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MORTALITY

Why did Danish women's life expectancy stagnate? The influence of interwar generations' smoking behaviour

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Abstract The general health status of a population changes over time, generally in a positive direction. Some generations experience more unfavourable conditions than others. The health of Danish women in the interwar generations is an example of such a phenomenon. The stagnation in their life expectancy between 1977 and 1995 is thought to be related to their smoking behaviour. So far, no study has measured the absolute effect of smoking on the mortality of the interwar generations of Danish women and thus the stagnation in Danish women's life expectancy. We applied a method to estimate age-specific smoking-attributable number of deaths to examine the effect of smoking on the trends in partial life expectancy of Danish women between age 50 and 85 from 1950 to 2012. We compared these trends to those for women in Sweden, where there was no similar stagnation in life expectancy. When smoking-attributable mortality was excluded, the gap in partial life expectancy at age 50 between Swedish and Danish women diminished substantially. The effect was most pronounced in the interwar generations. The major reason for the stagnation in Danish women's partial life expectancy at age 50 was found to be smoking-related mortality in the interwar generations.

Keywords Life expectancy · Smoking · Interwar Danish women · Cohort effects · Age decomposition · Mortality

Introduction

Clear-cut cohort patterns in mortality are seldom identified for populations. The mortality pattern of interwar generations of Danish women (born 1919–1939), however, provides an addition to a few other examples: the decline in mortality rates in nineteenth and early twentieth century Britain, starting approximately in 1850 [1]; improvement in mortality of Japanese people born around 1915 [2] and mortality improvement in the UK for cohorts born between 1925 and 1945 [3], which was more rapid than for those born before and after this period. It is now well known that the stagnation in Danish women's life expectancy is explained by the increased mortality of the interwar generations [4]. It has been suggested [5] that their increased mortality, compared to women born before and after the interwar period, was caused by higher levels of smoking throughout life. Analyses [6] of smoking-related causes of death support this hypothesis, but there have been no analyses in overall mortality differences between smokers and non-smokers for these generations of Danish women. In this study, we applied an updated version of the Preston–

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Glei–Wilmoth (PGW) method [7] to estimate mortality attributable to smoking, in order to examine the effect of smoking on the stagnation in life expectancy of Danish women in this period. Our hypothesis was that if smoking-attributable mortality is excluded, then the stagnation in life expectancy of Danish women would diminish. As a comparison population, we used Swedish women—a group that did not experience a similar stagnation in life expectancy in the same decades [4].

Methods

We applied an updated version of the PGW method [7]. By using excess deaths from lung cancer to estimate smoking exposure in a population, the method determines the level of total mortality attributable to smoking [7]. Next the resulting 5 year age and period data was ungrouped into 1-year age and period groups using the penalized composite link model [8]. Finally the partial life expectancy between age 50 and 85 when excluding smoking attributable deaths and when not excluding smoking attributable deaths was calculated.

As a first step, the PGW method uses relative risk estimates for lung cancer mortality of smokers and non-smokers from the US Cancer Prevention Survey II (CPS-II) to infer smoking's influence on mortality. The second step is the estimation of mortality attributable to smoking based on lung cancer death rates from the World Health Organization (WHO) Mortality Database. In this study, we used the PGW method on updated mortality data for the years 1950–2012, using the same high-income countries as used in the original PGW method. We estimated smoking-attributable mortality in five-year age groups above age 50, taking into account country and year of death. The estimation was based on a negative binomial regression [7].

To get more detailed information on age-specific mortality patterns (i.e. 1-year age and period categories), we used the penalized composite link model for ungrouping data, which estimates smooth mortality rates by single year of age from aggregated death counts and exposures [8]. Because the input data used for the PGW method, i.e. the WHO Mortality Database and the Cancer Prevention Study II data, are aggregated in five-year age groups with an open-ended interval starting at age 85, the resulting smoking and non-smoking-attributable mortality rates follow the same age grouping scheme. Very few deaths attributable to smoking was present for some years in the open-ended interval which sometimes provided negative mortality estimates. Therefore we chose to exclude the open ended interval (85+) when ungrouping and from the following calculations and analysis.

To give a more detailed overview of the age-specific mortality patterns when excluding smoking related mortality and when not excluding smoking related mortality, we estimated these rates by one-year age groups from age 50 to 85. To do so we applied the penalized composite link model twice: First, we estimated smooth distributions of exposures by single year of age from age 50 to 85; second, we estimated smooth mortality rates when excluding smoking related mortality and when not excluding smoking related mortality on the same detailed age grid by incorporating the estimated exposures as offset in the model (an example is given in Fig. 1b). For a more detailed explanation of the model, see Rizzi et al. [8]. The penalized composite link model [8] improved the death rates obtained with the Preston–Glei–Wilmoth method, by estimating mortality in 1-year age group from age classes of 5 years. We therefore used a complete life table instead of an abridged one to calculate partial life expectancy.

Based on the ungrouped mortality rates and data from the Human Mortality Database, we computed standard life tables by year and country. We calculated temporary life expectancy between ages 50 and 85 (the expected number of years lived between age 50 and 85 by those aged 50) as follows:

$$e_{50|85} = \frac{\sum_{x=50}^{84} L_x}{l_{50}}$$

where L_x is the person-years lived at age x and l_{50} is the number of individuals alive at age 50.

We then compared temporary life expectancy for the Danish and Swedish female all mortality populations and smoking eliminated mortality populations. For the rest of this paper we designate the partial life expectancy between age 50 and age 85 as partial life expectancy at age 50.

To better understand differences in the calculated partial life expectancy at age 50 between the two countries, we decomposed those differences into age-specific contributions, see Fig. 2. We first calculated age-specific contributions to the difference in life expectancies using Arriaga's discrete decomposition technique. The difference in life expectancies at age x can be estimated as:

$$\Delta_x = \frac{l_x^1}{l_0^1}\left(\frac{L_x^2}{l_x^2} - \frac{L_x^1}{l_x^1}\right) + \frac{T_{x+1}^2}{l_0^1}\left(\frac{l_x^1}{l_x^2} - \frac{l_{x+1}^1}{l_{x+1}^2}\right)$$

where l_x denotes the number of survivors at age x, L_x the number of life-years lived in age x, and T_x the number of life-years lived at age x and above. Superscripts 1 and 2 indicate the two populations of interest. Estimates from Arriaga's discrete decomposition technique provides an absolute term in differences in life expectancy measures.

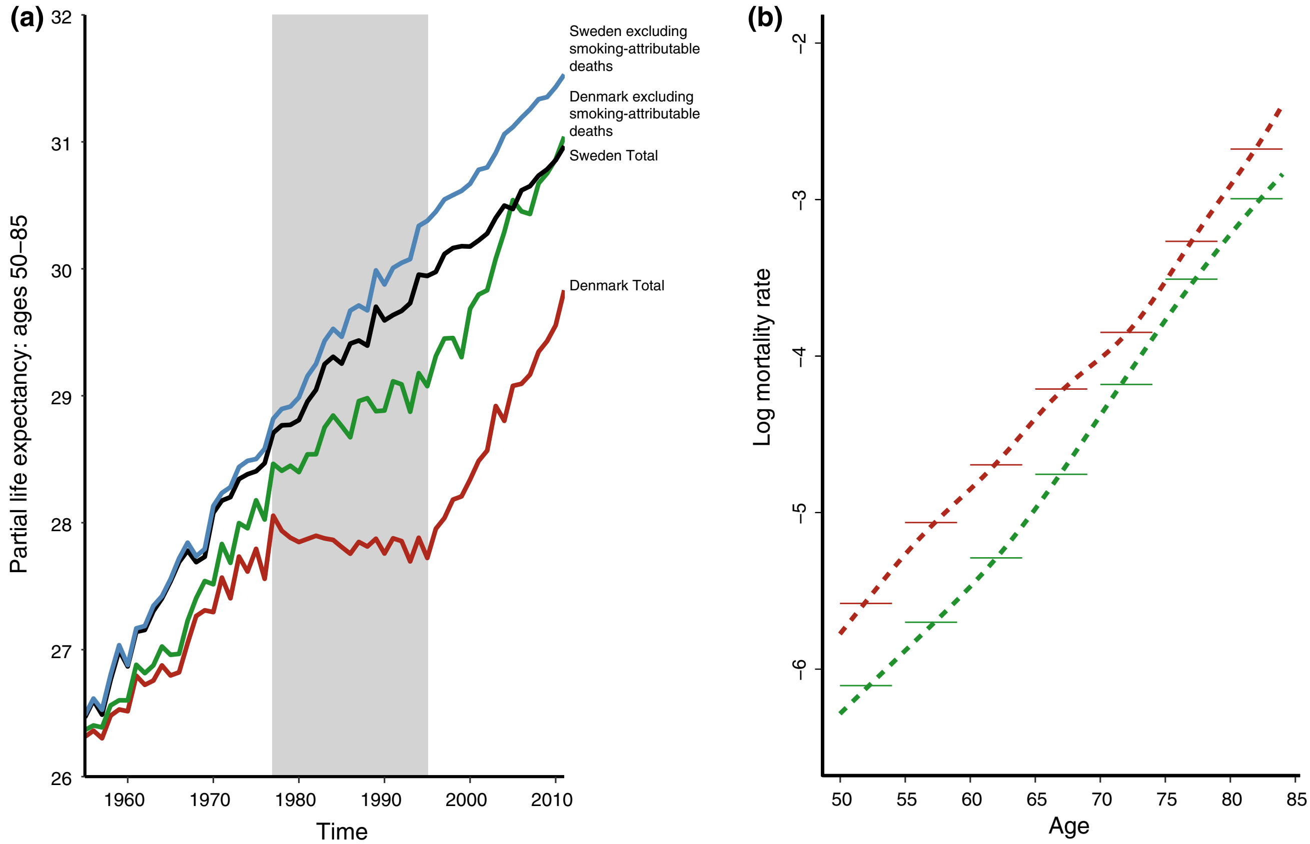

Fig. 1 **a** Trends and differences in partial life expectancy at age 50 for Danish and Swedish women since 1950 in total for Sweden (*black line*), in total for Denmark (*red line*), for Denmark on exclusion of smoking-attributable mortality (*green line*) and for Sweden when smoking-attributable mortality is excluded (*blue line*), **b** Mortality rates for Danish females in 2010: Grouped rates obtained with the Preston–Glei–Wilmoth method (step functions) and smooth ungrouped rates estimated with the penalized composite link model (lines); *red* and *green* colors correspond to total mortality rates and mortality rates when excluding smoking attributable deaths respectively

To achieve a relative term we estimated mortality rate ratios.

R 3.2.5 was used for all the analyses.

Results

The difference between total partial life expectancy at age 50 and smoking-eliminated partial life expectancy at age 50 was greater for Danish women than for Swedish women (Fig. 1a). When smoking-attributable deaths were excluded, Danish women had a slightly lower partial life expectancy at age 50 then Swedish women, until 1979. After 1979, the difference widened until 1995, when it started to become narrower with time.

The exclusion of smoking-related mortality (Fig. 1a) showed a reduction in stagnation in partial life expectancy at age 50 among Danish women, but it did not disappear. Excluding smoking-attributable mortality for Danish women reduced the difference in total partial life expectancy at age 50 towards Swedish women by 0.4 years in 1977 and by 1.2 years in 1995. During the rise of Danish women's partial life expectancy at age 50 (i.e. after 1995), partial life expectancy at age 50, with smoking-attributable mortality excluded, showed a similar trend as for the total Danish female partial life expectancy at age 50, and in 2003 it became similar to the partial life expectancy at age 50 of Swedish women (Fig. 1a).

The analysis of the age-specific contribution to differences in partial life expectancy at age 50 showed, in general, higher mortality rates for the interwar generations of Danish women than for their Swedish counterparts (Fig. 2a). Non-smoking-related mortality was still higher, but the difference was less substantial and shifted towards the difference found among the women born in the beginning of the century (i.e. born 1915–1930, Fig. 2b). For these interwar generations of Danish females, the age-specific contribution to differences in partial life expectancy at age 50, compared to Sweden, increased from approximately 0–0.05 years at age 50 to 0.1–0.15 years at age 60–70 (Fig. 2a). The age-specific contribution to

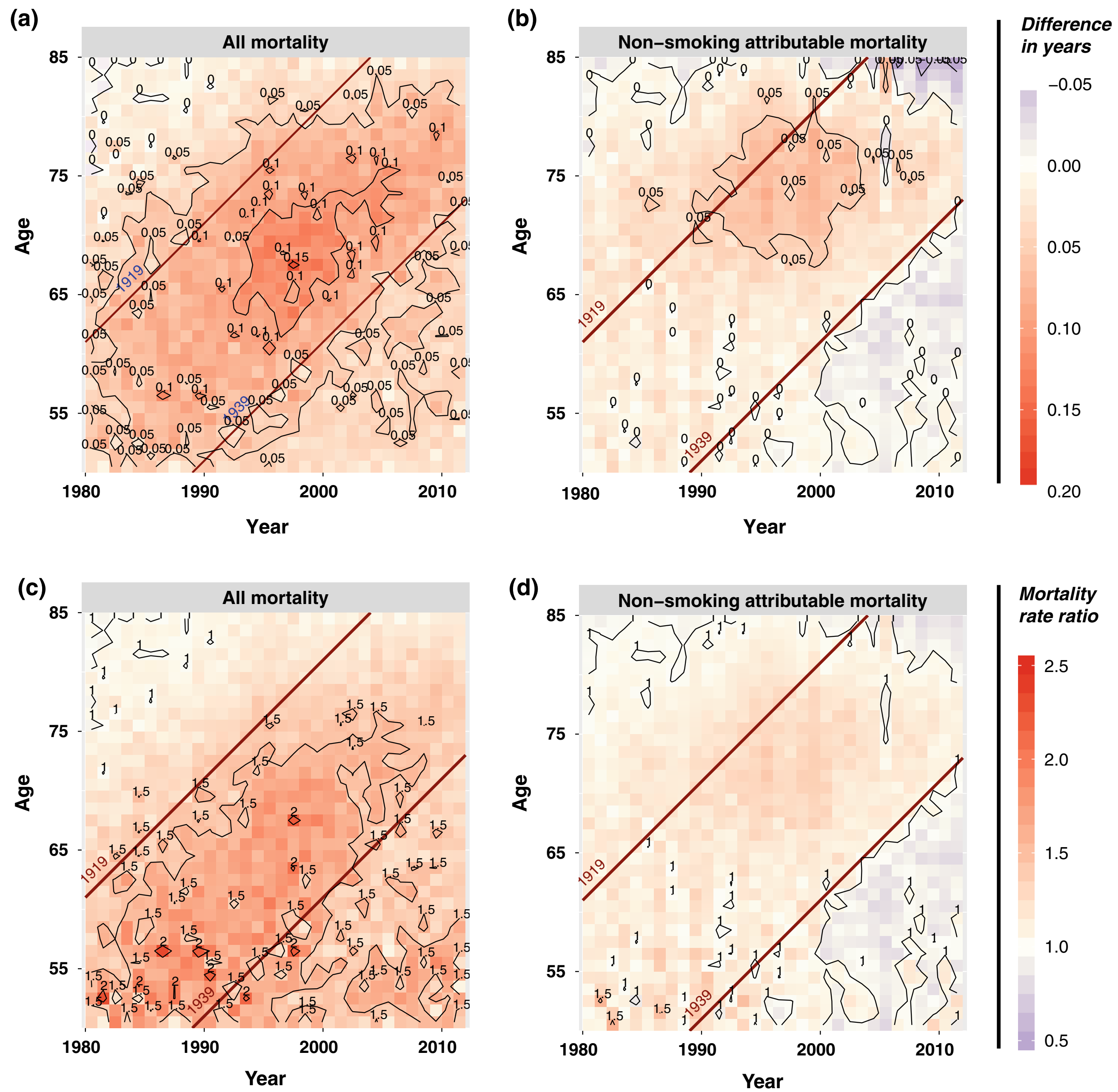

Fig. 2 Contour lexis map plot of age-specific contributions to differences in partial life expectancies at age 50: (**a**) contribution from all Danish women's mortality versus all Swedish women's mortality and (**b**) contribution from Danish women's mortality not attributable to smoking versus all Swedish women's mortality. The crossed red lines correspond to cohorts born between 1919 and 1939. (**c**) and (**d**) Are similar plots corresponding to the relative mortality rate ratios instead of the absolute differences

differences in Danish women's partial life expectancy at age 50, compared to Sweden, when excluding smoking-related mortality, was generally roughly 0–0.01 years, except for women born 1915–1930, where the difference was about 0.05 years in the 67–77 age interval (Fig. 2b). The mortality rate ratios calculated after excluding smoking attributable deaths (Fig. 2c) and after excluding smoking attributable deaths (Fig. 2d) gave similar patterns as the age-decomposition illustrating the robustness of the effects whether measured in terms of relative risks (i.e. mortality rate ratio) or differences in expected years lived.

Discussion

The mortality of the interwar generations of Danish women explains the stagnation in Danish women's life expectancy [4]: Our study shows that their smoking behaviour is the major cause behind the stagnation. When smoking-attributable deaths were excluded, the stagnation and the low partial life expectancy level of Danish women at age 50, when compared to Sweden women, diminished but did not disappear (Fig. 1).

The strong cohort effect identified for the interwar generations of Danish women adds to the few examples of cohort effects on mortality patterns in populations [1–3]. The difference in our study, however, is that the population experienced a mortality increase rather than an improvement [4]. The identification of the cohort effects on the mortality rates of the interwar generations of Danish women was based on an age-period-cohort analysis [5]. It became clear that an age-period model gave a poor fit, compared to the age-cohort model and the age-period-cohort model. This illustrated the importance of including an exploration of the cohort perspective when searching for causes behind mortality patterns [4]. The impact of these cohort effects on the life expectancy of Danish women was recently demonstrated [4]: had the Danish interwar generations had similar death rates as their Swedish counterparts, then the stagnation in Danish life expectancy during the 1970s and start of the 1990s would have been absent [4]. During the 1990s, some studies found that smoking had an influence on the mortality of Danish women (see, for example Juel [9]), but they failed to link this influence to the specific generations that experienced increased mortality. Following the identification of the cohort effect, studies have attempted to test the smoking hypothesis [5, 6] and found strong evidence that smoking influenced the mortality of these cohorts. However, these studies did not give an absolute measure of the level of impact of smoking on life expectancy. In this study, we showed how smoking-attributable deaths influenced the partial life expectancy trends of Danish women, by comparing their mortality to the mortality rates of Swedish women.

Surprisingly, deaths attributable to non-smoking-related causes also showed an increased risk for the interwar generations of Danish women (Fig. 2). This indicates that factors other than smoking possibly also contribute [10] or that the PGW method does not fully capture the total effect of smoking in these generations of women. For example, the exposure groups used in the model (smokers and non-smokers) might be too broad, and as categories they do not take into account altered risk patterns caused by smoking accumulation and intensity.

Based on the results from our study, the major reason for the observation of a cohort effect on the mortality of the interwar generations of Danish women is smoking. This exemplifies the great impact of the smoking epidemic during the last century on mortality patterns in Western populations.

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