Rise, stagnation, and rise of Danish women's life expectancy

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Contributed by James W. Vaupel, February 24, 2016 (sent for review November 4, 2014; reviewed by Michael Murphy and Samuel H. Preston)

Health conditions change from year to year, with a general tendency in many countries for improvement. These conditions also change from one birth cohort to another: some generations suffer more adverse events in childhood, smoke more heavily, eat poorer diets, etc., than generations born earlier or later. Because it is difficult to disentangle period effects from cohort effects, demographers, epidemiologists, actuaries, and other population scientists often disagree about cohort effects' relative importance. In particular, some advocate forecasts of life expectancy based on period trends; others favor forecasts that hinge on cohort differences. We use a combination of age decomposition and exchange of survival probabilities between countries to study the remarkable recent history of female life expectancy in Denmark, a saga of rising, stagnating, and now again rising lifespans. The gap between female life expectancy in Denmark vs. Sweden grew to 3.5 y in the period 1975–2000. When we assumed that Danish women born 1915–1945 had the same survival probabilities as Swedish women, the gap remained small and roughly constant. Hence, the lower Danish life expectancy is caused by these cohorts and is not attributable to period effects.

life expectancy | cohort effects | period effects | decomposition | interwar Danish women

Factors influencing human mortality and health may act at different ages, on specific generations, or at different points in time. A major challenge in analyzing particular mortality patterns is to disentangle the relative importance of the factors (1). A methodological problem arises from the interdeterminacy of linear effects attributable to period (points in time) or cohort (generations), which derives from the perfect correlation among cohort, period and age (age = period − cohort), making only deviations from the combined linearity of cohort and period comparable (1–4). As a result, debates have raged about whether period or cohort effects led to the rapid rise in life expectancy since 1900 in most western countries (1, 5–8).

During the latter half of the 20th century, emphasis was given to temporal effects because most population specialists thought that cohort mortality effects were small and need not be incorporated into models of mortality reductions (1, 9). Since the mid-1990s, however, the increased interest in life course effects on health and mortality has given new life to studies of cohort effects (1).

A few birth cohorts have been identified with clear-cut cohort patterns: those of Britain in the late nineteenth and early twentieth centuries (10, 11); those of Japan in the early twentieth century (12); and cohorts born in Britain in the 1930s, often referred to as the "golden generations" (1, 13). Here, we present another example of cohorts influencing mortality patterns, namely the case of the interwar generations of Danish women. We illustrate how to disentangle period and cohort effects using an approach based on age decomposition, exclusion of age-period effects, and replacement of survival probabilities.

Interwar Generations of Danish Women

Even though life expectancy has increased substantially in all high-income countries during the last century, some countries have experienced stagnation in life expectancy in some periods, including the United States, The Netherlands, and Denmark (14, 15); Russia provides the most significant example of a decline in life expectancy (16–18). In Denmark, the stagnation was especially pronounced for women (Fig. 1). The stagnation resulted in a steep decline in the rank of female life expectancy among Organisation for Economic Co-operation and Development (OECD) countries: Denmark ranked no. 4 in 1960 and no. 26 in 2006 (stats.oecd.org).

The first report on the stagnation of the life expectancy of Danish men and women in the period 1970–1986 was published in 1989 (19). In 1992, the Danish Ministry of Health set up a Life Expectancy Committee (LEC) to examine possible explanations for the decline of life expectancy in Denmark relative to that of other countries (20, 21). The LEC concluded that smoking was the single most important factor in explaining the higher mortality of Danes (21). During the work of the LEC and in subsequent years, a number of studies analyzed the reasons for the stagnation of life expectancy in Denmark (22–32). Both the work of the LEC and most of these studies examined mortality over calendar time. A number of studies of the life expectancy of Danish women, however, have included a cohort perspective (33–36). Those studies concluded that the stagnation in the life expectancy of Danish women was mostly attributable to high smoking prevalence over the life course (33, 34) of women born between the two world wars. As a corollary, a rise in life expectancy could be expected when these generations died out (33). The generations of Danish women born between the two world wars (1915–1945) reached the age of 70–100 in 2015, with only a fraction of smokers still alive (37).

Significance

Life expectancy is the most commonly used measure of health status in a population. Life expectancy has increased rapidly in most western populations over the past two centuries. There has been an ongoing debate about the relative contribution of cohort and period effects on a nation's life expectancy, but few concrete examples of strong cohort effects exist. In this study, we use demographic approaches to study cohort effects on the life expectancy of Danish women. We identify a clear-cut and strong cohort effect: the case of the interwar generations of Danish women.

Author contributions: R.L.-J., R.R., B.J., V.C.-R., A.L., K.C., and J.W.V. designed research; R.L.-J., R.R., K.C., and J.W.V. performed research; R.L.-J., R.R., and J.W.V. analyzed data; and R.L.-J., R.R., and J.W.V. wrote the paper.

Reviewers: M.M., London School of Economics; and S.H.P., University of Pennsylvania.

The authors declare no conflict of interest.

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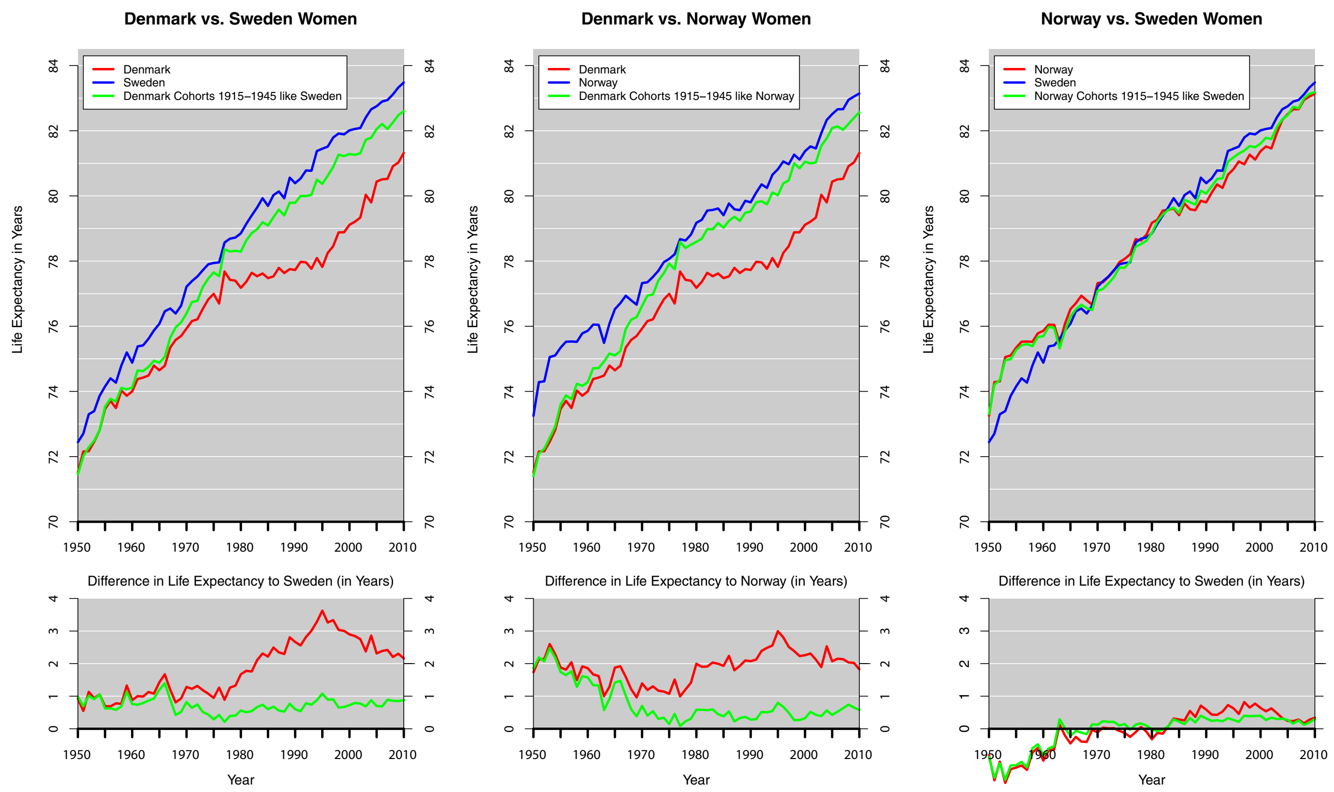

Fig. 1. Trends and differences in life expectancy for Danish, Norwegian, and Swedish women since 1950 and hypothetic life expectancy of Danish and Norwegian women when assuming survival probabilities of Danish and Norwegian women born 1915–1945 equal those of Swedish women born 1915–1945.

Here, we address the hypothesis that the recent increase in life expectancy of Danish women is explained by the dying out of high-mortality generations of Danish women born between the two world wars, 1915–1945, as predicted by Jacobsen et al. (33). To assess this possibility, we compare Danish mortality trends with two neighboring Scandinavian countries, Sweden and Norway, that had relatively stable trends in life expectancies (stats.oecd.org) in the period.

Results

The overall life expectancy of Danish women is markedly lower than the life expectancy of Swedish and Norwegian women, whereas Norwegian and Swedish women experienced similar life expectancies over time (Fig. 1). The previously unidentified approach of exchanging mortality rates for specific cohorts is useful for illustrating how much influence specific cohorts had on the differences in life expectancy (Fig. 1). If it is assumed that Danish women born 1915–1945 had the same survival probabilities as Swedish or Norwegian women, then Danish, Norwegian, and Swedish life expectancy show a similar trend in the whole study period (Fig. 1). The difference in life expectancy explained by other cohorts in the period of the stagnation (e.g., after 1977) is no larger than in the period before the stagnation. For example, in 1966, other cohorts than women born 1915–1945 explained 1.4 y of the difference between Swedish and Danish women (Fig. 1). In 1995, the difference explained was 1.06 y, and in 2011, the difference explained was 0.84 y.

The contribution to the differences in life expectancy for each birth cohort of Danish women is largest for Danish women born around 1930 compared with Swedish or Norwegian women. This effect increases until 1995–1999 and subsequently decreases (Fig. 2).

Period effects may show up as cohort effects simply as a result of a temporal shift in the median age with the largest contribution to a difference in life expectancy between two populations. For example, in two populations with an observed difference in life expectancy, a rise in life expectancy as a result of the same proportional reductions in mortality at each age over time will lead to a shift in the median age group with the largest contribution to the difference in life expectancy. The effect of such a shift will be a delayed increase in age-specific mortality with time, appearing to be a cohort effect. The observed pattern in Figs. 2–4 might be the result of an age-median-shift artifact. We approached this possibility by identifying the age-period component. We analyzed this component's potential influence on our results (see *Materials and Methods* for details about the approach). When removing the age-period component from our results, cohort effects still explained most of the stagnation and later rise in Danish women's life expectancy, as shown in Figs. 2*B* and 4*B*. Thus, the residual effects shown in Fig. 2 can be attributed to actual cohort differences.

The age-specific contribution to differences in life expectancy compared with Sweden for these interwar generations of Danish females increased from 1 d at age 30–31 mo during the age interval of 60–70 years (Fig. 3). When comparing Norwegian and Swedish females, the largest contribution to differences in life expectancy is 1 wk (Fig. 3), corresponding to the very small stagnation seen around 1985–1990 in Norwegian women's life expectancy (Fig. 1), which is caused mostly by mortality of women born 1915–1934.

Analysis of the contribution to the differences in life expectancy for 5-y cohorts makes it possible to identify the cohorts with the highest contribution to differences in life expectancy over time (Fig. 4). The comparison of Denmark to Sweden and to Norway is similar (Fig. 4). In Denmark, women born 1915–1945 explain most of the changes in life expectancy in the period 1975–2011 compared with Swedish women (Fig. 4*A*). The influence of the Danish women born 1915–1945 on the overall differences in life expectancy compared with Sweden increases until 1995–1999, by which time, 86% of the total difference between the two countries is

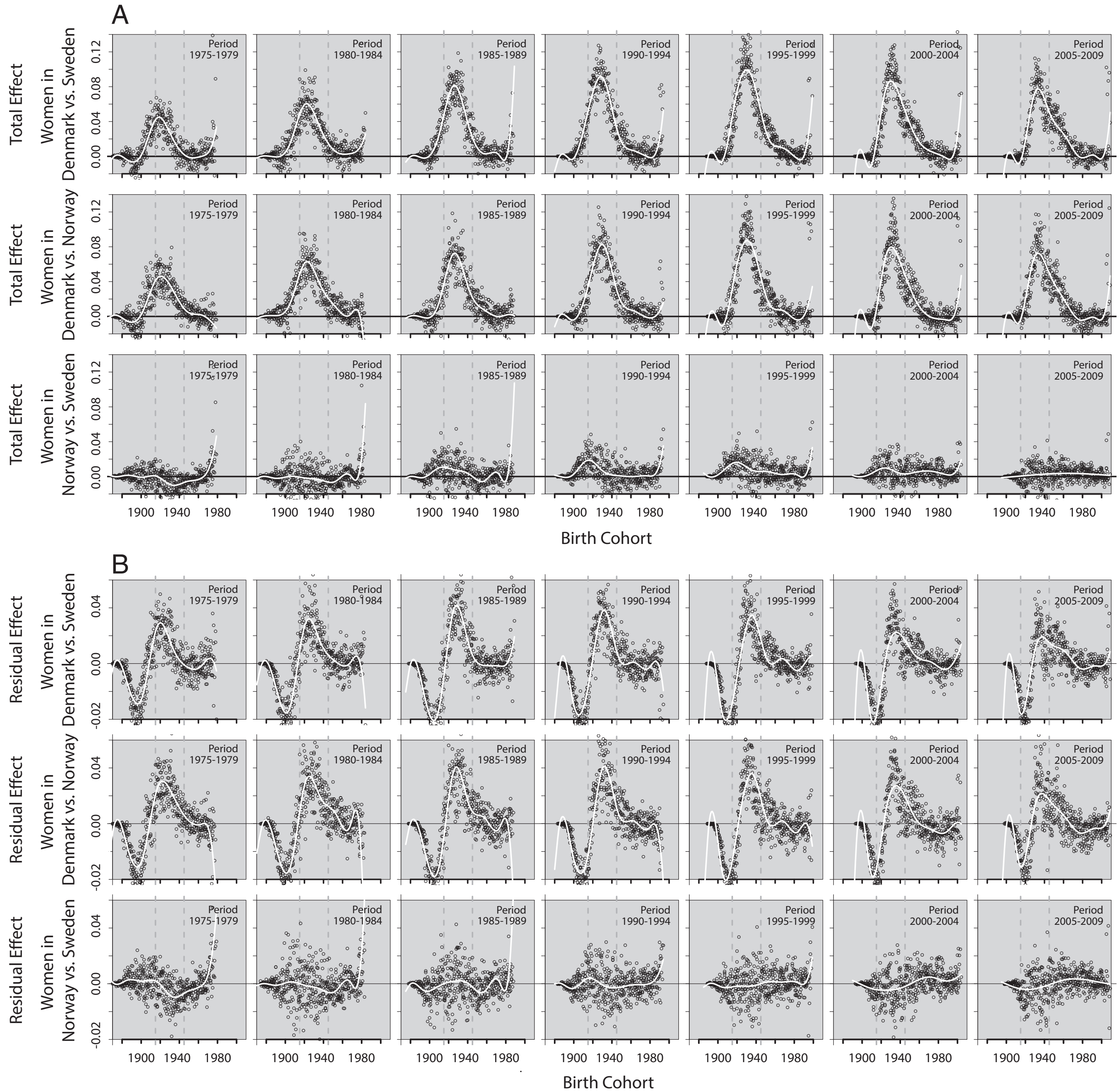

Fig. 2. Contribution of 1-y birth cohorts to the total difference in life expectancy when comparing Danish, Norwegian, and Swedish women. (*A*) Actual differences in life expectancy. (*B*) Depiction of the residual effects when assuming that the rise in life expectancy over time is solely caused by period effects and then leaving out these effects. A nonparametric smoother has been added in each panel as a white line (47, 48).

attributable to the 1915–1945 generations. This increase is followed by a marked decrease until the end of the study period by which time 62% of the total difference between Denmark and Sweden is explained by the 1915–1945 generations (Fig. 4*A*). The cohorts born 1925–1934 explain most of the contribution to the difference for the 1915–1945 cohorts. In general, the residual effects followed the general pattern observed for the total effects for Danish women born 1915–1945 and for women born after 1945 (Figs. 2 and 4). For women born before 1915 the contribution relative to Norway and Sweden becomes negative. An intriguing observation is that the residual effects for Danish women born 1915–1924 shift from higher mortality before 1995 to lower mortality after 1995. After 1995 the life expectancy for Danish women converges toward Swedish and Norwegian women (Figs. 1 and 4*B*).

Discussion

This study illustrates clear cohort effects on the life expectancy of Danish women. The decrease and later increase seen in life expectancy compared with Norwegian and Swedish women are driven by the high mortality of Danish women born 1915–1945. If these Danish interwar women had had a mortality pattern similar to that of Swedish women in the period of stagnation, then no stagnation would have occurred. The maximum contribution of 1-y birth cohorts to the total difference in life expectancy when comparing Danish women to that of Norwegian and Swedish

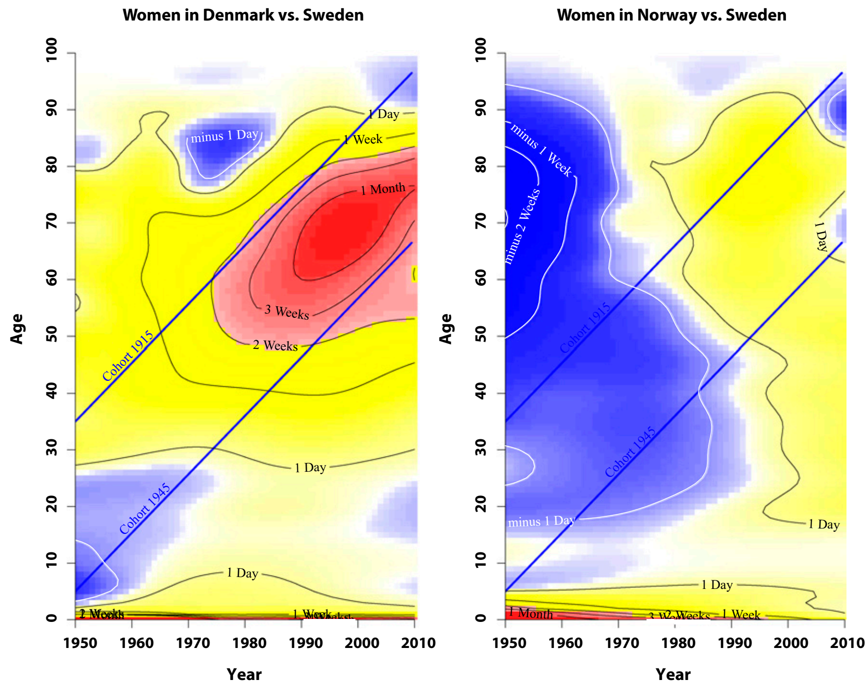

Fig. 3. Contour lexis map plot of differences in life expectancies when comparing Danish and Swedish women and Norwegian and Swedish women.

women peaked for women born around 1930 (Fig. 2) clearly illustrating a cohort effect. This was the case even when we attributed as much as possible of the rise in life expectancy to period effects.

As predicted in 2004 by Jacobsen et al. (33), the dying out of the 1915–1945 generations in the three Scandinavian countries has triggered a more rapid increase in the life expectancy of Danish women compared with Swedish and Norwegian women. The suggested explanation for the higher mortality of Danish women was previously that most of the increased mortality was smoking-related. This was a result of a smoking rate throughout life that was higher in Danish women born between the two world wars compared with Danish women born before and after the two world wars (33–35, 38). Sweden and Norway did not experience the same stagnation in women's life expectancy. This finding supports the conclusion that smoking is a major explanation for the difference in life expectancy between Danish women and Swedish and Norwegian women, because markedly lower smoking rates throughout life were found for Swedish and Norwegian women (33). With a higher selection pressure on the unhealthy part of the interwar generations of Danish women (i.e., smokers dying at younger ages), the excess mortality would decrease with age: the surviving population would increasingly consist of those women with a healthier lifestyle behavior and those having other factors compensating for unhealthy lifestyle behavior. Together with the fact that the entire interwar generations of Danish women were dying out, such a selection effect contributed to their decreased influence on total life expectancy. This can account for the rise in life expectancy from the mid-1990s, when the Danish women born 1915–1945 were between 50 and 80 y old.

In this study, such a selection effect is suggested by the following. The residual effects (i.e., excluding period effects on the rise in life expectancy) for Danish women born 1915–1924 shifted from higher mortality than Swedish and Norwegian women to increasingly lower mortality from 1995 and onwards for women over 70 y (Fig. 4*B*). The explanation of why Danish women's life expectancy began to rise around 1995 has previously been suggested to be the adoption of healthier lifestyles with respect to smoking, alcohol consumption, and physical activity as well as the implementation of the "Heart Plan" in Denmark in the mid-1990s (39). This conclusion implies that factors acting during the 1990s are responsible for the rise in life expectancy (i.e., period effects). This conclusion might be partially true, but our analyses suggest that cohort effects are the major explanation for the stagnation and later rise in Danish women's life expectancy. In particular, the lower mortality after 1995 of Danish women (compared with Swedish and Norwegian women) born 1915–1924 may be the result of mortality selection.

The applicability of the method we used in this study may be limited by the need for an appropriate population for comparison. The approach of choosing a standard for comparison is not a new idea in demography (9) and with regard to mortality dates back to the classic work of Kermack, McKendrick, and McKinlay, in which Sweden was used as reference population for Great Britain (11). If a comparison country with similar cohort effects acting on the female population as those seen in Denmark were selected, then the cohort effects would not have been identified. The choice of an appropriate comparison population when using our method is therefore crucial. The almost linear rise in the life expectancy of Swedish women made them a suitable reference population for examining period and cohort effects of Danish women.

The stagnation of Danish female life expectancy is attributable to specific cohorts born 1915–1945 and especially 1925–1934 and not to factors acting on all women between 1975 and 2000. These findings illustrate the importance of incorporating the cohort in studies of changes in life expectancy (9) and illustrate an important new example of cohort effects on population mortality patterns (1). The use of age decomposition from a cohort perspective over time, the exclusion of potential age-period-shift effects from rise in life expectancy and the exchange of cohort death rates between countries exemplify a possible strategy for examining cohort and period effects in other settings.

Conclusion

This study confirms that the stagnation and the recent increase seen in Danish women's life expectancy mostly are explained by the mortality of the interwar generations of Danish women. The

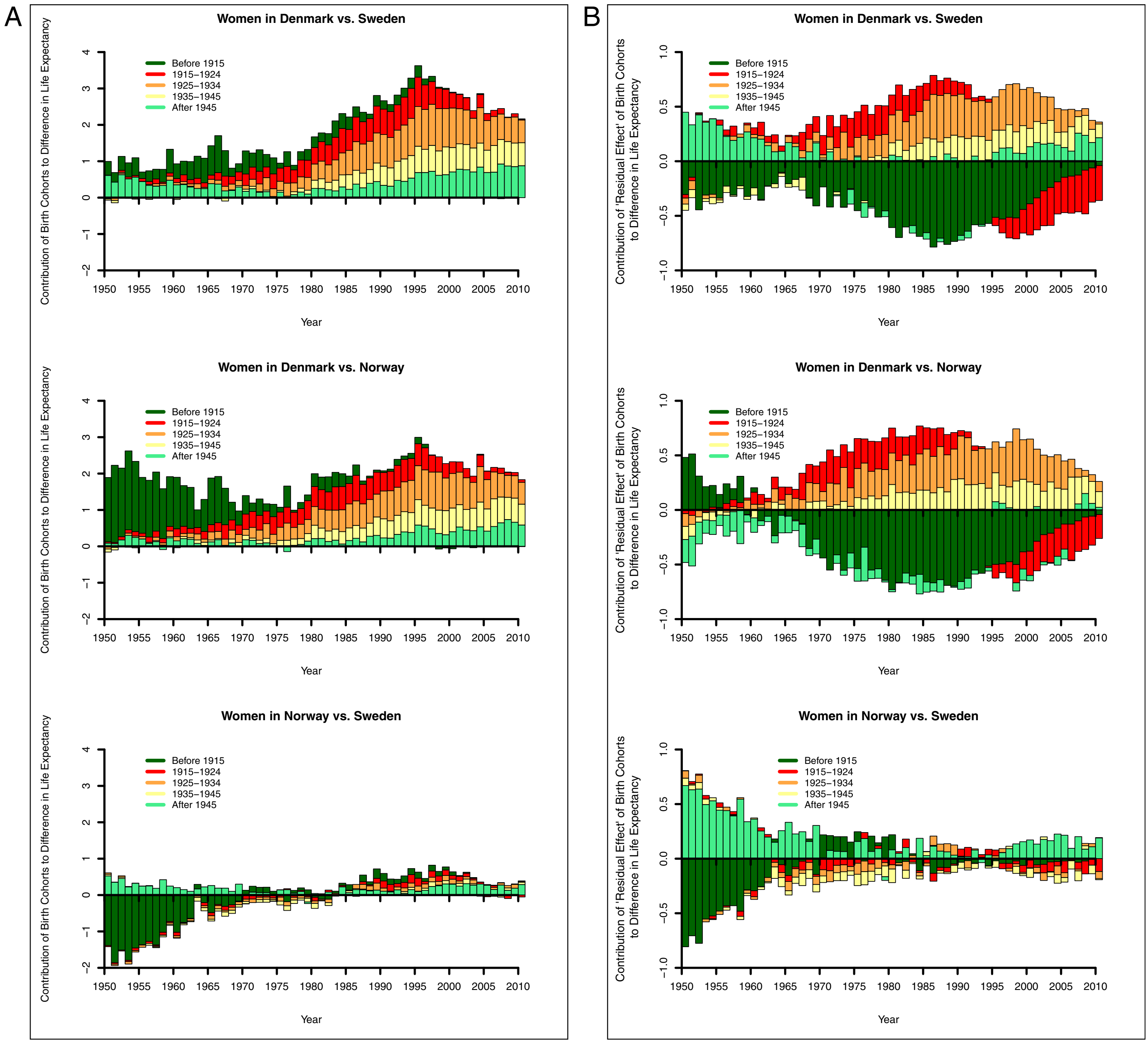

Fig. 4. Influence of the interwar generations and other generations of Danish and Norwegian women on differences in life expectancy compared with Swedish women. (*A*) Actual difference. (*B*) Depiction of the residual effects when assuming that the rise in life expectancy over time is solely caused by period effects and then leaving out these effects. The sum of the stacked bars is equivalent to the total difference in life expectancies for a given year with (*B*) and without (*A*) the residual effect.

approach used in this study to examine cohort and period variations in mortality provides an approach to complement traditional age-period-cohort analysis (3, 4, 40–43).

Materials and Methods

All estimates presented in the article are based on death counts and corresponding exposure times by single year of time and age obtained from the Human Mortality Database (HMD) (www.mortality.org). No subjects were directly involved in the study. Only vital statistics from the HMD were used for the study; thus, no individual data was used. The HMD compiles census and vital statistics information for national populations. It employs uniform methods to allow comparisons across countries and over time. Based on these death counts and exposure times, period life tables have been estimated using a standard methodology (44). The required $a(x)$ values required for life table estimations (i.e., the mean number of person-years lived at age x by those who died at age x) were also taken from the HMD. The resulting estimates of life expectancy at birth for women in Denmark, Sweden, and Norway are presented in Fig. 1 for the years 1950–2010. In Fig. 1, we further replaced death counts and exposures for Danish women born 1915–1945 with the ones from Sweden using the relationship cohort = period − age.

To better understand differences in life expectancy among countries, we decomposed those differences into birth cohort-specific contributions in Figs. 2 and 4. To do so, in a first step, we estimated age-specific contributions to the difference in life expectancies, following Arriaga's (45) discrete decomposition approach. Using the notation of Preston et al. (44), 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. We approximated birth cohorts in a second step by subtracting the current age from the current calendar year. A black dot in a given graph in Fig. 2 depicts the contribution of a single birth-year cohort to the difference in life expectancies between the two selected countries in a single calendar year during the selected 5-y calendar time observation periods. The white lines in each panel are the results of fitting generalized additive models, using P-splines for the estimation of the smooth birth-year component (46). Dashed vertical reference lines have been added to localize the birth cohorts of interest (1915–1945). In Figs. 3 and 4, we represent the data in the period perspective and replace cohort with age. To produce Fig. 3, we used Arriaga's decomposition method to estimate the contribution of each age to the difference in life expectancy between females in Denmark and Sweden (Fig. 3, *Left*) and Norway and Sweden (Fig. 3, *Right*) in each year from 1950 to 2010. Similar to heat maps, we depict the same contributions with the same colors on this age-by-calendar-year plane. Blue colors were used for negative contributions (i.e., Swedish mortality was higher than in Denmark or Norway; deeper shades of blue were used with an increasing mortality gap). If Danish or Norwegian mortality was somewhat higher at an age in a given year, we used yellow tones. Stronger saturation translates to differences from 1 d to 2 wk. In case a single age contributed from 2 wk to more than 1 mo to the difference in life expectancy between the two countries in a given year, we used red colors. To enhance the readability of Fig. 3, we added contour lines to denote the same contribution to the difference in life expectancy, analogously to topographic maps for equal elevation. The cohort-specific contribution to the difference in life expectancies for the year 1950–2010 is shown in Fig. 4. Because of the additive nature of the decomposition, the sum of the stacked bars is equivalent to the total difference in life expectancies for a given year.

Using Arriaga's method to decompose differences in life expectancy into age-specific contributions and attributing the differences to birth cohorts can lead to spurious results: the cohort effect in our estimates could be partly explained by pure period effects, defined as changes in mortality by the same proportion at each age. Consequently, we pursued a two-step procedure. First, we decomposed the difference in life expectancies into age-specific contributions by using Arriaga's standard method and assigned the respective birth cohorts to those ages. Second, we estimated the factor required to account for the gap in life expectancies if it applied to every age. This proportional effect can be interpreted as a pure period effect. Subtracting this period effect from the total effect of the first step yields a residual effect that is completely void of any period interference. We interpret this residual effect as a minimum estimate of the impact of differences among the birth cohorts.

ACKNOWLEDGMENTS. We thank Michael Murphy for suggesting the age-median-shift artifact. R.R. and V.C.-R. are supported by European Research Council Starting Grants 263744 (to R.R.) and 240795 (to V.C.-R.).

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