6 Cohort and Age Effects

The last chapters provide ample evidence that life span and month of birth are related. Two questions arise: first, does this influence also exist for the ages 1 to 49? Second, is the magnitude of the excess mortality of the spring-born similar in all age groups? There are at least two different hypotheses concerning these questions. A first hypothesis is that the excess mortality of the spring-born is age-specific because of the changing distribution of causes of death with age. The analysis of the US death certificates presented in Chapter 5 shows that the month-of-birth effect exists in all major groups of causes of death and that its magnitude differs, however. The excess mortality of the spring-born is largest for heart disease and considerably smaller for the group of malignant neoplasms. Thus, the month-of-birth pattern might be comparatively small at younger ages and increase its magnitude at middle and old ages when heart disease becomes an important cause of death. A second hypothesis is that the differences decrease with age due to mortality selection. Among both the spring- and the autumn-born, the frailer will die first, resulting into an ever more homogeneous and "robust" population at higher ages. In practice, it is most probably the case that both forces work simultaneously.

In trying to test these two hypotheses one has to overcome two problems. The first problem is that longitudinal data are needed to identify age-specific effects; the second problem is that datasets have to be large so as to allow for the estimation of age-specific mortality at ages where death rates are low.

Longitudinal data based on population registers exist in the Scandinavian countries. Most of them were started during the 1960s. In the case of Denmark, the register was established in April 1968, and it contains everybody who was alive in March 1968. This study uses the Danish register data together with a mortality follow-up until 1998. Because of the small number of deaths at younger ages in Denmark today, it is not possible to use the register for studying age-specific changes in the month-of-birth pattern for contemporary young cohorts. This is also true for other Scandinavian countries with population registers. The number of deaths are sufficient only after age 50 for studying age-specific patterns in mortality by season of birth. Thus, the Danish register data provide only a partial answer to the question of how the month-of-birth pattern changes with age.

The second longitudinal dataset used in this chapter is the Danish twin register, which contains twins born in Denmark between the years 1870 and 1930. The twins were followed from age six onwards until August 1995. For the study of age-specific month-of-birth patterns, twins have two advantages. First, the mortality of twins does not differ from the mortality of singletons once they survive their sixth birthday (Christensen et al. 2001). Second, the differences in life span by season of birth should be larger among twins than among singletons. There are two reasons for this. First, *in-utero* twins belong to the most vulnerable group because they have to share scarce resources, so seasonal differences in nutrition should therefore affect them more severely. Second, they have lower birth weights than singletons, which should make them more susceptible to infectious disease during their first years of life.

In theory both the Danish register data and the Danish twin data should allow us to calculate age-specific death rates by quarter of birth using simple life-table techniques. In practice, however, it appears that these death rates are highly volatile and do not lead to conclusive results. In order to arrive at consistent estimates of age-specific death rates, a functional form is imposed on the age-specific intensities of death.

Finally, a demographic method is applied that has been widely used in the study of genetic traits of longevity. This method allows for the use of repeated cross-sections of populations to estimate the effect of the "fixed attribute" month of birth on survival. In our search for repeated, large cross-sectional datasets, we obtained the US censuses for the years 1960, 1970, and 1980. These are the only three censuses that contain information about the quarter of birth. The census data were extracted from http://www.ipums.umn.edu/usa/index.html. The seasonal distribution of birth dates for, e.g., ages 10-19 in 1960 was then compared with the distribution for ages 20-29 in 1970 and for ages 30-39 in 1980. The changes in the distributions between the three census rounds indicate whether or not there exists a significant level of excess mortality of the spring-born.

All three datasets lead to the same conclusion, namely, that there is an excess mortality of the spring-born at all ages. The Danish register data show that the excess mortality after age 50 is lower in more recent cohorts and that it decreases with age. The excess mortality of the spring-born is larger for Danish twins than for the general Danish population. It exists at all ages and also tends to decrease with age. The US census data reveal that the mortality advantage of the autumn-born exists at all ages and that the difference in survival between the spring- and the autumn-born starts to accelerate at middle ages. However, the census data do not allow us to distinguish between cohort and age effects. It is therefore not obvious whether the increase in the excess mortality of the spring-born around age fifty is due to the age-specific onset of diseases with a strong month-of-birth pattern or due to cohorts that experienced worse conditions early in life.

6.1 Method and Data

The Danish register data and the Danish twin data are analysed by imposing a functional form on the age-specific force of mortality. In the Danish register data mortality increases from age 50 on, following a Gompertz function [6.1]

$$\mu(x) = ae^{bx} \tag{6.1}$$

where $\mu(x)$ is the force of mortality at age x, a is the age-independent level of mortality and b the increase in mortality over age. The parameter estimates a and b are estimated by maximising the likelihood function. All individuals are distinguished according to their quarter of birth and for each quarter a separate model is estimated. The age-specific death rates of the four models are presented in the form of ratios of the first three quarters to the last quarter. These ratios are compared with the ratios of the age-specific probabilities of death for one-year age groups on the basis of simple life-table methods.

The Danish register data consist of sufficiently large numbers of exposures and deaths to distinguish between age and cohort effects. Two ten-year birth cohorts are followed over an age-span of 20 years. The birth cohort April 1908 to March 1918 enters the study period between the ages of 50 and 59 and 11 months. They are followed from age 60 to age 79 in order, theoretically, to allow each member of the cohort to reach each age. The second cohort is aged 60 to 69, 11 months at the 1968-baseline and is followed from age 70 to age 89. This specification allows us to study age-specific death rates at ages 70 to 79 for both cohorts.

The Danish twin data include all twins from the age of six onwards. In contrast to older ages, the force of mortality does not follow a simple parametric form between ages 6 and 100. In the twin data, mortality decreases between the ages of 6 and 15. It then increases sharply until age 20, stagnates until age 40, and increases exponentially thereafter. A possible solution is to estimate four mortality functions which are joined together at ages 15, 20, and 40.

The following model [6.2] is specified

$$\ln \mu_{ij}(x,U_j) = \alpha_0 + \alpha' y(x) + \beta' C_j + \delta I_j + U_j \qquad [6.2]$$

in which $\ln \mu_{ij}(x,U_j)$ denotes the logarithm of the force of mortality at age x for individual i of twin pair j, and $\alpha_0+\alpha' y(x)$ the age-dependent baseline hazard. Let C_j stand for the ten-year birth cohorts and their parameters β', I_j for an indicator variable that indicates the half-year people are born in (I_j=0 if they are born in the first half-year, 1 otherwise), and δ for the parameter.

Since the large amount of variability in mortality under age 20 leads to unstable estimates of the age-independent mortality level α_0, the analysis is restricted to ages 20 and above. The baseline hazards $y(x)$ is a vector of piecewise-linear spline transformations of age x

$$y(x) = \begin{pmatrix} (\min[x, \upsilon_1]), \\ (\max[0, \min[x-\upsilon_1, \upsilon_2-\upsilon_1]]) \\ (\max[0, x-\upsilon_2]) \end{pmatrix} \qquad [6.3]$$

with the nodes υ_1 and υ_2 of the splines set at ages 40 and 60. Thus, three slopes of mortality are estimated. The first slope estimates the yearly percentage increase in mortality between ages 20 and 40. The second one estimates this for the ages 40 to 60, and the third is for ages over 60.

Since the life spans of twins are not independent, a random variable U_j is included which accounts for unobserved shared heterogeneity among twins. The random variable U_j is assumed to follow a normal distribution with mean zero and variance σ^2. Separate models are estimated for the two sexes.

In order to release the model from the proportionality assumption concerning the baseline hazard for people born in a specific half-year, model 6.4 is specified.

$$\begin{aligned} \ln \mu_{ij}(x,U_j) = z_i(\alpha_{01} + \alpha_1' y_1(x)) + (1-z_i)(\alpha_{02} + \alpha_2' y_2(x)) \\ + \beta' C_j + U_j \end{aligned} \qquad [6.4]$$

In Equation 6.4 $\ln \mu_{ij}(x, U_j)$ denotes the logarithm of the force of mortality at age x for individual i of twin pair j, $\alpha_{01}+\alpha_1' y_1(x)$ and $\alpha_{02}+\alpha_2' y_2(x)$ the age-dependent baseline hazards for people born in the first and second half of the year, and z_i an indicator variable for the first or second half-year of birth (z_i=1 if born in the second half-year, z_i=0 if born in the first half-year).

Specifying two baseline functions overcomes the proportionality assumption and allows for the estimation of two separate age-independent levels of mortality (α_{01} and α_{02}) and of separate age-dependent slopes of mortality (α_1' and α_2'). The baseline hazards $y_1(x)$ and $y_2(x)$ as well as the terms C_j, β', and U_j are defined similarly to Equation 6.2. Separate models are estimated for the two sexes. All estimations are performed in aML vers. 2.

In order to compare the pattern in life expectancy by season of birth between twins and the general Danish population, life tables are calculated by week of birth. For each week of birth the life expectancy is estimated. The 52 age values are smoothed by estimating the cosine function $age = a_0 + a_1 * cos(t - a_{11})$ with t = *week of birth*/52*2π.

To estimate differences in survival according to the quarter of birth on the basis of the US censuses for the year 1960, 1970, and 1980, a method called Survival-Attributes Assay (Vaupel 1991, Christensen et al. 2001) is applied. This method uses cross-sectional data on "fixed-attributes" to estimate the effect of a fixed trait on survival.

The Survival-Attributes Assay can be demonstrated on a simple example. Let N_{50} be the number of people at age 50. Let p_{50} be the proportion of 50-year-olds who have some fixed attribute such as the season of birth. Let p_{70} be the proportion at age 70. Let s be the conditional survival probability from age 50 to age 70 for the individuals who have the fixed attribute. Let S be the conditional survival probability from age 50 to 70 for the entire cohort.

Then, because

$$p_{50} N_{50}\, s = N_{50}\, S\, p_{70}, \qquad [6.5]$$

it follows that

$$s = S\, p_{70} / p_{50}. \qquad [6.6]$$

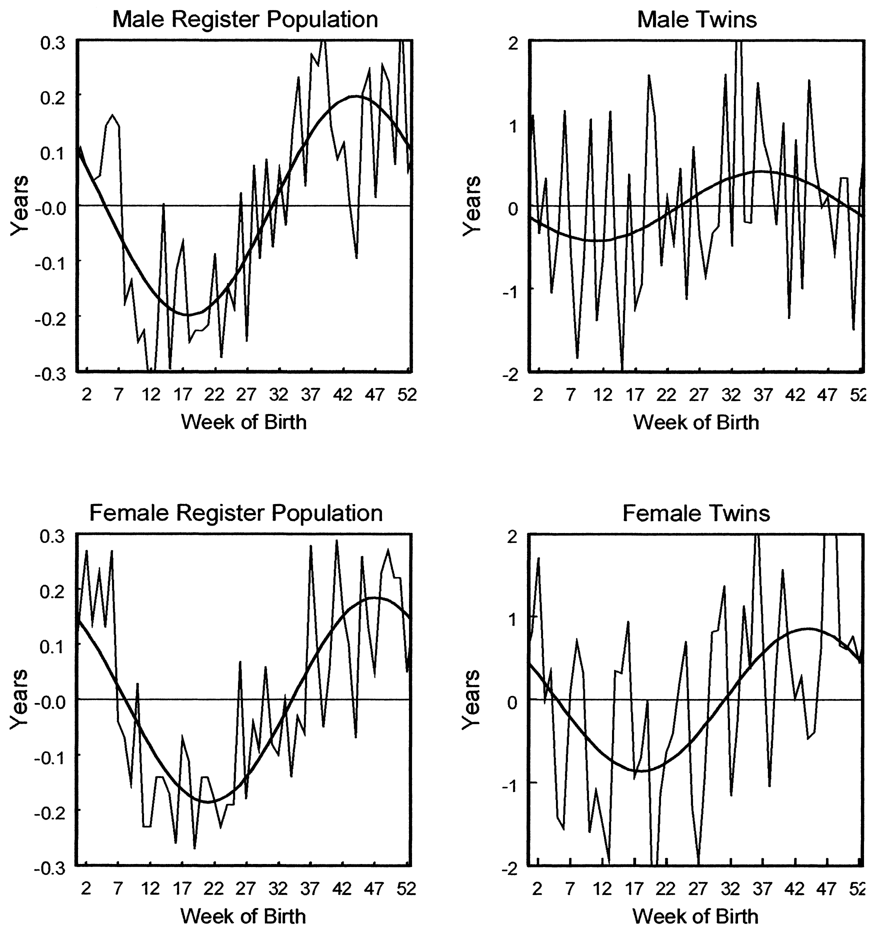

Figure 6.1 Differences in life expectancy by week of birth in the Danish register population (e^{50}) and the Danish twin register (e^{6}). The fitted lines are estimated by sinusoidal functions with a period of 52 weeks.

Thus, the relative risk of surviving from age 50 to age 70 for people born in a specific quarter is the ratio of their observed proportions in the two cross-sections. In this study we calculate the proportion of the population within ten-year age groups that is born in a certain quarter of the year. These age groups are then followed over the three census rounds.

This is a very simple and useful method but it relies on some crucial assumptions. The most important of these assumptions is that the 70-year-olds in the third cross-section were similar to the 50-year-olds in the first cross-section. The three US census rounds used in this study, however, allow us to follow a ten-year cohort on an aggregate level over a period of 20 years. The 70-year-olds in 1980 are the survivors of the 60-year-olds in 1970 and the 50-year-olds in 1960. In other words, the change in the proportion of the fixed attribute over an age range of twenty years is solely due to age effects and cohort effects do not confound it. Cohort effects confound comparisons of ages further apart than 20 years, however.

The three US census rounds 1960, 1970, and 1980 are used because these are the only census rounds that include information about the quarter of birth. Data are extracted from the "Public Use Microdata Samples", which are accessible under http://www.ipums.umn.edu/usa/index.html. The extract is restricted to the native-born white and black US population aged 0 to 100. For whites, this gives a sample size of 1,490,444 in 1960, 1,672,107 in 1970, and 1,812,839 in 1980. For blacks, we have 187,849 observations for the year 1960, 220,670 for 1970, and 256,447 for 1980.

The Danish population register was described in the second chapter of this manuscript. The Danish twin registry was established in 1954 as the first nationwide twin registry in the world. It includes all twin pairs born in Denmark between 1870 and 1910 and all same-sex pairs born between 1911 and 1930. The birth registers from all 2,200 parishes of the relevant calendar years were manually scrutinized to identify all twin births. Through regional population registers (in operation since 1924) and other public sources, a search was made for the twins, or whenever needed, their closest relatives. For twins who died or emigrated at an early age, it was impossible to obtain reliable data to be used in zygosity classification. Consequently, pairs were not followed up if one or both partners died or emigrated before the age of six. In this study 12,530 female and 11,237 male twins are followed until August 1995, and for each twin the exact age at death or at censoring is known.

6.2 Results

6.2.1 Comparison of the Month-of-Birth Pattern in the Danish Register Data and the Danish Twin Data

In both populations, life expectancy decreases sharply for those born in the first quarter. It reaches a trough for people born in the second quarter and then increases sharply for the summer-born. Life expectancy peaks for people born in the autumn.

The fit of the sinusoidal functions is significant for both sexes (p=0.001) and both registers. The striking difference between the pattern of the twins and that of the general population lies in the amplitude. In the female register population the amplitude is 0.19 years and for twins it is 0.85 years; for males the difference is 0.20 years and 0.42 years, respectively. Thus, the peak-to-trough difference among the female twins is about four times as large as among the register population. In interpreting this difference one has to keep in mind that, for twins, it reflects the difference in life expectancy from age six onwards while, for the general Danish population, it refers to differences in remaining life expectancy at age 50.

6.2.2 Age-Specific Mortality at Ages 50+ in the Danish Register Data

Figures 6.2a,b contain the parameter estimates *a* and *b* of the Gompertz models for the two cohorts 1889 to 1908 and 1909 to 1918, which are the basis for the mortality ratios displayed in Figure 6.3. As previously discussed, in the Gompertz-model the parameter *a* depicts the age-independent mortality level and *b* the increase in mortality over age. Excess mortality of the spring-born as compared to the autumn-born implies a significantly higher level for parameter *a* for the spring-born. If the excess mortality is age-dependent then parameter *b* should also differ significantly.

Significant differences in both the level of and increase in mortality between the spring- and the autumn-born exist in the older female cohort, although the increase in mortality is only of borderline significance. The level of mortality is lower among the autumn-born while the increase in mortality with age is higher. This implies that, with advancing age, mortality increases more rapidly among the autumn-born and that the excess mortality of the spring-born becomes lower. This is also true for males and in the younger female cohort, although the results are not significant.

Figure 6.3 shows the ratio of the age-specific death rates for people born in the first three quarters of the year to the death rates of those born in the fourth quarter. The smooth lines are based on the mortality estimates from the Gompertz models, the fluctuating lines on the life-table estimates. The solid lines pertain to the birth cohort 1909 to 1918, the dashed lines to the birth cohort 1898 to 1909. For men there is little evidence of age-specific mortality patterns after age 60, with the exception that the excess mortality of those born in the first half of the year decreases between ages 70 and 89. Among females this differs insofar as the excess mortality tends to increase between ages 60 and 70 and then starts to decrease at later ages.

There is still a decrease in excess mortality for the higher ages. There is a strong cohort effect among women and a weak effect among men. In the overlapping age groups 69 to 79 the excess mortality of the spring-born is much larger in the older female cohort than in the younger one. Although

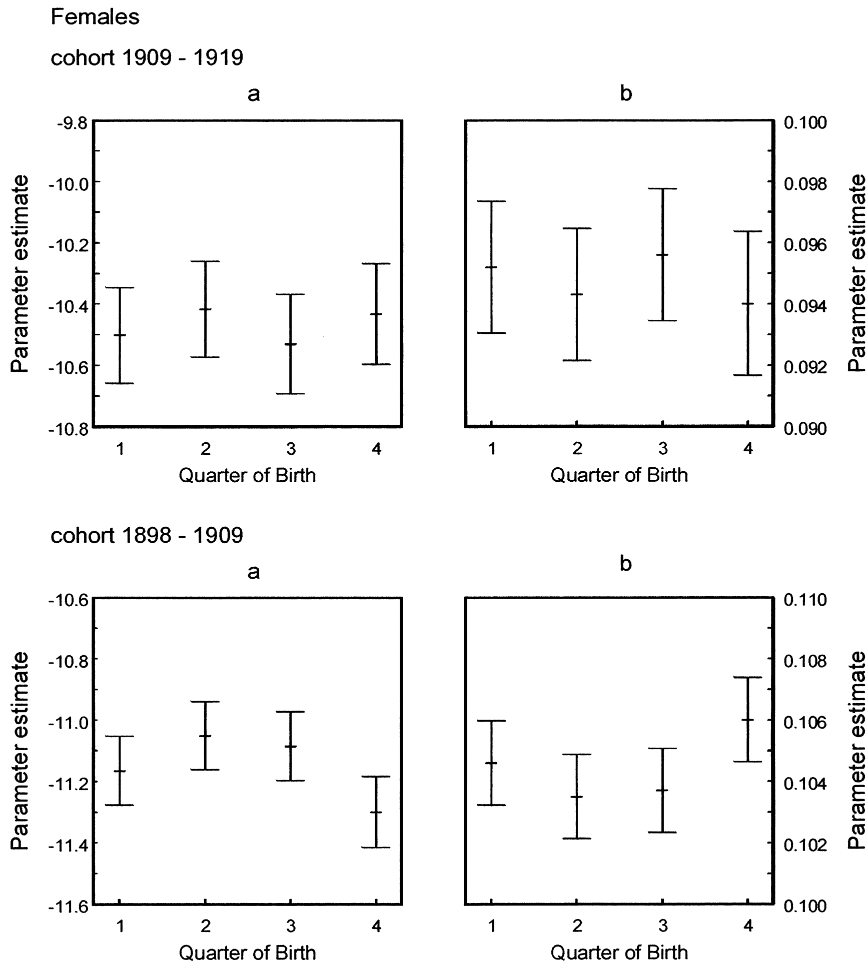

Figure 6.2.A Danish population register: parameter estimates *a* (level of mortality) and *b* (increase in mortality with age) of the Gompertz model specified in Equation 6.1 and 95% confidence intervals by quarter of birth for the two birth cohorts April 1909 – March 1918 and April 1898 – March 1908, females.

there is a similar tendency for all cohorts and both sexes one has to keep in mind that, on the basis of the Gompertz model, the differences are only significant for the older female cohort.

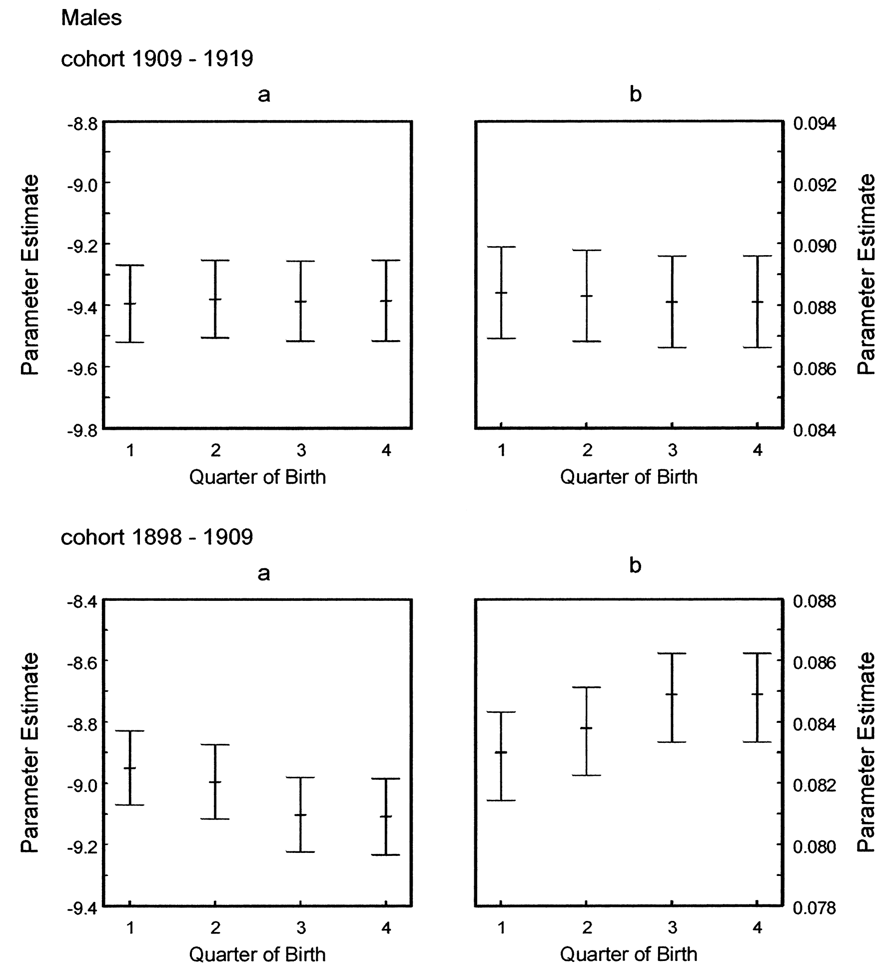

Figure 6.2.B Danish population register: parameter estimates *a* (level of mortality) and *b* (increase in mortality with age) of the Gompertz model specified in Equation 6. 1 and 95% confidence intervals by quarter of birth for the two birth cohorts April 1909 – March 1918 and April 1898 – March 1908, males.

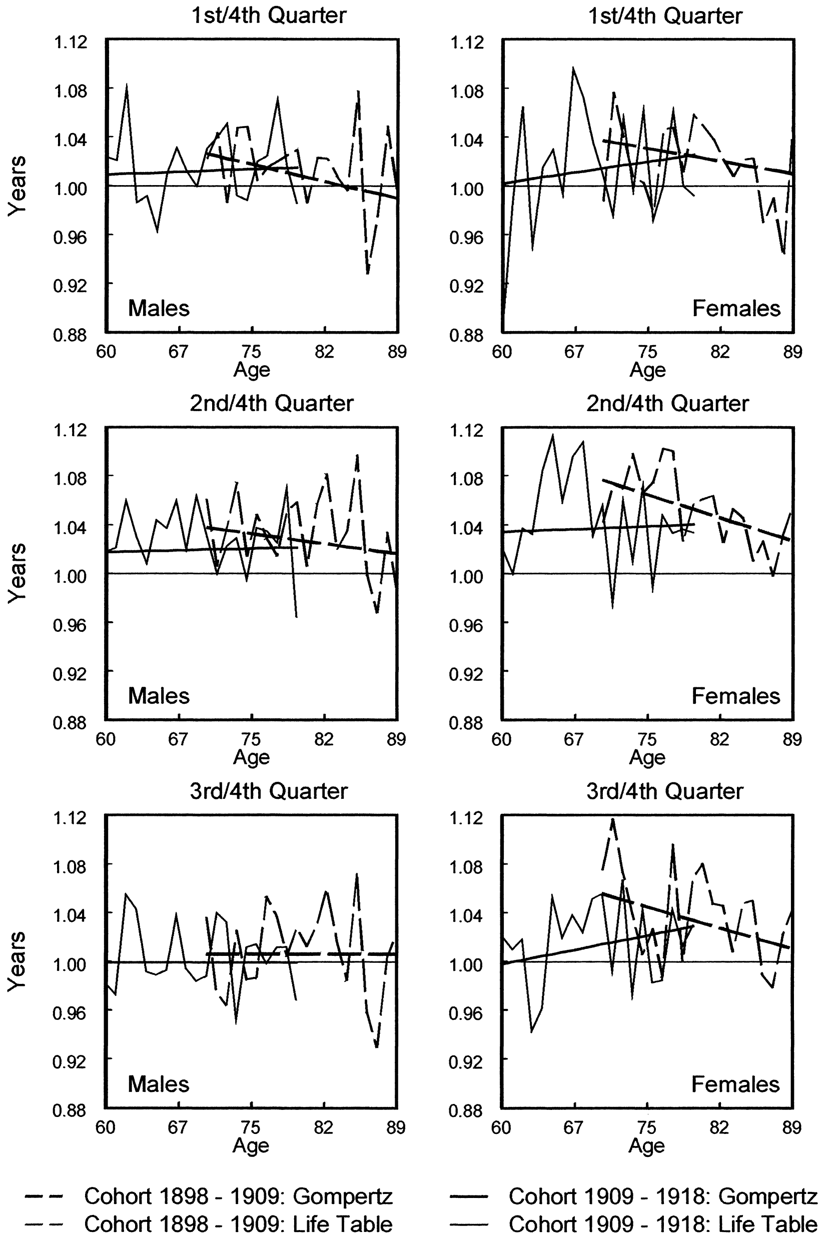

Figure 6.3. Danish population register: rate ratios by quarter of birth for the two birth cohorts April 1909 – March 1918 and April 1898 – March 1908.

6.2.3 Age-Specific Mortality at Ages 20+ in the Danish Twin Data

Significant differences in the force of mortality after age 20 by half-year of birth exist among female twins (Table 6.1). The proportional hazard model specified in Equation 6.2 reveals that those born in the first half-year experience excess mortality of 8 per cent ($p<0.001$). The increased mortality risk of 4 per cent among male twins is not statistically significant. Although the mortality of twins is followed from age six onwards the analysis has to be restricted to ages 20+. Only very few deaths are observed under age 20, which causes problems when estimating α, the age-independent level of mortality. Restricting the analysis to age 20+ stabilizes the estimates of α. This is particularly true for the second model, in which the proportionality assumption has been overcome by estimating separate baseline functions for those born in the first and second half-year. Although the differences between the two baseline functions in Equation 6.4 are statistically not significant, a general trend emerges. Table 6.2 shows that the age-independent mortality levels $exp(\alpha_{01})$ and $exp(\alpha_{02})$ are lower for those born in the second-half year (males first half-year: $e^{-6.17}=0.0021$, second half-year $e^{-6.25}=0.0019$; females first half-year: $e^{-6.26}=0.0019$, second half-year $e^{-6.41}=0.0017$). Figure 6.4 displays the loga-

Table 6.1. Danish twin data: parameter estimates of the proportinal hazard model specified in Equation 6.2

	Parameter estimates	
	Males	Females
Baseline hazard		
constant	-6.2282 ***	-6.3696 ***
slope 20-40	0.0020	-0.0002
slope 40-60	0.0881 ***	0.0698 ***
slope 60+	0.1170 ***	0.1157 ***
Birth cohort		
1870-1879	-0.0354	0.3532 ***
1880-1889	0.1167 **	0.2919 ***
1890-1899	0.0320	0.1725 ***
1900-1909	0.0503	0.0013
1910-1919	-0.0352	-0.0922 *
Born in first half-year	0.0443	0.0802 ***
σ^2	0.6321 ***	0.5522 ***
ln-L	-81186.0	-81397.3

*** p=0.001, **p=0.05, *p=0.1

rithmic hazards and Figure 6.4b the ratios of the hazards of the first and second half-year born. The latter reflects the excess mortality of those born in the first half of the year, which varies by sex. Among males, the excess mortality of the first half-year born increases between ages 20 and 40; among females, it decreases. An opposite trend exists between ages 40 and 60: excess mortality decreases among males and increases among females. From age 60 onwards the differences start to decline for both sexes. In interpreting this result one has to keep in mind that the maxima and minima in the trajectories of the hazard ratios in Figure 6.4b are determined by the positioning of the knots at ages 40 and 60. The knots are positioned such that they reflect changing points in the increase of the force of mortality with age. They do not necessarily reflect the ages where the difference between the first and second half-year born is largest or smallest.

Table 6.2. Danish twin data: parameter estimates of the hazard model with two baseline functions specified in Equation 6.3.

	Parameter estimates	
	Males	Females
Baseline hazard born in 1st half-year		
Constant α_{01}	-6.1696 ***	-6.2545 ***
Slope 20–40	0.0035	-0.0039
Slope 40–60	0.0858 ***	0.0734 ***
Slope 60+	0.1166 ***	0.1135 ***
Baseline hazard born in 2nd half-year		
Constant α_{02}	-6.2447 ***	-6.4126 ***
Slope 20–40	0.0001	0.0041
Slope 40–60	0.091 ***	0.0658 ***
Slope 60+	0.1174 ***	0.1179 ***
Birth cohort		
1870–1879	-0.0379	0.3545 ***
1880–1889	0.1164 **	0.2924 ***
1890–1899	0.0317	0.1745 ***
1900–1909	0.0507	0.0027
1910–1919	-0.0354	-0.0902 *
σ^2	0.6323 ***	0.5524 ***
Ln-L	-81185.3	-81395.9

***p=0.001, **p=0.05, *p=0.1

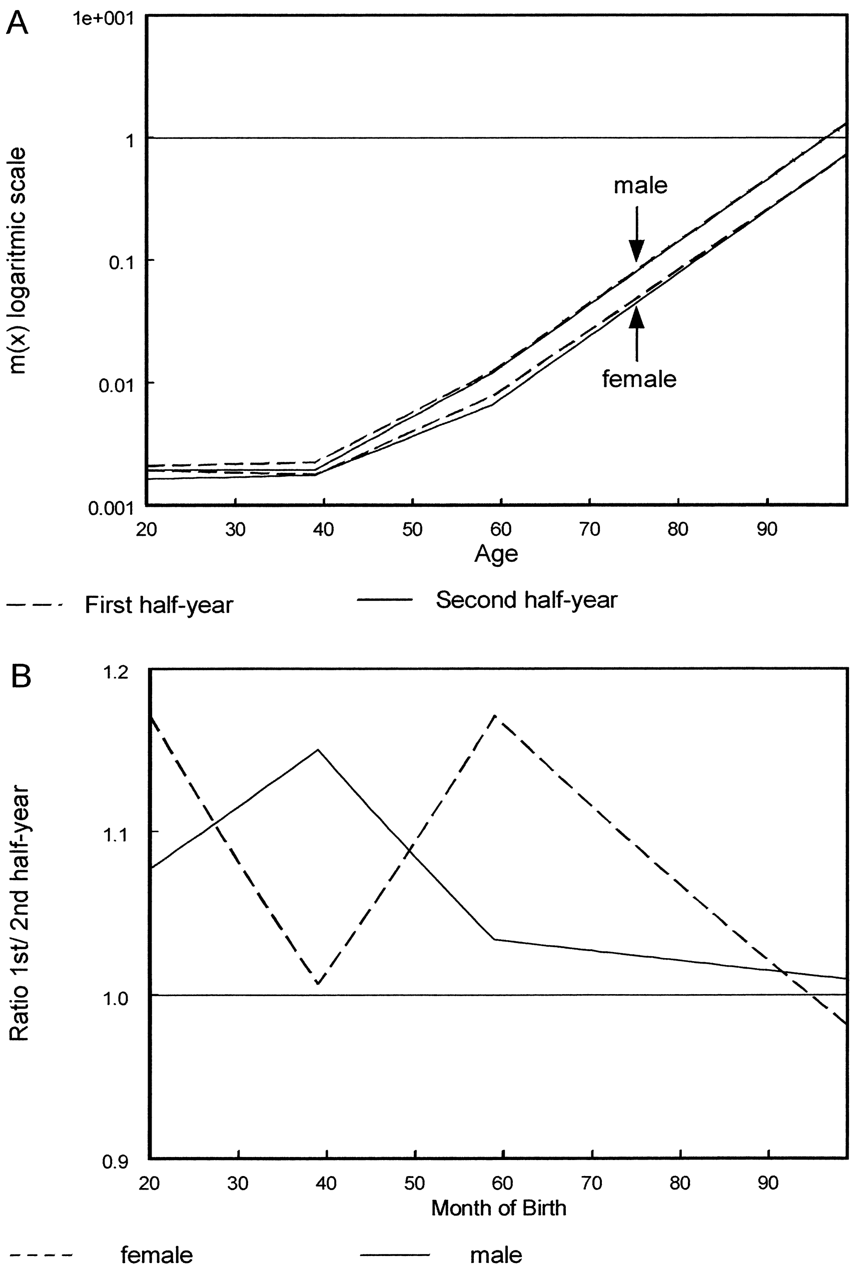

Figure 6.4. Danish twin data: (A) hazards for those born in the first and second half-year of the hazard model specified in Equation 6.4 and (B) ratios of the hazards of those born in the first/second half-year.

6.2.4 US Census Data

The eight trajectories in each square of Figures 6.5.A and 6.5.B depict the change in the distribution of people born in a specific month as they age. For example, the first trajectory shows the percentage of people aged 0-9 in 1960, 10-19 in 1970, and 20-29 in 1980; the second trajectory shows the percentage of people aged 10-19 in 1960, 20-29 in 1970, and 30-39 in 1980. The differences in the starting values of the trajectories for a particular age group are probably random effects due to census sampling.

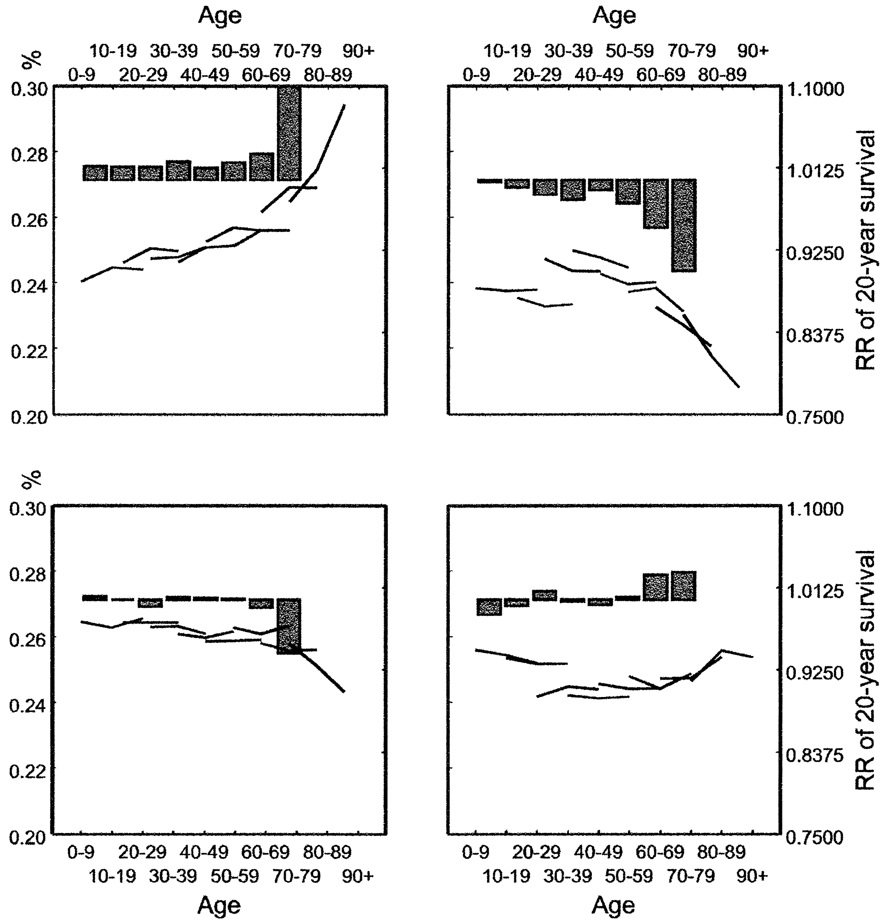

Figure 6.5.A US census data: changes in the proportion of people born in a specific month (lines) and relative risks of 20-year survival (bars) for US whites, based on the census data for the years 1960, 1970, and 1980; females.

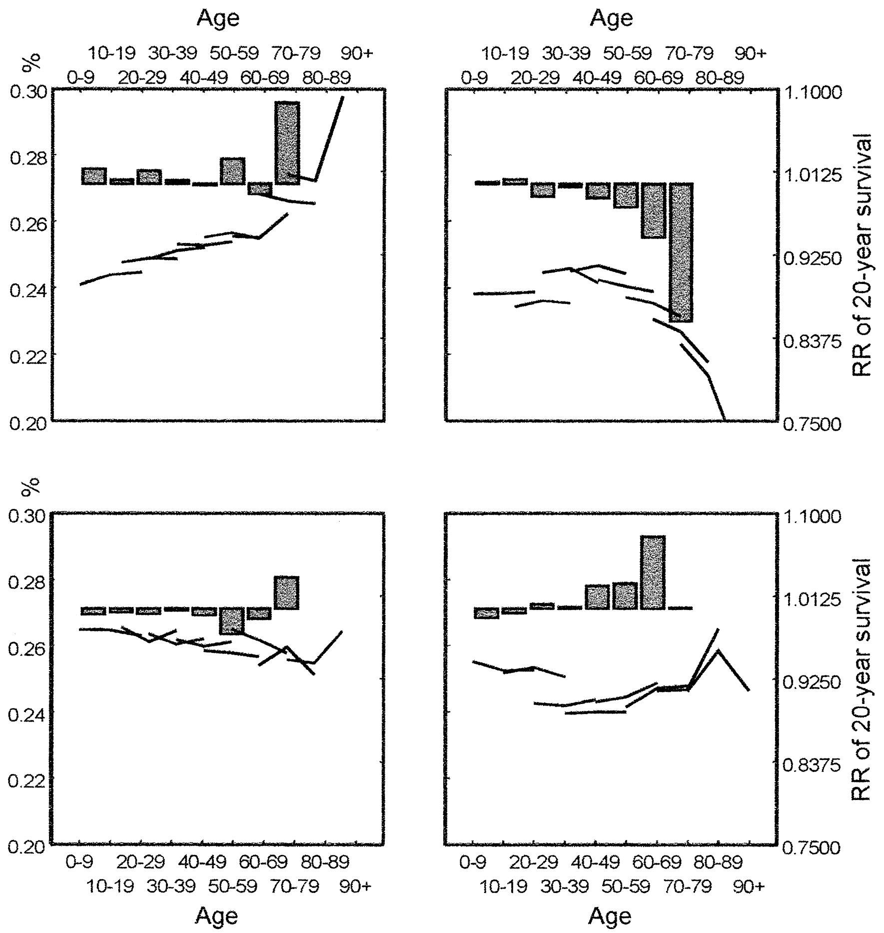

Figure 6.5.B US census data: changes in the proportion of people born in a specific month (lines) and relative risks of 20-year survival (bars) for US whites, based on the census data for the years 1960, 1970, and 1980; males.

Among whites the proportion of people who are born in the first and the fourth quarters increases continuously with age; the proportion of those born in the second and third quarters decreases continuously. Based on the Chi-square test statistic, the changes in the proportion are significant starting from the age group 30 to 39. The mortality disadvantage of the spring-born seems to be particularly large from age 60 onwards, however.

The decrease between ages 0 and 39 in the proportion of people born in the fourth quarter is highly significant (p=0.001).

An rather similar age pattern exists for blacks (results not shown): a continuous increase in the proportion of those born in the first quarter of the year; a decrease in the proportions of those born in the second and the third quarters. The pattern of those born in the fourth quarter is less consistent, suggesting both an increase in the proportion during middle ages and a decrease at older ages. For blacks, the changes in the distribution tend to be not significant, mainly due to the smaller numbers of observations, especially for the oldest age groups.

The US results from the comparison of the three census rounds are consistent with the results from the US death data. An increasing proportion with age of those born in the first and the fourth quarters is consistent with a higher mean age at death.

The bars in Figure 6.5a and 6.5b show the relative risks of the 20-year survival probabilities conditional on age for people born in a specific quarter compared to the average population. At younger ages the mortality advantage of the autumn-born and the disadvantage of the spring-born is minor. For males it is a maximum of one per cent over an age range of 20 years. In other words, up to the age of 40 the conditional survival probability of surviving the next 20 years is about one per cent higher for the autumn-born than for the average population; it is one per cent lower for the spring-born. Differences in the 20-year survival start to accelerate from the age group 40-49 onwards, when those born in the fourth quarter have a higher chance of 2.4% to survive the next 20 years; this advantage increases to 7.8 % for ages 60-69. The disadvantage in the 20-year survival of people born in the second-quarter starts at ages 50-59 and is about minus 2.8 per cent. It increases to minus 6.6 per cent for the age group 60-69. Similar trends emerge for women, which are more consistent, however.

6.3 Discussion and Conclusion

A look at all three populations leads us to the same conclusion: the mortality advantage of the autumn-born and the disadvantage of the spring-born exist in all age groups, but its magnitude is age-dependent. Both among the Danish twins and the general Danish population, the excess mortality of those born in the first half-year decreases in the highest age groups. In both populations this decrease is stronger among females than among males. The decreasing excess mortality at the highest ages is consistent with the effect of mortality selection. Among both the spring- and the autumn-born only the strongest survive up to the highest ages and differences according to the month of birth start to fade out.

The magnitude of the excess mortality differs also at younger ages. The results from the twin data suggest that, among men, the excess mortality increases between age 20 and age 40 and slowly declines thereafter. The slow decline in the excess mortality above 40 is supported by the results from the general Danish population. Among female twins excess mortality decreases between age 20 and 40, increases between 40 and 60 and declined rapidly thereafter. Again, the general Danish population trend supports this finding, where the peak of excess mortality appears to be in the mid-60s and is followed by a rapid decline.

Most interestingly, among female twins the excess mortality of those born in the first half-year disappears at middle ages. Pre-menopausal breast cancer may be one explanation. A Swedish study that compared the birth distribution of 115,670 women with breast cancer to the total number of live births in their birth cohorts found different month-of-birth patterns for women with pre-menopausal and post-menopausal breast cancer. The risk of pre-menopausal breast cancer was increased for women born in the autumn, and the risk of postmenopausal breast cancer was increased for those born in late spring (Yuen et al. 1994).

A comparison of the week-of-birth pattern in life expectancy among the general Danish population and the Danish twins shows a high degree of correlation, particularly among females. The male twin pattern, however, diverges to a larger extent from the pattern of the male general population, although the fitted sinusoidal function is significant. In particular, male twins born in the fourth quarter do not experience a mortality advantage similar to that of males in the Danish population.

Looking at the Danish register data, the difference in remaining life expectancy at age 50 between the autumn- and the spring-born is 0.3 years; among the Danish twins it ranges from 0.58 years in the youngest cohort (1910-1930) to 0.88 years in the cohort 1890-1909. In other words, for both sexes together the difference is at least two to three times higher among twins than among the general population. For females, the difference is about four times as larger in the twins than in the register population. Larger differences among twins than among the general population are in accordance with the hypothesis that seasonal changes in nutrition and infectious disease affect the foetus *in-utero* and the infant in the first year of life. Twins have to share scarce resources in-utero, they usually have lower birth weights than singletons, and they have a higher risk of mortality during their first years of life.

In Denmark the extent of the peak-to-trough difference in life span changes over cohorts. At similar ages they are larger in the older cohort

(1898-1908) than in the younger cohort (1909-1918). This decrease was first described in Doblhammer & Vaupel (2001). The age-specific analysis now provides further evidence that the extent of the season-of-birth pattern in the life span decreases over the time period from 1898 to 1918, when considerable improvements in nutrition took place and public health measures reduced the risk of infectious diseases. The decrease over birth cohorts appears to be stronger among females than among males.

The age-specific analysis on the basis of the three US censuses further supports the finding that the mortality advantage of those born in the second half of the year exists at all ages. In contrast to the Danish data, however, the mortality disadvantage of the spring-born starts to accelerate from age 40-50 onwards. The most probable explanation is that this increase reflects a cohort effect rather than an age effect since the US data do not allow one to distinguish between age and cohort effects for ages more than twenty years apart. Particularly the oldest age groups were born at a time before dietary patterns started to change and to resemble contemporary dietary patterns (Levenstein 1988, 1993). They were also born before improvements in infrastructure and the introduction of public health measures that significantly reduced infant mortality – particularly mortality caused by infectious disease (Preston & Haines 1991).

In all three datasets, namely, the Danish twins, the Danish register population, and the US censuses, the extent of the age-specific month-of-birth patterns seems to be sex-specific. First, the decrease in the excess mortality at advanced ages is more pronounced among females than males; this appears to be true also for the decrease over cohorts. Second, the twenty-year survival risk in the US censuses appears to be more consistent for females than males. Third, among females the excess mortality of those born in the first-half year reaches its maximum at a later age (60s) than among males (40s). Sex-specific causes of death may be responsible for the finding that, at middle ages, the mortality advantage of the autumn-born disappears among female twins. This result is consistent with a study conducted by Gavrilov et al. (2002), which reports sex-specific differences in the month-of-birth pattern among the European nobility. In particular, they find a more consistent pattern among females with higher excess mortality than among males.

The month-of-birth pattern in adult mortality exists at all ages. Over the whole life course those born in the first part of the year experience higher mortality than those born in the second part. The month-of-birth pattern is age-specific for two reasons: first, different causes of death are important at different ages and the magnitude of the excess mortality depends on the cause of death. Second, mortality selection results in a more homogenous group at higher ages because among people born both in the first and second half-year, only the most robust individuals survive, which means that differences are reduced.

All three datasets provide evidence that the month-of-birth pattern decreases in younger cohorts. This finding raises the question whether the differences still exist for people born today or whether the differences in life span by month of birth are merely of historical interest. An answer to this question will be provided in Chapter 8.