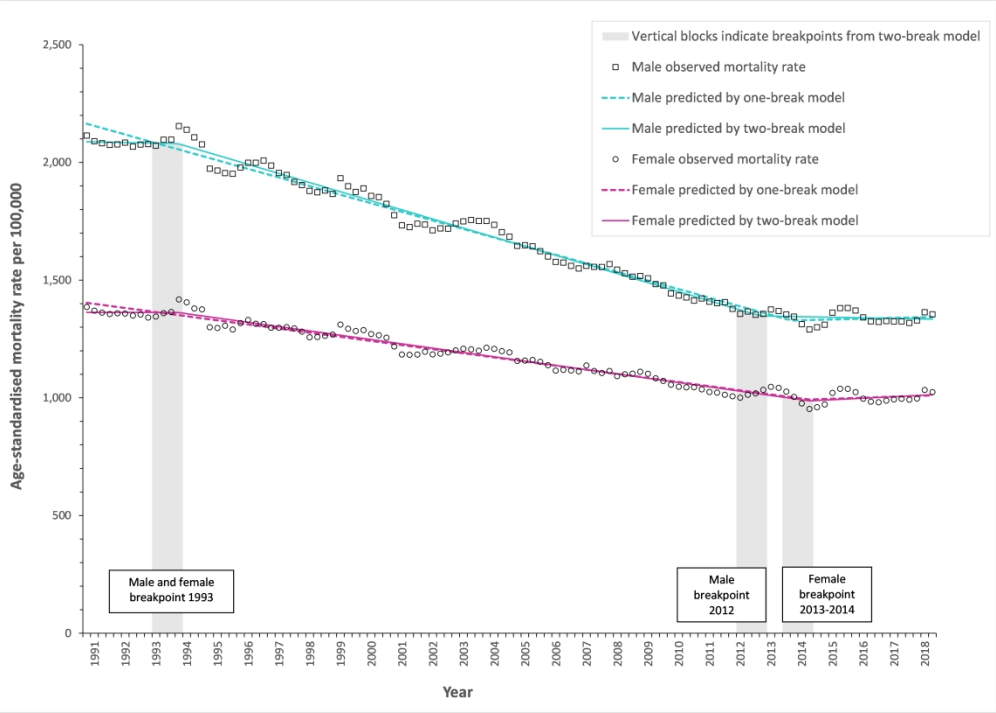
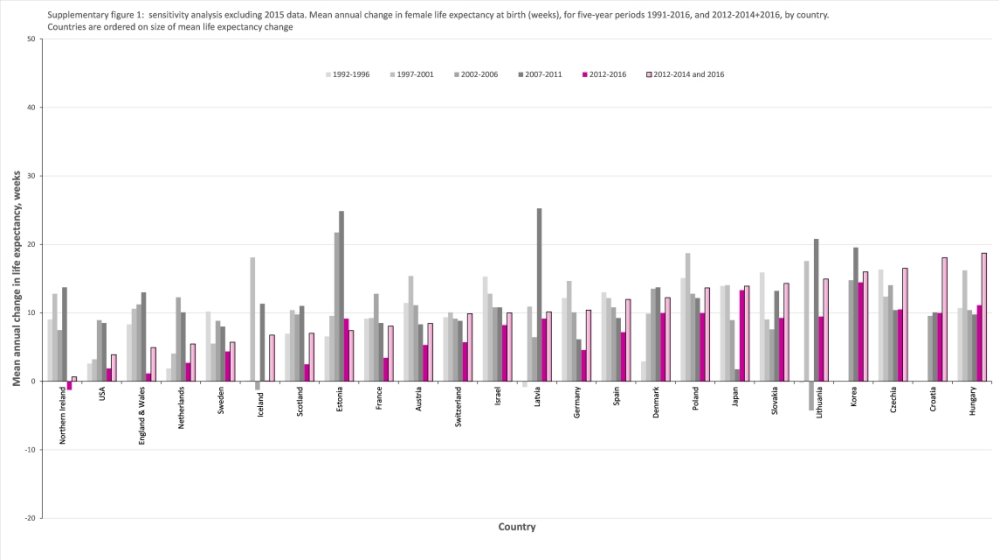


Figure 4: Age-standardised rolling four-quarterly mortality rates for men and women in Scotland, with segmented regression models fitted, 1990-2018.

336x239mm (300 x 300 DPI)



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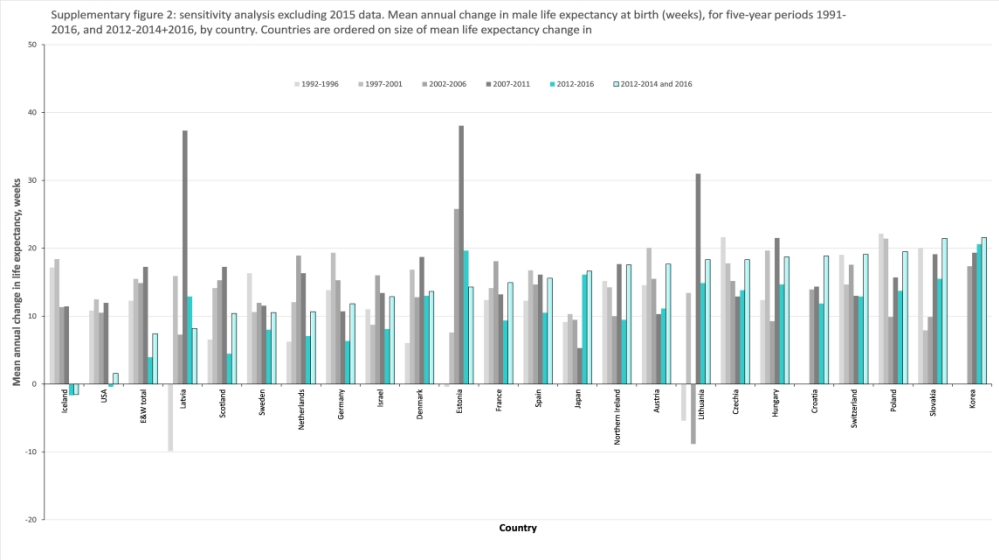

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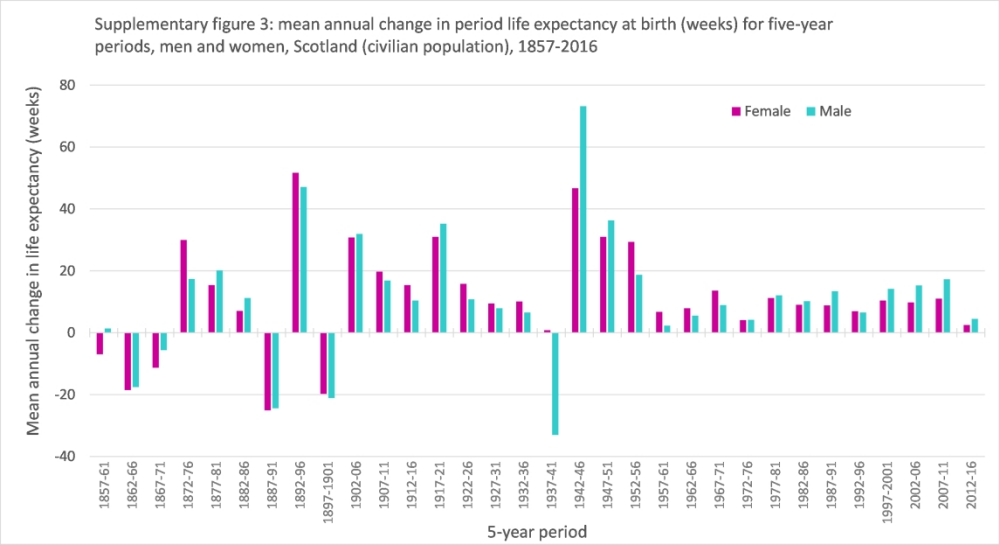

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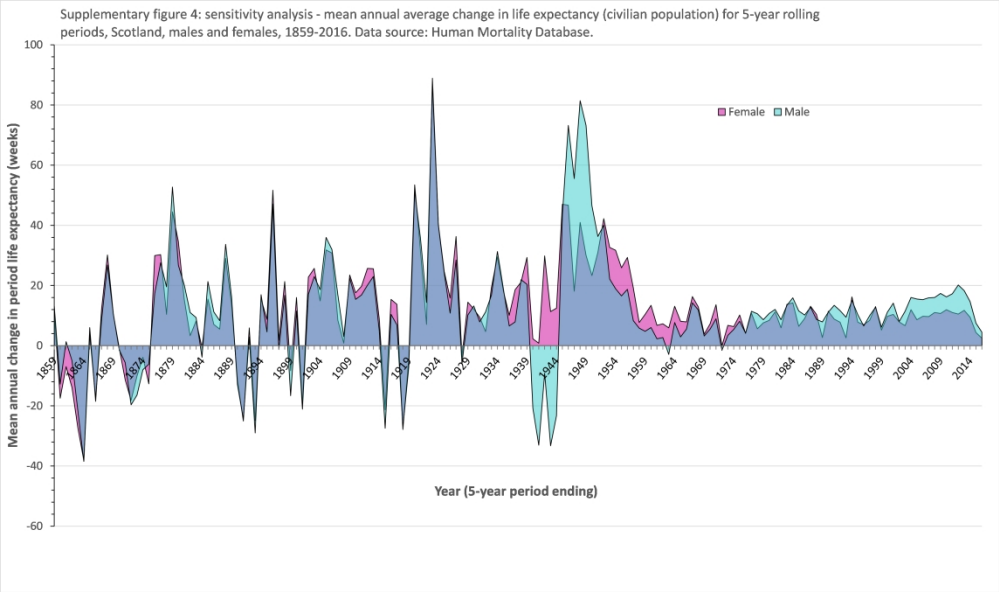

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Supplementary table 1: mean annual change in life expectancy at birth (weeks), for five-year periods 1992-2016, for females and males, by country.

Female					
Country	**1992-1996**	**1997-2001**	**2002-2006**	**2007-2011**	**2012-2016**
Northern Ireland	9.0	12.8	7.5	13.7	-1.2
Iceland	0.1	18.1	-1.2	11.3	0.1
England & Wales	8.3	10.6	11.2	13.0	1.1
USA	2.6	3.2	8.9	8.5	1.9
Scotland	7.0	10.4	9.8	11.0	2.5
Netherlands	1.9	4.1	12.3	10.1	2.7
France	9.2	9.3	12.8	8.5	3.4
Sweden	10.2	5.5	8.8	8.0	4.4
Germany	12.2	14.7	10.1	6.1	4.6
Austria	11.4	15.4	11.1	8.3	5.3
Switzerland	9.4	10.1	9.2	8.8	5.7
Spain	13.0	12.2	10.8	9.3	7.2
Israel	15.3	12.8	10.8	10.8	8.2
Estonia	6.6	9.6	21.7	24.9	9.2
Latvia	-0.8	10.9	6.4	25.3	9.2
Slovakia	15.9	9.0	7.6	13.2	9.3
Lithuania	-0.2	17.6	-4.3	20.8	9.5
Poland	15.1	18.7	12.8	12.2	10.0
Denmark	2.9	9.9	13.5	13.7	10.0
Croatia*	0.0	0.0	9.6	10.1	10.0
Czech Republic	16.3	12.4	14.0	10.4	10.5
Hungary	10.7	16.2	10.4	9.8	11.1
Japan	13.9	14.0	8.9	1.8	13.3
Korea*	0.0	0.0	14.8	19.6	14.5
Male					
Iceland	17.2	18.4	11.3	11.4	-1.7
USA	10.8	12.5	10.5	12.0	-0.4
England & Wales	12.3	15.5	14.9	17.3	4.0
Scotland	6.6	14.1	15.3	17.3	4.5
Germany	13.8	19.3	15.3	10.7	6.3
Netherlands	6.2	12.1	18.9	16.3	7.1
Sweden	16.3	10.6	12.0	11.5	8.0
Israel	11.0	8.7	16.0	13.4	8.1
France	12.4	14.1	18.1	13.2	9.4
Northern Ireland	15.2	14.2	10.0	17.7	9.5
Spain	12.3	16.7	14.7	16.1	10.5
Austria	14.6	20.1	15.5	10.3	11.1
Croatia*	0.0	0.0	13.9	14.4	11.9
Switzerland	19.0	14.7	17.6	13.0	12.9
Latvia	-9.9	15.9	7.3	37.3	12.9
Denmark	6.0	16.8	12.8	18.7	13.0
Poland	22.2	21.4	9.9	15.7	13.7
Czech Republic	21.6	17.8	15.2	12.9	13.8
Hungary	12.4	19.7	9.3	21.5	14.7
Lithuania	-5.4	13.4	-8.8	31.0	14.9
Slovakia	20.1	7.9	9.9	19.1	15.5
Japan	9.2	10.3	9.5	5.3	16.1
Estonia	-0.4	7.6	25.8	38.1	19.7

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract; methods – p.2 Abstract; setting – p.2 N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Background		Background; paragraphs 1, 2, 4 - p.4
Objectives	3	State specific objectives, including any prespecified hypotheses	Background		Background; paragraph 5 – p.4
Methods					
Study Design	4	Present key elements of study design early in the paper	Abstract, methods		Abstract: methods – p.2 Methods – p.4-5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Abstract, methods		Abstract: setting, methods –p.2 Methods – p.4-5

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	Methods	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Methods	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	N/A
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Methods, Results, supplemental appendix		Methods p.4-5

Bias	9	Describe any efforts to address potential sources of bias	Methods, Supplemental appendix		Methods p.4-5 Discussion; strengths and weaknesses - p. 10-11 Sensitivity analysis – supplemental files 2, 3, 5
Study size	10	Explain how the study size was arrived at	Methods		Methods p.4-5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Methods		Methods p.4-5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	Methods, Supplemental appendix		Methods p.4-5

Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods p.4-5 None
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods p.4-5
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest	Population-wide data, age-standardised, stratified by sex.		n/a – no individual participants

		(c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	Results		Figures 1, 2, 7 Supplemental table 1 Figure 8
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Results		Table 2
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Supplemental appendix		Supplemental files 2, 3, 4, 5
Discussion					
Key results	18	Summarise key results with reference to study objectives	Discussion		Discussion; principal findings – p.10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision.	Discussion	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the	Discussion; strengths and

		Discuss both direction and magnitude of any potential bias		specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	weaknesses – p.10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Discussion		Discussion; meaning – p.12
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion		Discussion; how this fits – p.11
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	End of paper		p.13
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Publicly accessible data via HMD, other data (calculated mortality rates) will be uploaded to Dryad

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.