Age, Period and Cohort Trends in Caries of Permanent Teeth in Four Developed Countries

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ABSTRACT

Objective: To assess the relative influences of age, period and cohort effects on trends in caries experience of permanent teeth in four different populations.

Methods: We used data from England and Wales, United States, Japan and Sweden where a number of cross-sectional, nationally representative surveys have been conducted periodically since the early 1960s. For each country, trends in caries experience (measured using the DMFT index – the number of decayed, missing and filled permanent teeth) were analyzed in an age, period and cohort (APC) analysis using partial least square regression.

Results: There was a strong effect of age on caries experience, independent of period and cohort effects. Caries levels increased from childhood to adolescence and then there was a larger increase in DMFT in adulthood. Compared to the effect of aging, period and cohort effects on caries experience were relatively small. There were decreases in population DMFT scores over time in all countries except Japan. Cohort effects on caries experience displayed a non-linear pattern in all four countries, with slightly lower caries levels among the oldest and the most recent generations.

Conclusion: Despite the marked recent declines in caries among children, caries levels increased with increasing age and continue to be a major problem in adults. Our analysis casts doubts on the assumption that concentrating prevention of caries mainly on children will lead to major reductions in caries in all ages in the population in the near future.

INTRODUCTION

Dental caries is the single most prevalent chronic condition in the world, affecting slightly over a third of the world's population.[1, 2] Dental caries rates in children have declined dramatically in the past 30 years in most industrialized countries.[3] Therefore, it was assumed by planners that the decline in children would affect all age groups and caries could become a minor dental health problem when the post-1970s cohorts get older. That assumption was not based on a rigorous analysis of the relative influences of age, period or cohort effects on caries trends.

It is a well-established finding that caries increases as people age. Observational population-based studies indicate that most caries occurs in adulthood and not in children. In the best longitudinal study of dental caries to date with several oral examinations through the first half of life and high participation rates, caries progressed inexorably in most participants of the Dunedin study (New Zealand) from age 5 years to 38 years, despite widescale free access to dental care and preventive measures in childhood and adolescence.[4-6] Despite the widely known facts that caries increases as people age, there has never been a detailed analysis of whether the changes in caries levels were more closely related to chronological age, period (year at examination) or cohort (year of birth). The outcome of such an analysis has implications for setting targets and choosing preventive strategies.

Age, period, and cohort effects all refer to some type of time-related variation in the outcome of interest, but they carry distinct substantive meanings.[7] *Age effects* refer to variation associated with different age groups; whether caries risk is greater at younger ages. Thus, age effects reflect the biological and social processes of aging internal to individuals and represent developmental changes across the life course. *Period effects* refer to variation over time periods or calendar years that affect all age groups simultaneously. For example, dental caries is less likely to occur after a particular event (such as the widescale use of fluoride toothpaste since the early 1970s) that affects everybody irrespective of age. Lastly, *cohort effects* refer to variation among groups born in different years. For example, individuals born in Japan during the Second World War were less likely to develop caries during childhood due to food rationing, which included low exposure to sugars.[7, 8]

A clear distinction between age, period, and cohort influences has important implications for both theory and policy. Consistent age variations in a health outcome across time and place reflect the developmental nature of true age changes within individuals. On the other hand, period and cohort effects reflect the influences of social forces. Period variations often result from shifts in social, historical and cultural environments. Cohort variations may reflect the effects of early life exposure to environmental, socioeconomic and behavioral factors that act persistently over time to produce differences in life course health outcomes for specific cohorts.[9, 10] Therefore, analyses that distinguish between the three influences should provide a better understanding and help identify the underlying social and environmental factors that are amenable to modification.[7]

Although only a longitudinal panel study design provides data from true birth cohorts that follow exactly the same individuals over time, the *synthetic cohort approach*, if based on census data or repeated national representative sample surveys, allows for the classic age-period-and-cohort (APC) analysis that traces essentially the same groups of individuals from the same birth cohorts over a segment of the life span.[7] Therefore, it was hypothesized that age effects on caries experience in permanent teeth would be stronger than period and cohort effects. In other words, despite improvements in caries levels seen in recent years (period effects) and in new generations (cohort effects), levels of dental caries increase from childhood to adulthood (age effects). To test that hypothesis, the objective of this study was to assess the relative influences of age, period and cohort effects on trends in caries experience of permanent teeth in four different populations.

MATERIALS & METHODS

Data sources

We used aggregated data from four series of cross-sectional, nationally representative surveys that have been conducted periodically since the early 1960s in different developed countries. The four countries were chosen because of accessibility of data from numerous large representative samples of all ages, comparability of survey methods, and varying levels of caries in the youngest age groups. They all reported caries levels as the number of decayed, missing and filled teeth (DMFT index), which ranges between 0 and 32 teeth. A brief description of each survey is presented below.

England and Wales: The Adult Dental Health Survey (ADHS) is a national cross-sectional survey, first carried out in 1968 and repeated each decade since then. The ADHS covers all the UK, but only England and Wales have participated in all five surveys. Each survey is based on a nationally representative sample of adults, aged 16 and over. The condition of all teeth, including third molars, was recorded during dental examinations. For comparability across surveys, a tooth was defined as decayed if it (i) had cavitated caries lesions; (ii) was so broken down, possibly with pulpal involvement, that was unrestorable; or (iii) has restorations with recurrent cavitated caries or restorations which were lost, broken or damaged.[11-15] The mean DMFT index was obtained for 10-year age groups (from 16-24 to 75+ years) in 1968, 1978, 1988, 1998 and 2009.

United States: The US data were from the 1959/70 National Health Examination Survey (NHES) and the 1971/75, 1988/94 and 1999/04 National Health and Nutrition Examination Surveys (NHANES), conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention.[16] The time of data collection for these surveys roughly corresponds to the decades 1960, 1970, 1990 and 2000, respectively. Each survey is based on a nationwide sample of the civilian, non-institutionalized US population. The examination protocol for dental caries was based on the Radike's criteria and included all teeth. A tooth was considered decayed if it had either a frank (cavitated) or an enamel lesion (visual evidence of demineralization accompanied by tactile surface softness).[17] The mean DMFT index was obtained for 10-year age groups (from 6-14 to 85+ years) in the 1960, 1970, 1990 and 2000.

Japan: The Survey of Dental Diseases has been conducted nationwide every six years from 1957 to 2011 by the Ministry of Health, Labor and Welfare. In each of the ten cross-sectional surveys, representative areas of all prefectures in Japan were randomly selected. All individuals aged 1 year and above, residing in the designated areas, were included. Third molars were excluded from clinical examinations. A decayed tooth was one where a cavity could clearly be seen or a lesion could be felt with an explorer in a pit or fissure, or on a smooth surface.[18, 19] The mean DMFT index was obtained for 10-year age groups (from 5-14 to 85+ years) in 1957, 1963, 1969, 1975, 1981, 1987, 1993, 1999, 2005 and 2011.

Sweden: In 1973, random samples of ages 3, 5, 10, 15, 20, 30, 40, 50, 60 and 70 years were selected from four parishes in Jönköping, a city considered representative of Sweden. New samples from the same parishes and age groups were examined every ten years. From 1983, 80-year-olds were also included. All teeth, excluding third molars, were clinically examined. Dental caries was defined as any loss of mineral in the enamel causing chalky appearance or a carious lesion on previously unrestored or restored surfaces that could be verified as cavities by probing and in which, on probing in fissures using light pressure, the probe stuck. Radiographs were also used to diagnose caries in proximal surfaces.[20, 21] The mean DMFT was obtained for ages 10 to 80 years in 1973, 1983, 1993 and 2003.

Statistical analysis

When exploring trends in health, analyzing the independent effects of age, period and cohort must be taken into consideration.[22] The APC analysis of tabulated data suffers from the identification problem induced by the linear dependency between the three effects (period-age=cohort). The most widely used method to solve the identification problem is to treat each of these effects as a set of dummy variables and impose some restrictions on the model; that is, the effects of at least two age, period or cohort groups are constrained to be equal.[22, 23] However, this approach requires considerable prior knowledge on the equality constraints to be imposed because choice of constraints may yield different estimates but identical model fit.[10, 24] Given these limitations, two novel approaches have been proposed.[10, 25] They are the intrinsic estimator and partial least squares (PLS) regression.[10, 25] They do not use the original collinear covariates in the estimation process but extract weighted components. The outcome is then regressed onto these components, and corresponding regression coefficients are calculated using linear algebra. Although both approaches yielded similar results when used with aggregated data,[25] we chose PLS regression because it allowed for different age and period intervals, and for missing values in some cells.

Analyses were run for each country separately. We first present the crude caries levels by age and period. This is followed by a full APC analysis using PLS regression. Age, period and cohort were centered at the mid-point of their respective interval scales and each converted to a set of indicator (dummy) variables before analysis. Confidence intervals for estimates from PLS regression were obtained using the jackknife method because there is no distribution assumption for PLS regression coefficients. Analyses were undertaken using the XLSTAT (version 2013.3.04, Addinsoft).

We used different approaches to control for the fact that the M component of the DMFT index may be related to teeth extracted for conditions other than caries, particularly among old groups. First, we used extra information from the US series for the DMFT calculation. That ascertained whether teeth had been lost because of caries or other reasons. Second, we conducted supplemental analyses on each of the three components of the DMFT index, namely the numbers of decayed (DT), missing (MT) and filled teeth (FT), to determine their contributions to explaining age, period and cohort trends.

RESULTS

The distribution of caries by age and period for each country is shown in Figure 1. Missing values were present in all surveys except the Japanese series, mainly due to how the oldest group was defined in earlier surveys. In England and Wales, the oldest group was 55+ years until 1978, when it changed to 75+ years. The US surveys conducted in the 1960s and 1970s included only adults up to 79 and 74 years, respectively. The Swedish series only included adults up to 70 years in 1973 but 80 year-olds were included from 1983 to 2003. Two trends are evident in all four countries; first, a marked increase in DMFT is observed with age, and second, the lowest DMFT values are seen among the youngest in more recent surveys (Figure 1).

Table 1 shows the results from the PLS regression carried out with each data series. Since PLS regression coefficients indicate changes in DMFT values from one age group, period, or cohort to the next, they represent DMFT trends along each of these three dimensions, independent of the effects of the other two. A stronger effect of age on DMFT was evident in the four countries (i.e. larger differences across age groups), compared to those of periods and cohorts. Furthermore, the 95% confidence intervals (CI) revealed that several regression coefficients for age effects were statistically significant at the 5% level whereas fewer were significant for cohort and period effects.

Figure 2 reports the fitted DMFT trends with 95% CI by age, period and cohort in each country, calculated from their respective PLS regression model. By inspecting the overlap of the 95% CIs across age groups, it was found that DMFT values significantly increased from childhood to adolescence. Thereafter, there was a larger increase in adults. This was true for all the four countries assessed; the DMFT index increased from 11.4 (95% CI: 8.9-14.0) in 16-24-year-olds to 21.4 (17.8-24.9) in 75+ year-olds in England and Wales, from 5.3 (0.1-10.6) in 6-14-year-olds to 17.9 (14.2-21.5) in 85+ year-olds in the US, from 3.6 (1.6-5.7) in 5-14-year-olds to 24.0 (22.2-25.9) in 75+ year-olds in Japan, and from 7.1 (3.2-11.0) in 10-year-olds to 21.4 (17.6-25.2) in 80-year-olds in Sweden.

Compared to the effects of aging, period and cohort effects on DMFT were relatively small (Figure 2). There were decreases in population DMFT values over time in all countries except Japan. From 18.0 (16.7-19.3) to 15.7 (13.8-17.7) over four decades in England and Wales, from 17.0 (14.4-19.6) to 12.5 (11.0-14.0) over four decades in the US, and from 18.3 (16.7-20.0) to 15.3 (13.5-17.0) over three decades in Sweden. In Japan, caries levels have remained fairly stable since 1957. Cohort effects on caries experience displayed a non-linear pattern in the four countries, with lower caries levels among the oldest and most recent generations assessed.

In analyses by DMFT components (Figure 3), the number of missing teeth (MT) was the main contributor to age, period and cohort trends in England and Wales, United States and Japan, whereas the number of filled teeth (FT) was the main contributor to DMFT trends in Sweden. Compared to the numbers of filled and missing teeth, both of which increased with age, the number of decayed teeth remained fairly stable across ages suggesting that new caries lesions continued to develop in adults and that the caries was subsequently treated with either dental fillings (FT) or extractions (MT).

DISCUSSION

This study shows that age effects on caries experience in permanent teeth, as assessed by the DMFT index, were stronger than those of period and cohort. The major caries problem occurs in adults, not in children, and there is an unabating increase in caries as people get older. This pattern of large increases in caries with age, as opposed to relatively small declines across time and generations, was observed in all the four countries evaluated. Our findings conform to those from the Dunedin longitudinal study where adults had much higher levels of caries than when they were children.[4-6]

The finding that the DMFT increased with age may not be surprising, as caries is cumulative and chronic in nature and the DMFT measures past and present caries experience. However, the fact that the DMFT is a cumulative index does not mean it cannot remain stable over time, indicating that no further caries has developed. As shown in Figure 3, there must have been some caries activity for the DMFT to increase regardless of whether caries was treated or not later in life. Once a particular tooth is diagnosed as DMFT, any subsequent treatment will not change its status. The number of surfaces affected (DMFS) may increase, but not the DMFT. Adults are indeed a caries-active group, with incidence rates at least as great as that of children and adolescents.[4, 26-29] Our findings also indicate that caries is occurring later than in previous decades, as reported by Poorterman et al.[30]

Our findings cast doubt on a widespread assumption about the dramatic caries decline among children in the four countries since the widespread availability of fluoride toothpastes starting in the 1970s. It is assumed that the low levels of caries will continue to be manifested as the children become young adults and middle-aged. However, contrary to this belief, as shown in this study, caries levels increased with increasing age and continue to be a major problem in adults.

The present findings have major implications for policy. Dental caries is not only the single most common disease worldwide,[1, 2] but it is among the top 35 causes of years lived with disability globally[1] and is the fourth most expensive chronic disease group to treat according to the WHO,[31] more expensive than obesity. The US is projected to spend $122 billion treating dental disease in 2014.[32] Dental caries therefore places a major financial burden on both individuals and health care systems.[33] The dominant strategy that dentistry has adopted worldwide is to promote prevention directed mainly at children, with WHO international goals for improving oral health set mainly for children aged 6 and 12 years,[34] on the assumption that if caries can be prevented in them, the high burden of dental disease will be markedly reduced in all age groups. Based on findings presented here on the unabating increase in caries rates with age in four developed countries, some with well organized dental prevention programs directed at children, and high levels of use of fluoride toothpastes, more attention should be directed at preventing caries at all stages of the lifecourse and at addressing the main cause of caries, namely sugars consumption, and the social determinants of chronic diseases affected by sugars, such as obesity and diabetes.

Some limitations of this study need to be addressed. First, we used age-by-period tables from each country, which may raise concerns about generalizability of results to the source populations. Conventional APC analysis focuses on modeling data at the population level, only using tables with aggregated data.[7, 24] Furthermore, similar APC trends were found when modeling population- or individual-level data on verbal ability scores,[23] supporting the validity of using tabular data for APC analysis. Second, we based our analysis on repeated cross-sectional survey data rather than longitudinal panel data. Although it is preferable to use data from successive birth cohorts when exploring APC effects, such information is rarely available. Most researchers thus rely on synthetic cohorts to perform APC analysis.[7] Third, as our aim was to identify APC changes in caries experience rather than explain those changes across periods or cohorts, the APC model did not include any other covariates. Fourth, even though we found similar APC effects across the four countries evaluated, they all are developed countries. Thus, findings are not applicable to all populations. Fifth, we used the DMFT index as our primary outcome measure, which has a number of limitations.[35] However, the index is well established as the key measure of caries experience in dental epidemiology. Further studies, using individual-level data from successive birth cohorts in different countries, should explore the drivers of changes in caries trends.

CONCLUSIONS

Despite the marked recent declines in caries among children in industrialized countries, caries levels increased with increasing age and continue to be a major problem in adults. Our analysis cast doubts on the assumption that concentrating prevention of caries mainly on children, will lead to major reductions in caries in the whole population. It would be relevant to explore what determinants cause the continuous increase in the DMFT with age.

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CONTRIBUTOR STATEMENT

AS conceived the study and EB performed data analysis and drafted the first version of the article. Both authors contributed equally to the reviewing and editing of the article.

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HUMAN PARTICIPANT PROTECTION

Not applicable

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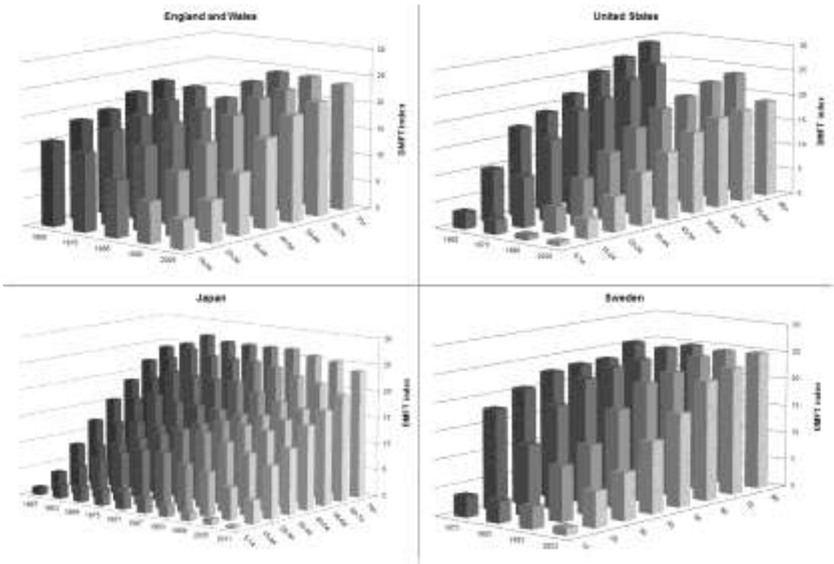
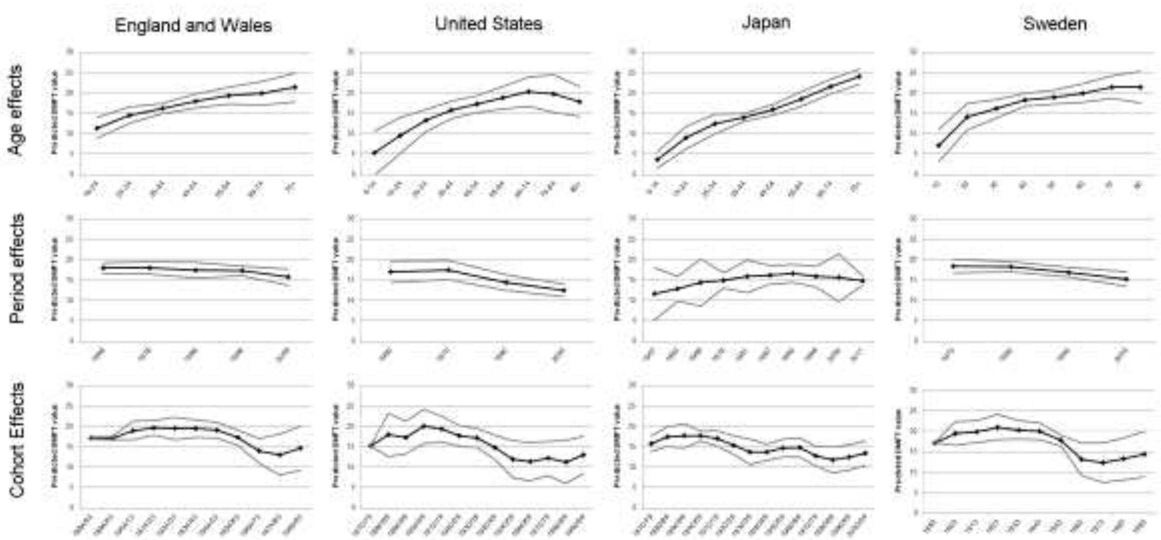
Table 1. Age, period and cohort effects on caries experience in permanent teeth in four countries

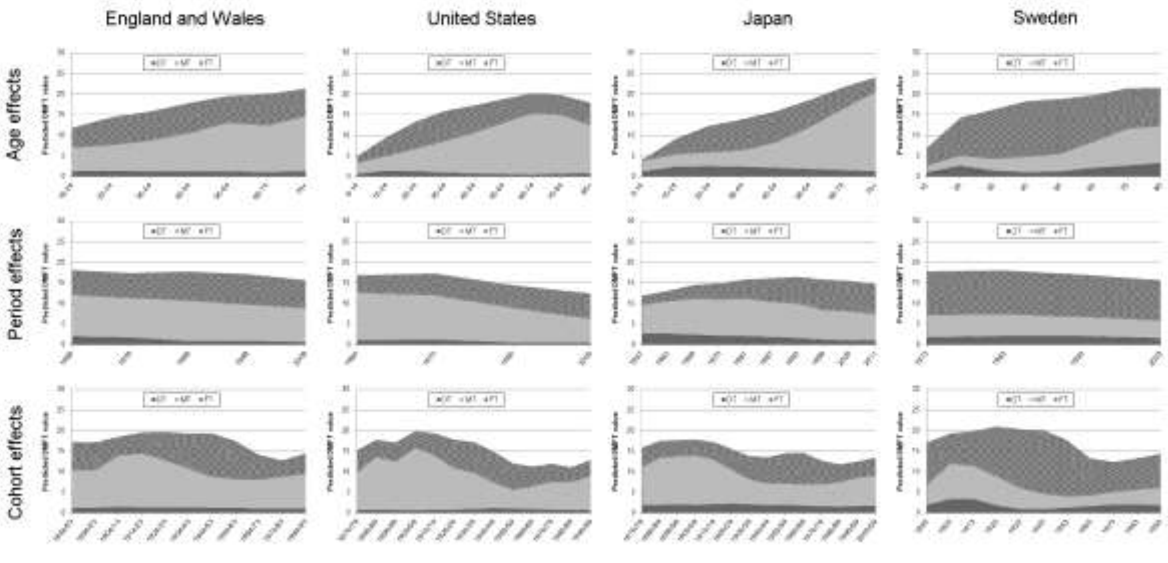
Age	Coef.	(95% CI)	Period	Coef.	(95% CI)	Cohort	Coef.	(95% CI)
				England and Wales				
16-24	-5.82	(-8.34, -3.30)	1968	0.71	(-0.61, 2.02)	1884/93	-0.10	(-0.32, 0.12)
25-34	-2.70	(-4.68, -0.72)	1978	0.67	(-0.83, 2.17)	1894/03	-0.20	(-0.57, 0.17)
35-44	-1.10	(-2.34, 0.14)	1988	0.18	(-1.81, 2.16)	1904/13	1.75	(-0.47, 3.97)
45-54	0.78	(-0.93, 2.48)	1998	-0.02	(-1.22, 1.18)	1914/23	2.40	(0.59, 4.20)
55-64	2.08	(-0.03, 4.18)	2009	-1.54	(-3.51, 0.44)	1924/33	2.23	(-0.50, 4.97)
65-74	2.66	(-0.20, 5.52)				1934/43	2.18	(0.05, 4.31)
75+	4.11	(0.56, 7.65)				1944/53	1.84	(-0.11, 3.80)
						1954/63	-0.01	(-1.84, 1.82)
						1964/73	-3.26	(-6.30, -0.22)
						1974/83	-4.19	(-9.24, 0.87)
Intercept	17.27					1984/93	-2.64	(-8.01, 2.73)
				United States				
6-14	-10.08	(-15.45, -4.70)	1960	1.66	(-0.95, 4.27)	1870/79	-0.08	(-0.25, 0.10)
15-24	-5.73	(-10.10, -1.36)	1970	2.07	(-0.30, 4.44)	1880/89	2.59	(-2.66, 7.84)
25-34	-2.07	(-4.72, 0.57)	1990	-0.89	(-2.81, 1.02)	1890/99	1.90	(-2.09, 5.89)
35-44	0.49	(-1.61, 2.59)	2000	-2.84	(-4.32, -1.35)	1900/09	4.66	(0.45, 8.87)
45-54	1.93	(-0.16, 4.01)				1910/19	4.03	(0.87, 7.19)
55-64	3.49	(0.77, 6.21)				1920/29	2.38	(-0.17, 4.92)
65-74	4.95	(1.38, 8.52)				1930/39	1.81	(-0.48, 4.10)
75-84	4.49	(-0.17, 9.16)				1940/49	-0.48	(-3.43, 2.46)
85+	2.53	(-1.13, 6.19)				1950/59	-3.37	(-7.89, 1.14)
						1960/69	-3.95	(-8.65, 0.75)
						1970/79	-3.18	(-7.38, 1.02)
						1980/89	-4.06	(-9.34, 1.23)
Intercept	15.34					1990/99	-2.25	(-6.80, 2.30)
				Japan				
5-14	-11.25	(-13.26, -9.23)	1957	-3.28	(-9.71, 3.15)	1870/79	0.91	(-1.04, 2.86)
15-24	-5.83	(-8.63, -3.04)	1963	-2.00	(-5.00, 0.99)	1880/89	2.61	(0.18, 5.03)
25-34	-2.45	(-4.90, 0.01)	1969	-0.51	(-6.29, 5.28)	1890/99	2.79	(-0.14, 5.71)
35-44	-0.87	(-1.83, 0.09)	1975	0.03	(-1.86, 1.92)	1900/09	2.79	(1.59, 3.98)
45-54	0.98	(-0.37, 2.32)	1981	1.05	(-2.96, 5.07)	1910/19	2.13	(0.21, 4.06)
55-64	3.62	(1.85, 5.38)	1987	1.35	(-0.89, 3.60)	1920/29	0.54	(-1.77, 2.84)
65-74	6.66	(4.86, 8.46)	1993	1.74	(-0.44, 3.91)	1930/39	-1.09	(-4.15, 1.96)
75+	9.14	(7.30, 10.97)	1999	1.00	(-1.53, 3.53)	1940/49	-1.22	(-3.18, 0.74)
			2005	0.72	(-5.17, 6.60)	1950/59	-0.14	(-2.33, 2.06)
			2011	-0.10	(-1.22, 1.01)	1960/69	-0.09	(-2.39, 2.22)
						1970/79	-2.17	(-4.59, 0.25)
						1980/89	-3.13	(-6.27, 0.01)
						1990/99	-2.45	(-5.58, 0.68)
Intercept	14.89					2000/09	-1.48	(-4.52, 1.57)
				Sweden (Jonkoping county)				
10	-10.10	(-14.05, -6.16)	1973	1.14	(-0.51, 2.80)	1893	-0.03	(-0.09, 0.04)
20	-2.99	(-6.20, 0.21)	1983	1.06	(-0.23, 2.36)	1903	2.27	(-0.60, 5.13)
30	-1.04	(-3.33, 1.24)	1993	-0.26	(-1.46, 0.93)	1913	2.79	(0.07, 5.50)
40	1.11	(-0.46, 2.69)	2003	-1.94	(-3.72, -0.17)	1923	3.85	(0.76, 6.93)
50	1.82	(0.12, 3.51)				1933	3.20	(0.89, 5.51)
60	2.75	(0.49, 5.01)				1943	2.86	(0.73, 4.98)
70	4.26	(1.48, 7.05)				1953	0.63	(-0.69, 1.95)
80	4.20	(0.35, 8.04)				1963	-4.09	(-8.08, -0.09)
						1973	-4.81	(-9.64, 0.02)
						1983	-3.93	(-9.07, 1.21)
Intercept	17.20					1993	-2.73	(-8.33, 2.87)

Coefficients for age, period and cohort effects were calculated from partial least squares regression. Grey cells indicate significant coefficients.

List of Figures:






England and Wales
United States
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Age effects
Period effects
Cohort effects