Including the Smoking Epidemic in Internationally Coherent Mortality Projections

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RUNNING HEAD: Smoking Epidemic in Internationally Coherent Mortality Projections

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Abstract We present a new mortality projection methodology that distinguishes smoking- and non-smoking-related mortality and takes into account mortality trends of the opposite sex and in other countries. We evaluate to what extent future projections of life expectancy at birth (e_0) for the Netherlands up to 2040 are affected by the application of these components. All-cause mortality and non-smoking-related mortality for the years 1970–2006 are projected by the Lee-Carter and Li-Lee methodologies. Smoking-related mortality is projected according to assumptions on future smoking-attributable mortality. Projecting all-cause mortality in the Netherlands, using the Lee-Carter model, leads to high gains in e_0 (4.1 for males; 4.4 for females) and divergence between the sexes. Coherent projections, which include the mortality experience of the other 21 sex- and country-specific populations, result in much higher gains for males (6.4) and females (5.7), and convergence. The separate projection of smoking and non-smoking-related mortality produces a steady increase in e_0 for males (4.8) and a nonlinear trend

for females, with lower gains in e_0 in the short run, resulting in temporary sex convergence. The latter effect is also found in coherent projections. Our methodology provides more robust projections, especially thanks to the distinction between smoking- and non-smoking-related mortality.

Keywords: Life expectancy, Projection, Smoking, Europe, Li-Lee methodology

Introduction

In most projections of mortality patterns, trends in mortality rates, life expectancy, or other life table parameters and their constructs are extrapolated (Bongaarts 2005; Murphy 1990; Olshansky 1988; Pollard 1987; Wilmoth 2000). Increasingly, the Lee-Carter (LC) model is being adopted as the benchmark method (e.g., Shang et al. 2011). This model summarizes mortality by age and period for one single population into an overall time trend, an age component, and the extent of change over time by age (Lee and Carter 1992). However, just as with many of the other mortality forecasting models, (1) it does not include any epidemiological information (either causes of death or determinants); (2) it ignores cohort effects; and consequently, (3) it cannot adequately model and project nonlinear trends. The LC model is often applied to single populations/countries without taking into account trends in other populations/countries; thus, it will lead to divergence, even though there may have been convergence in the past (Giannakouris 2004; Li and Lee 2005; Lundström 2003). Furthermore, it is dependent on the historical period of the past trend that is used as input to the model.

Divergence in mortality levels between populations in the long run is not a likely outcome. In Western Europe, convergence has been observed in old-age mortality (Janssen et al. 2004), and convergence between countries is likely thanks to common socioeconomic policies, similar progress in medical technology, and shared importance of certain lifestyle factors over

time. Also between the sexes, no divergence in mortality levels is expected, at least not for the short term (Gjonca et al. 2005; Meslé 2004; Pampel 2005; Trovato and Lalu 1996; Waldron 1993). Taking into account the trend in other countries has traditionally been applied in forecasts from national statistical offices, mostly by target setting (Goméz de Leon and Texmon 1992; Olshansky 1988; van Poppel and de Beer 1996). Currently, international agencies also adopt a convergence scenario in their forecasts (e.g., Eurostat 2010; United Nations Department of Economic and Social Affairs Population Division 2004). In other mortality projections, divergence between different populations is overcome by assuming similar rates of mortality decline (Bongaarts 2006; Ediev 2008; Janssen and Kunst 2007). In addition, the possibility of taking into account the mortality trends in other populations has recently been incorporated in a more formal manner in the Lee-Carter methodology by Li and Lee (2005). The latter identify the central tendency within the group and preserve interpopulation mortality differences in trends in the short term. In comparison with the many applications of the Lee-Carter method, the Li-Lee methodology, however, has not often been applied; and when used, it is used more often for regional than national purposes (e.g., Lee and Nault 1993; Statistics Canada 2010). Nor has the effect of including the mortality experience of other populations/countries been investigated in these or other attempts (Alho 2008; Wilson and Bell 2007).

Not including cohort effects and ignoring nonlinear trends in mortality projections is an additional important shortcoming, which has been recognized recently. Several recent studies have shown evidence of changes in the historical pattern of mortality decline (e.g., Booth et al. 2002; Janssen et al. 2007; Renshaw and Haberman 2006). As a response, stochastic models have been introduced to integrate the cohort dimension in mortality forecasting (see Cairns et al. 2011), including the cohort-based extension to the Lee-Carter model (Renshaw and Haberman

2006). Approaches have also been proposed to detect and deal with structural change (Booth et al. 2002; Coelho and Nunes 2011). So far, these models have not been used often. At the same time, however, there has been increased interest recently in the potential of including information on smoking in mortality forecasting (e.g., Bongaarts 2006; Janssen and Kunst 2007; Pampel 2005; Wang and Preston 2009). Smoking, undoubtedly one of the most important determinants of mortality levels and mortality trends and differences in European countries (e.g., Doll et al. 1994; Lopez et al. 1994), is being taken up differently by different birth cohorts and shows nonlinearity (Janssen and Kunst 2005; Janssen et al. 2007; Preston and Wang 2006). The smoking epidemic has increased mortality levels over a long period of time, first and stronger for males than females, with a time lag of about 30 years between the increase and subsequent decline in smoking prevalence on the one hand and the increase and subsequent decline in smoking-attributable mortality on the other hand (Lopez et al. 1994). Future trends in mortality will be substantially influenced by smoking, although differentially for males and females and differentially for different countries. This influence is not a straightforward extrapolation of past trends and cannot be captured by age-period modeling or projection. Instead, a separate projection of non-smoking-related mortality and smoking-related mortality seems appropriate.

The general aim of this article is to present a new mortality projection methodology that distinguishes smoking- and non-smoking-related mortality, and that takes into account mortality trends of the opposite sex and in other countries. In this way, epidemiological information is being included, and a more robust long-term trend might be generated to be used as a basis for projection. This will lead to less dependence on the historical period of one country used as input.

Our specific aim is to evaluate to what extent future projections of life expectancy at birth (e_0) for the Netherlands up to 2040 are affected by (1) the separate projection of smoking- and non-smoking-related mortality, (2) taking into account the mortality experience of the opposite sex and in 10 other low-mortality countries, and (3) their combination.

Mortality decline in the Netherlands has been less favorable in the past than in other low-mortality countries, with a stagnation in the increase in e_0 for Dutch males in 1950s and 1960s and for Dutch females in the 1980s and 1990s (Janssen et al. 2003, 2004; van Bodegom et al. 2010; van Oers 2002). Therefore, we expect that the inclusion of the long-term trend observed in a group of other low-mortality countries will lead to a substantial increase in the projected life expectancy for the Netherlands.

Smoking-related mortality among Dutch males has declined since 1983, whereas the turnover from the current increase into a future decline of smoking-related mortality has yet to occur among Dutch females (see the appendix). Therefore, we expect the separate projection of smoking- and non-smoking-related mortality to lead to nonlinearity in the projected trends and to smaller differences between the sexes in the short run.

Data and Methods

Data

For the Netherlands, data on all-cause mortality and population numbers by age (0, 1–4, 5–9, . . . , 110+), sex, and year (1970–2006) were obtained from Statistics Netherlands. The data for the Netherlands form the basis for all projections. For the coherent projections of mortality in the Netherlands, additional data were included on the mortality experience in 10 other European countries: Denmark, England and Wales, Finland, France, Italy, Norway, Spain, Sweden, Switzerland, and West Germany. These data were obtained from the Human Mortality Database.

The lung cancer deaths by sex, age (0–4, 5–9, . . . , 80+), and year (1950–2006) needed for the estimation of smoking- and non-smoking-related mortality (see "Estimating Smoking- and Non-Smoking-Related Mortality") were largely obtained from WHOSIS. For the Netherlands (2005–2006), West Germany (1991–2004), Denmark (2002–2006), and Italy, additional recent data were obtained from Statistics Netherlands cause of death statistics, Gesundheitsberichterstattung (GBE) des Bundes, NORDCAN, and ISTAT, respectively.

Estimating Smoking- and Non-Smoking-Related Mortality

To arrive at non-smoking-related mortality for these countries, we estimated smoking-attributable mortality by country, five-year age groups, and sex by means of the observed lung cancer mortality rates, using an adapted and simplified version of the indirect Peto-Lopez method (Bonneux et al. 2003; Ezzati and Lopez 2003; Peto et al. 1992), and we subtracted that from all-cause mortality. The indirect method of estimating smoking-attributable mortality, and our version of it, takes into account the fact that not all lung cancer mortality is due to smoking, and it includes deaths from other causes that could be attributed to smoking (see Pampel 2005; Rostron and Wilmoth 2011 for more elaborate descriptions and appraisals of the Peto-Lopez method). In the first step, the historical smoking prevalence (p) was estimated by comparing the observed national age- and sex-specific lung cancer mortality rates with the age- and sex-specific lung cancer rates of smokers and never-smokers (smoothed) of the ACS CPS-II study (Peto et al. 1992). In the second step, we estimated the age- and sex-specific etiological fraction (EF): that is, the proportion of all deaths attributable to smoking. We did so for all causes of death combined instead of by cause of death, as in the original Peto-Lopez method. The EF was calculated as a function of the proportion of the population that is exposed to smoking (p) and the relative risk of smoking for all causes of death combined (RR), using the formula $EF = p$(RR

– 1) / (p(RR – 1) + 1). The age- and sex-specific RRs were obtained by dividing the all-cause mortality rates among CPS-II smokers by the all-cause mortality rates among CPS-II nonsmokers and by subsequent smoothing by applying a second-degree polynomial (Bonneux et al. 2003). To take into account residual confounding due to exposure of smokers to other risk factors and to obtain conservative estimates of the numbers of deaths attributable to smoking, the age- and sex-specific RRs were adjusted downward by reducing the excess risk by 30 %. This adjustment was proposed by Ezzati and Lopez (2003) and is based on an analysis of the effect of confounding on the RRs in the CPS-II study. Smoking-related mortality is obtained by multiplying all-cause mortality with smoking-attributable mortality (EF).

Applying the Lee-Carter and Li-Lee Projection Methodologies

All-cause mortality and non-smoking-related mortality for the period 1970 until 2006 by age and sex were projected by (1) the Lee-Carter model applied to males and females separately; (2) the Li-Lee model, taking into account the mortality experience of the opposite sex; (3) the Li-Lee model, taking into account the mortality experience in the 10 other European countries by sex; and (4) the Li-Lee model, taking into account the mortality experience in all the other 21 populations.

The Lee-Carter (LC) model decomposes the log of the mortality rate, log[$m(x,t)$], into a time-invariant age component $a(x)$, an overall time trend $k(t)$, and $b(x)$ denoting the magnitude of the age-specific change over time (Lee and Carter 1992).

The Li-Lee method takes into account the mortality trends in other populations by applying the LC model twice (Li and Lee 2005). In the first round, the LC model is applied to the aggregate mortality of all populations, which results in a common time trend $K(t)$ and a common age-specific trend factor $B(x)$, next to the subpopulation's age pattern $a(x,i)$, hereafter

referred to as the "common factor model." In the second round, a country-specific LC model is applied to the country-specific residuals from the first round, resulting in a subpopulation-specific time trend $k(t,i)$ and a subpopulation-specific age-specific trend factor $b(x,i)$, which are added to the common factor model to result in the so-called augmented common factor model. $b(x,i)$ and $k(t,i)$ describe the difference between the rate of change of age x of country i at time t and the rate of change implied by the common factor $B(x)$ and $K(t)$. In the augmented common factor model, the eventual constant ratio between the age-specific mortality rates resulting from the common model will thus be adjusted in the short term according to the population-specific deviations from the common pattern and trend. If the $k(t,i)$ values become constant, the Li-Lee model leads to nondivergent forecasts of life expectancy in the long run but not necessarily in the short run (Li and Lee 2005).

To estimate the parameter estimates for all different models, we used the "coherent LC forecast" application of the webbased software LCFIT (Sprague, 2009). We selected age 90 as the age for extension, implying the use of a smoothing algorithm (a version of the Coale-Guo method) from age 95 onward. We also assume that age-specific mortality will not increase: that is, $b(x) > 0$ and $B(x) > 0$. The constraint has little effect on the outcome. Only for the Lee-Carter projection for all-cause mortality among males, it led to a slight increase in life expectancy at birth in 2040 of 0.03 years.

We evaluated how well the different models work for our population of interest through explanation ratios: that is, the "explained" sums of squares as a ratio of the total sums of squares in the rates (Li and Lee, 2005). Because the explanation ratio of the common factor model is high for each sex in the male-female application, and because the augmented common factor explanation ratios are not much better, we decided—in line with the recommendations by Li and

Lee (2005)—to use the common factor model when taking into account the mortality experience of the other sex.

Projecting All-Cause and Non-Smoking-Related Mortality

Projection of all-cause and non-smoking-related mortality by the Lee-Carter and Li-Lee models entails the extrapolation of the $k(t)$, $K(t)$, and $k(t,i)$ terms and combining this with the estimated $a(x)$, $b(x)$, $B(x)$, and $b(x,i)$ terms. For the $k(t)$ and $K(t)$ terms, a random walk with drift (RWD) is commonly selected, whereas the $k(t,i)$ are usually fitted by a random walk with zero drift or a first-order autoregressive model (AR1) with a constant (Li and Lee 2005). We deterministically estimated future all-cause and non-smoking-related mortality rates by applying to the adjusted $k(t)$ and adjusted $K(t)$ terms in 2006 the drift terms obtained through RWD (also based on adjusted $k(t)$ and $K(t)$). Because of nonstationary results for the AR1 model for the $k(t,i)$ terms for two of the coherent all-cause mortality models, and because of optimal comparability, we chose a random walk with zero drift for the extrapolation of the $k(t,i)$ term, which deterministically entails keeping the $k(t,i)$ at the same level as in 2006. By doing so, we assume zero convergence and, consequently, zero divergence. This is in line with the recent plateau in the $k(t,i)$ terms that was observed. Regarding the coherent models, we present projections for the Netherlands for both the common factor model and the augmented common factor model.

Separate Projection of Smoking-Related Mortality

The projection of smoking-related mortality was guided by the smoking epidemic model (Lopez et al. 1994) and by historical evidence on trends in both smoking prevalence and smoking-attributable mortality. More specifically, future levels of the age- and sex-specific etiological fraction (EF) for the Netherlands were projected by (1) estimating the maximum level of EF and the future year in which this will be reached for females based on age-period-cohort analysis, (2)

estimating the age-specific trends up to this maximum for females, and (3) applying equal declining patterns for males and females and for the different age groups after the year in which the maximum is reached, in line with the current trend in smoking prevalence. See the appendix for more information.

Combined Projection of Smoking- and Non-Smoking-Related Mortality

We arrived at the indirect projection of all-cause mortality (*T*) by combining the projected non-smoking-related mortality rates (*NS*) with the projected etiological fractions (*EF*) by means of the following formula:

$$m(x,t)^{T} = m(x,t)^{NS} \cdot \left(\frac{1}{1 - EF(x,t)} \right).$$

Life Table Calculations

On the basis of the directly and indirectly projected all-cause mortality rates, we applied life table techniques to calculate the future values of the life expectancy at birth. We used the ${}_{n}a_{x}$ values for Dutch males and females combined in 2006 from the Human Mortality Database.

In our projections, we chose the projected rates for 2006 instead of the observed jump-off rates, given that this is in line with the original idea of time series analysis (see Lee and Carter 1992, Li and Lee 2005 for a discussion of this issue). It will also increase the robustness of the results when an additional year is added to the historical period (Cairns et al. 2011). When comparing the different projections, however, we focus on the differences in the gain in life expectancy as against the projected life expectancy in the jump-off year. These gains are not affected by our choice in this matter.

Past Trends

In the period 1970–2006, mortality among the Dutch generally declined. A stronger decline has been evident since 2002. Clear differences between the sexes in past all-cause mortality trends

can be observed: a linear trend up to 2000 for males, but a strong decline up until 1984 and a stagnation from 1984 to 2002 for females. Mortality decline among men mainly stems from declines at the youngest ages. For females, on the other hand, a strong contribution is observed for those aged 60 to 90 (Fig. 1). The drift in the $k(t)$ parameter was higher among Dutch males (–0.43) than among Dutch females (–0.39) (Table 1).

[place Figure 1 and Table 1 about here.]

For non-smoking-related mortality, the mortality decline was more linear. Furthermore, it clearly shows that past non-smoking-related mortality levels, patterns, and trends have been more equal for males and females, compared with all-cause mortality (Fig. 1). The drift in the $k(t)$ parameter for non-smoking-related mortality was higher than for all-cause mortality for females but lower for males. A sex difference in the drift in the $k(t)$ parameter for non-smoking-related mortality remained, as is shown in Table 1.

These results clearly illustrate the role of shifts in smoking prevalence followed by shifts in smoking-attributable mortality for sex differences in all-cause mortality trends. The decline in smoking-attributable mortality for males since 1983 has resulted in faster declines in all-cause mortality among males since, whereas the increase in smoking-attributable mortality for females since the 1970s has resulted in slower declines in all-cause mortality among females. The decline in smoking prevalence started only later among older males, thus leading to a much slower improvement in all-cause mortality among older males.

Improvement in mortality for the 11 countries combined was more linear than for the Netherlands alone, both for all-cause mortality and for non-smoking-related mortality, and especially for females. Interestingly, the shape of $b(x)$ after age 40 showed more similar between

the Netherlands and the 11 countries combined for non-smoking-related mortality than for all-cause mortality (see Fig. 1).

The drift in the $K(t)$ parameter for the 11 countries combined was slightly higher among females than among males, almost similar for non-smoking-related mortality and all-cause mortality, and substantially higher than the drift $k(t)$ for the Netherlands alone (see Table 1).

Overall, no convergence of the mortality trends between the Netherlands and the 11 European countries showed (the *c1* values of the AR(1) model for $k(t,i)$ were not statistically significantly different from 1). However, the general worse past trends in mortality in the Netherlands turned into parallel trends from 2001 onward, almost similarly so for all-cause mortality and non-smoking-related mortality.

According to the explanation ratios, the age-period LC and Li-Lee models applied to the past trends generally performed better for males than for females, slightly better for non-smoking-related mortality than for all-cause mortality, and best when the remaining 21 populations are included through the augmented common factor model. The latter effect, however, is small for non-smoking-related mortality (see Table 2).

[place Table 2 about here]

Projected Trends

The Lee-Carter Model Applied to All-Cause Mortality

In the projection of all-cause mortality rates in the Netherlands up to 2040 with the Lee-Carter model for both sexes individually, life expectancy at birth (e_0) increased by 4.1 years for males and 4.4 years for females. The female advantage in e_0 is thus expected to increase (see Table 3).

[place Table 3 about here]

Including the Experience of the Other Populations for All-Cause Mortality

By including the mortality experience of the other sex (common model) for all-cause mortality, we obtain higher gains in e_0 for males (4.9 years) and lower gains for females (4.0 years), resulting in convergence between the sexes.

By applying the average sex-specific mortality experience in the 11 European countries (common models), we find much higher gains in e_0, especially for males (6.1 years for males, and 5.8 years for females), resulting in much higher life expectancy values in 2040. When the mortality differences in the trends in the short term for the Netherlands are taken into account (augmented common models), the gains do not change much (6.0 for males, and 6.1 for females). Life expectancy at birth in 2040, however, drops by about 1 year but still results in considerable higher values compared with the individual LC model. As a result, the sex difference in e_0 increases.

An additional effect can be observed when both the other countries and the trends for the opposite sex in all countries are taken into account: that is, convergence of e_0 between the two sexes (see Table 3).

The Separate Projection of Smoking- and Non-Smoking-Related Mortality

When non-smoking-related mortality is projected by the LC model and combined with projected smoking-related mortality for the Netherlands, the resulting gains in life expectancy over the period 2006–2040 (4.8 for males, and 4.6 for females) are higher compared with all-cause mortality, especially for males (see Table 3). However, nonlinearity is evident in the projected trends, especially for females. For females, we see smaller increases in life expectancy in the short run but higher increases in the long run. This added nonlinearity results in convergence of the sex difference in life expectancy in the short run, followed by divergent trends in the long run (see Fig. 2).

[place Figure 2 about here]

Combined Effects

The effect of including the opposite sex in the separate projection of smoking- and non-smoking-related mortality is in the same direction as in the direct extrapolation of all-cause mortality, but stronger.

The effect of including the mortality experience in the other 10 European countries in the separate projection of smoking- and non-smoking-related mortality leads to lower increases in life expectancy over the LC model for females but higher for males, as compared with all-cause mortality. Convergence of the sex difference in e_0 is found.

For the coherent models, as well, an effect of the separate projection of smoking- and non-smoking-related mortality shows in terms of the convergence of the sex difference in life expectancy and the added nonlinearity.

Throughout, including the smoking epidemic in the projections thus leads to clear convergence of the sex difference in e_0 in 2040; comparatively, in the projection of all-cause mortality, convergence in e_0 between the sexes is observed only in those models in which the opposite sex is taken into account (see Table 3). We will return to this aspect in our discussion.

When we include the smoking epidemic in coherent projections based on 22 sex-specific populations, the results indicate that life expectancy at birth in 2040 will increase to 85.0 years for Dutch males and 87.2 years for Dutch females (see Table 3).

Discussion

Our results for the Netherlands show that indeed the inclusion of the long-term trend observed in a group of other low-mortality countries leads to a substantial increase in the projected life

expectancy at birth (e_0). Increase in the sex difference in life expectancy occurs when the opposite sex is not taken into account.

The separate projection of smoking- and non-smoking-related mortality produces a steady increase in e_0 for males and a nonlinear trend for females, with lower gains in e_0 in the short run. Temporary convergence between the sexes results. The latter effect is also found in coherent projections of smoking- and non-smoking-related mortality. The positive effect on e_0 of the inclusion of other countries remains when smoking- and non-smoking-related mortality is projected separately.

Previous Research and Forecasts

To our knowledge, there has been only one previous application of the Li-Lee methodology for different countries, which is in the original Li and Lee (2005) article. In that application, the coherent forecasting method was conducted for both males and females combined on 15 low-mortality countries, using a historical period 1952–1996. Higher life expectancy values at birth in 2050 for the coherent forecast instead of the separate forecast were obtained for eight countries, including the Netherlands. Where the generalizability of results is concerned, it is interesting to note that for the Netherlands, the effect of including the experience in other countries was higher than in other countries, and it amounted to a difference of 2.4 years (Li and Lee 2005).

Previous work on separate projections of smoking- and non-smoking-related mortality has been conducted Bongaarts (2006) and Janssen and Kunst (2007), focusing on the projection of non-smoking-related mortality; Pampel (2005), focusing on sex differences in mortality; and Wang and Preston (2009), focusing on the effect of including the projection of smoking-related mortality in an all-cause mortality projection.

Bongaarts (2006) applied linear extrapolation to the average historical pace in senescent life expectancy without smoking for both sexes and in 16 low-mortality countries, keeping senescent life expectancy with smoking and juvenile and background life expectancy constant. Female life expectancy was expected to rise from 81.5 to 89.1 years, on average, between 2000 and 2050; male life expectancy was expected to increase from 75.8 to 83.3 years. Differences between the sexes remain at the levels observed in 2000 and thus neither converge nor diverge. His assumed average rate of increase in life expectancy without smoking (i.e., 0.15 years annually)—which he assumed to be the average rate of future improvement—is almost identical to our estimate for non-smoking-related mortality in the period 2006–2040 for the 11 countries combined: that is, 0.15 for males and 0.16 for females. His estimated e_0 for the Netherlands in 2050—83.3 years for males and 88.4 years for females—is very close to our results for females but is lower than our estimates for males (see Table 4). Furthermore, his estimates result in divergence in e_0 between the sexes given that he did not take into account the fact that men and women had contrasting trends in smoking.

[place Table 4 about here]

Janssen and Kunst (2007) applied—for seven low-mortality countries, separately—the annual change in non-smoking-related mortality to the observed age- and sex-specific all-cause mortality rates in 1999 for those aged 80 and older (Janssen and Kunst 2007). They also did not take into account the nonlinear, short-term future trend in smoking-related mortality.

Pampel (2005) forecasted sex differences in all-cause mortality in 21 high-income countries from 2000 up to 2020 by combining forecasted logged ratios of smoking mortality with presumed changes in logged mortality ratios from non-smoking-related causes of death. By employing regression models expressing the relationship between smoking prevalence and

smoking mortality 25 years later, he predicted a rapid decline of the sex difference in smoking-related mortality between the 1990s and 2020 for the countries combined. This convergence is countered, however, by the assumed ongoing divergence in non-smoking-related mortality rates, especially for countries reaching the end of the smoking epidemic. For the Netherlands, an ongoing sex difference was also observed when the LC model was used to project non-smoking-related mortality: that is, from 2.7 in 2006 to 3.9 in 2040. The strong convergence between Dutch males and females in smoking-related mortality will for the Netherlands still exert a stronger influence on the sex difference up until 2021.

Wang and Preston (2009) projected age-specific mortality rates for males and females in the United States at ages 50–84 for the period 2004–2034, by including a variable representing cohort smoking behavior in the Lee-Carter projection methodology. They projected much faster mortality declines when smoking was introduced into the model, especially for older males. In addition, when smoking was accounted for, the sex difference in mortality was projected to converge faster. These results are very much in line with what we observed as the effect of the separate projection of smoking- and non-smoking-related mortality, except that our convergence is only temporary, attributable to the increasing sex difference in non-smoking-related mortality.

Our methodology results in substantially higher life expectancy values in 2040 than those predicted by Statistics Netherlands (see Table 4). In its forecasts, Statistics Netherlands made use of the projection of eight broad groups of causes of death, including assumptions on specific determinants (e.g., smoking, obesity) up to the age of 80, whereas it applied a cohort approach from age 80 onward (van Duin et al. 2006, 2009). Their lower values mainly resulted from the assumption of a future leveling-off of mortality decline for those under age 80.

Our methodology also produces substantially higher values than the international forecasts by Eurostat (Eurostat 2010; Giannakouris 2004) and the United Nations (2006 revision) (United Nations Population Division 2007) (see Table 4), in which the trends in other countries are not taken into account, nor the recent more favorable mortality decline in the Netherlands from 2002 onward. The predictions made by the Uncertain Population of Europe (UPE) project (Alders et al. 2007) resemble our results more closely, especially for females, but still show lower life expectancy values in 2049. The predictions by the UPE project can be considered coherent projections because they used country-specific initial rates of decline and the same eventual rate of decline based on the recent trend in 11 low-mortality countries. The assumptions underlying the UPE project are considered more optimistic than other forecasts, although lower values were predicted for the Netherlands than for the other countries included in the project (Alho et al. 2006). This again might be due to the inclusion of the trend up to 2002 only, which leaves out the recent, more favorable mortality decline in the Netherlands.

Evaluation of Data and Methods

Our estimation of smoking-attributable mortality, based on a modified version of the indirect Peto-Lopez method, showed approximately the same results for 2000 as the original version and a recently introduced regression method (see Preston et al. 2010). The estimates based on a modified version of the Preston et al. method and another modified version of the Peto-Lopez method (Rostron 2010) are slightly lower for males but approximately the same for females. The underlying assumptions of a time-invariant effect of smoking on mortality and of a constant difference between males and females might have affected the trend in the estimates over time, which might contribute to the persisting difference between males and females and the continued nonlinearity in the non-smoking-related mortality trends. However, this nonlinearity might also

be the result of other cohort effects in mortality due to especially lifestyle factors—for example, exercise, drinking, and (to a lesser extent) obesity. Moreover, the more favorable overall non-smoking-related mortality improvement is likely to be due to more positive trends for females in other sociobehavioral determinants of sex differences in mortality, such as drug and alcohol use, diet, and health care (Gjonca et al. 1999; Pampel 2005; Trovato and Lalu 1996).

The projection of smoking-related mortality (see the appendix) involves important assumptions that no doubt affected our results, especially for females. A crucial factor is the estimation of the year in which smoking-attributable mortality for females will reach its maximum. Being potentially one or more years off (for example because of a change in anti-smoking campaigns) will most likely have an effect on the timing of the year from which the life expectancy for females will turn from a slow increase into a faster increase, and will thus also affect the projected sex difference in life expectancy.

Any mortality projection is dependent on the applied projection method or model, method-specific assumptions and choices, and a number of standard choices that need to be made.

Important issues in the Lee-Carter methodology are the assumptions of (1) a linear $k(t)$ trend, (2) constant ratios of age-specific change over time, (3) the adjustment of $k(t)$ so that estimated values closely resemble observed values, and—more generally—(4) the selection of an appropriate historical period, (5) the use of the projected or the observed jump-off rates, and (6) the use of smoothing (see Booth 2006; Booth et al. 2006; Lee and Miller 2000). An additional issue in the Li-Lee methodology is the selection of the populations that can be treated as a group (Li and Lee 2005).

Our methodology, and especially the projection of non-smoking-related mortality, seems less sensitive to some of the aforementioned assumptions and seems to better fit the Lee-Carter and Li-Lee framework.

The assumption of a linear $k(t)$ trend and consequently the selection of an appropriate historical period are crucial for the Netherlands—which has different periods of stagnation of mortality decline (Janssen et al. 2003)—as shown in a previous study on old-age mortality projections (Janssen and Kunst 2007). The sensitivity of the results for the choice of historical period is less for the more linearly behaving non-smoking-related mortality. The past non-smoking-related mortality trends prove to be more stable judging from the better fit of the age-period model and from the more parallel patterns between the sexes for non-smoking-related mortality compared with all-cause mortality. By using the more stable non-smoking-related mortality trends as an input, the arbitrariness surrounding the length of the historical period diminishes, as was also previously demonstrated by Janssen and Kunst (2007).

By applying coherent projections, the likelihood of unexpected divergent trends between populations diminishes. Including only experiences in other countries—and not in the opposite sex—for all-cause mortality can still, however, lead to an increase in the sex difference in e_0.

The assumption of constant age components $b(x)$ over time is a crucial one and is especially strong in the case of cohort effects, which give rise to age-period interaction. By separately projecting non-smoking-related mortality in which an important cohort effect in the past trends—that is, smoking—is excluded from the trends, this assumption decreases in importance.

Our application of the Li-Lee methodology to non-smoking-related mortality is assumed to be less affected, compared with all-cause mortality, by the selection of the countries in the group because a part of the national differences in mortality is explained by smoking.

The remaining issues (would not have major effects on our comparison of the different alternatives shown because we used the same application and assumptions for the different models and because we focused on comparing the gains in life expectancy against the projected values in 2006. Moreover, Booth et al. (2006) revealed no significant differences in the forecast accuracy for life expectancy in their comparison of extensions of the LC method that addressed these remaining issues.

Evaluation of the Observed Effects

When the experience in the other 10 countries was included, by means of both the common model and the augmented common model for all-cause mortality, it led to a substantial increase in Dutch life expectancy, as expected. Because the stagnation in the increase in life expectancy for Dutch females was observed in the 1980s and 1990s, which was a prominent feature of the included past trend of 1970–2006, the effect was higher among females. Dutch males also experienced stagnation but did so already in the 1950s and 1960s, after which an increase commenced again. Nonetheless, this increase in e_0 among males in the Netherlands remained lower than the increase for their male counterparts in other countries up until the end of the twentieth century. For females, the effect of including the mortality experience in the other 10 countries proved less for non-smoking-related mortality compared with all-cause mortality. This likely reflects an effect of smoking in the observed stagnation in e_0 among females, which was also suggested in previous research (Janssen et al. 2007; van Bodegom et al. 2010; van Oers

2002). Smoking, however, does not account for the whole gap between the Netherlands and the pattern for the 11 countries combined.

When applying separate projections of smoking- and non-smoking-related mortality, the nonlinearity that is added to the projected trends among females but not males reflects the smoking epidemic in the Netherlands. Among Dutch males, those born around the start of the twentieth century had the highest lifetime exposure to smoking (Gunning-Schepers 1988); consequently, the increase in smoking-related mortality among males reached its peak around 1983 and started to decline afterward. Among Dutch females, the uptake of smoking was much later than among males, and this resulted in large increases in smoking-related mortality only around 1970. According to our projections, females born around 1953 will exhibit the highest smoking levels and the highest smoking-related mortality, implying that smoking-related mortality among females will continue to increase until about 2020, after which a decline will set in; in contrast, smoking-related mortality among males already shows a decline (see the appendix).

Furthermore, our results show that with the inclusion of the trends in the opposite sex for all-cause mortality, and in all separate projections of non-smoking-related and smoking-related mortality, an increase in the sex difference in life expectancy is avoided, at least in the short run. Thus, relative to females, males will make faster gains in life expectancy at birth. This is in line with the general expectation behind the sex difference in life expectancy (Gjonca et al. 2005; Meslé 2004; Pampel 2005), which is based on the observed narrowing of the difference in e_0 between males and females in many low-mortality countries since the 1980s (Trovato and Lalu 1996; Waldron 1993). For the Netherlands, the sex difference in e_0 amounted to more than 6.5 years in 1980 and to 4.2 years in 2006. In general, the observed narrowing of the sex difference

in e_0 is related to the rise in smoking-attributable deaths of females relative to males (Pampel 2001, 2002), which can be linked to the narrowing of the gap in cigarette smoking between males and females (Pampel 2003). This convergence between the sexes is temporary, however, and will be observed only as long as it counterbalances further divergence in other deaths (Pampel 2002). For those countries already in the final stage of the smoking epidemic, ongoing divergence in non-smoking-related mortality is expected to counter convergence in smoking-related mortality (Pampel 2005). For the Netherlands, this trend of convergence followed by divergence is also clearly evident in the separate projection of smoking- and non-smoking-related mortality, leading to higher convergence of the sex difference even in 2040, compared with projections of all-cause mortality that show no or slight convergence. For the Netherlands, the sex-divergence in non-smoking-related mortality clearly shows from the drift of the $k(t)$ parameter of –0.39 for males and –0.42 for females, combined with the almost similar $a(x)$ and $b(x)$ values between the sexes. When projected by means of the Lee-Carter model, the future sex-divergence in non-smoking-related mortality amounts to 1.1 years up to 2040. However, this divergence would not occur if the projection method explicitly takes into account sex-specific trends in smoking-related mortality.

Similar Effects at Older Ages and for Other Low-Mortality Countries?

Additional analysis for remaining life expectancy at age 80 shows almost the same effects of adding the experience in the 10 other countries as for e_0 but much stronger effects of the separate projection of smoking- and non-smoking-related mortality. The latter is evident in higher gains in life expectancy for males, stronger nonlinearity for females, hardly any effect of including the opposite sex, and projected values for 2006 that are much closer to the observed values for 2006. For older females, the larger nonlinearity results are due to the later onset of the decline in

smoking-related mortality. For older males, the stronger effect of the separate projection of smoking- and non-smoking-related mortality can be linked to the important role of smoking in recent old-age mortality trends among elderly Dutch persons (Janssen et al. 2003, 2007). More generally, because the smoking epidemic will affect the elderly the latest, the greatest effects of separately projecting smoking- and non-smoking-related mortality for countries already approaching the end of the smoking epidemic will be found at the higher ages.

The effects noted in our article can thus be clearly linked to the past trends in the Netherlands with regard to both smoking and mortality. For other countries, effects from (components of) our methodology are likely to differ, depending on the nonlinearity of the selected past trends and on the phase of the smoking epidemic that a country is in. Countries with less nonlinearity are likely to exhibit a smaller effect. Countries still in the middle of a strong smoking epidemic are likely to show a greater effect. For those countries still in the early phases of the smoking epidemic, nonlinearity is likely to increase in the coming years.

Based on the application of the different models to the past trends between 1970 and 2006 for the 22 single populations under study, we can conclude that judging from the comparison of explanation ratios for the vast majority of populations, effects can be observed from either the inclusion of other countries (all countries, except Sweden), or distinguishing smoking- and non-smoking-related mortality (all countries, except France), or both (not in West Germany, Switzerland, and Sweden). For Denmark and Norway, we can expect the largest effects. For countries in which past trends have been more regular (explanation ratios for the Lee-Carter model ≥ 0.94)—such as West Germany, England, Wales, and France—improvements in explanation ratios are only limited. Still, however, an improvement over the application of age-period models can be obtained by taking into account nonlinear trends in mortality

attributable to smoking. The latter will also have an effect on future trends in the sex difference in life expectancy. An additional advantage of including the trends in other countries is that this will avoid an unlikely degree of divergence in mortality trends between the countries in the long run.

Conclusion

Our new mortality projection methodology resulted in substantially revised estimates of future trends in life expectancy in the Netherlands. The effects of the separate projection of smoking- and non-smoking-related mortality and of the coherent projections can be clearly linked to the past trends in the Netherlands in terms of smoking and its international positioning as regards mortality.

Also for other low-mortality countries, the separate projection of smoking- and non-smoking-related mortality is likely to generate effects in terms of a smaller sex difference in life expectancy in the short term and added nonlinearity, differently so for both sexes and for different ages. Coherent projections will lead to smaller differences between sexes and countries on the whole. In particular, the separate projection of smoking- and non-smoking-related mortality is likely to produce a more meaningful and robust projection of future life expectancy, with less dependence on the choices and assumptions that underlie mortality projections, such as the selection of an appropriate historical period.

In applying the proposed methodology to other low-mortality countries, we recommend a stepwise approach as to assess the effects of the different components. Particular attention should be given to the projection of smoking-related mortality, for which a common method needs to be developed that can be applied to countries in different phases of the smoking epidemic.

All in all, mortality projections can benefit from a more thorough study of past mortality trends. Especially relevant would be to look into the determinants behind the deviations from the linear trend and behind sex- and country-specific deviations from the common pattern.

Appendix: Projection of Smoking-Related Mortality

Future levels of the age- and sex-specific etiological fraction (EF) (i.e., the proportion of all deaths attributable to smoking) for the Netherlands were estimated by applying the general ideas from the descriptive model of the smoking epidemic (Lopez et al. 1994), by examining historical trends in etiological fractions by age and sex, and by studying recent trends in smoking prevalence.

The descriptive model of the smoking epidemic shows the common pattern of an increase and thereafter a decrease in smoking prevalence, followed by similar patterns in smoking attributable mortality three to four decades later. For females, the increase in both smoking prevalence and smoking-attributable mortality started later than for males and is more modest. All countries follow more or less the same patterns, but with a different timing of onset, saturation, and so on (Lopez et al. 1994).

Females in Denmark and in England and Wales are among the few who already experienced a peak in smoking-attributable mortality. In these two countries, the smoking-attributable mortality trends by age for males show a clear cohort pattern up to the peak, followed by a period pattern after the peak. For females, the cohort pattern is much less evident. An important observation is that for each age group the time span between the maximum EF for males and the maximum EF for females is almost the same and approximately equals the number of years between males and females in reaching the maximum EF for all ages combined.

In the Netherlands, the maximum level of EF for all ages combined was reached for males in 1983, whereas the maximum has not yet been reached by females in any of the age groups. For

females, we therefore need to estimate the year and level of the maximum EF, as well as the trend up to and after this maximum. For males, it is necessary to estimate only the future decline.

To estimate the year in which EF will reach its maximum among Dutch females, we applied an age-period-cohort Poisson regression model to lung cancer mortality data from 1950 to 2004 by five-year age groups and five-year periods. As an offset term, we used the log of the average population. By adding the average age of dying from lung cancer (68) to the cohort with the highest lung cancer mortality (1953), we obtained the year in which EF reaches its maximum for females: 2021. This year resembles adding a lag time of 35–41 years to the years 1980–1986, in which smoking prevalence reached its maximum level among Dutch females. The years in which EF will reach its maximum for females for the separate age groups were subsequently estimated by applying the difference in timing between males and females of the maximum EF for all ages combined (38) to the years in which the maximum EF was reached for males in the separate age groups. These years in which the EF reached its maximum for males were assessed by means of the smoothed trends, obtained by fitting fourth-degree polynomials.

For females, the trend in the age-specific EF up to the maximum was based on the age-specific growth rate observed over the past 10 years. A deceleration of the growth rate to 1 was applied.

The age-specific long-term decline after the maximum for both males and females was set equal to the trend in EF for all ages combined after the maximum for males (–1.5 %), which reflects the current trend in smoking prevalence for all ages combined (–1.7% for males, and –1.3% for females), as well as the similarity in the current decline in smoking prevalence in the Netherlands between both sexes and the different age groups.

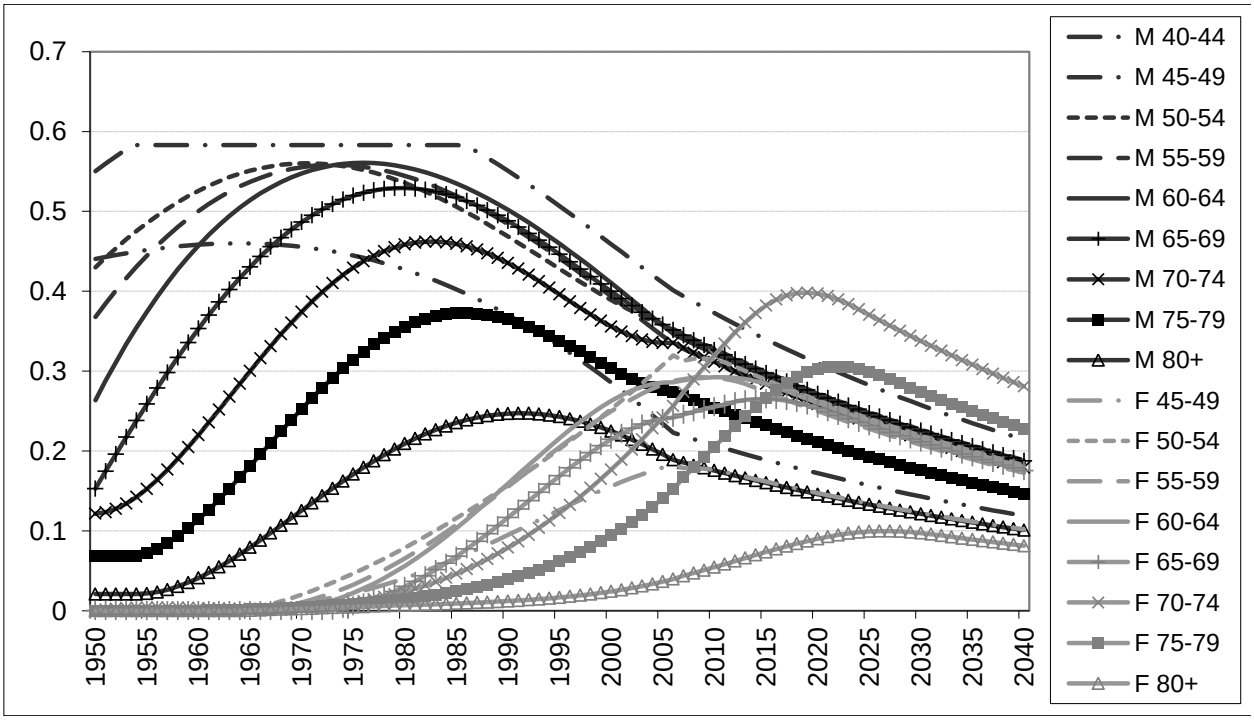

Fig. 3 Smoking-attributable mortality fractions (EF) by age and sex, observed (smoothed) and projected, 1950–2040. The restriction that the proportion of the population exposed to smoking should be smaller or equal to 1 is responsible for the plateau for males aged 45–49 in 1954–1985.

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Table 1 Drift $k(t)$ and $K(t)$ for all-cause mortality and non-smoking-related mortality for the individual and combined populations respectively, by sex, 1970–2006

	Males	Females	Males and females
All-Cause Mortality			
The Netherlands	-0.43	-0.39	-0.42
All 11 Countries Combined	-0.48	-0.50	-0.48
Non-Smoking-Related Mortality			
The Netherlands	-0.39	-0.42	-0.41
All 11 Countries Combined	-0.46	-0.52	-0.49

Table 2 Explanation ratios of the different models for the Netherlands (NL), 1970–2006

Model	Sex	Individual Lee-Carter Model	Common Factor Model	Augmented Common Factor Model
All-Cause Mortality				
NL male + female	Male	0.90	0.90	0.90
	Female	0.87	0.85	0.88
NL + 10 countries	Male	0.90	0.80	0.92
	Female	0.87	0.66	0.90
NL + 21 populations	Male	0.90	0.79	0.93
	Female	0.87	0.67	0.90
Non-Smoking-Related Mortality				
NL male + female	Male	0.92	0.90	0.92
	Female	0.90	0.87	0.87
NL + 10 countries	Male	0.92	0.74	0.93
	Female	0.90	0.77	0.91
NL + 21 populations	Male	0.92	0.68	0.93
	Female	0.90	0.80	0.91

Note: These explanation ratios were obtained directly from the LCFIT program output.

Table 3 Projected life expectancy at birth (e_0) in the Netherlands (NL) in 2040, by sex, for the different models

		All-Cause Mortality			Smoking- and Non-Smoking-Related Mortality		
		M	F	F – M	M	F	F – M
e_0 2040							
NL Lee-Carter	Individual	81.89	86.50	4.6	82.42	86.48	4.1
NL male + female	Common	82.17	86.55	4.4	83.98	85.49	1.5
NL + 10 countries	Common	84.46	89.36	4.9	85.63	88.69	3.1
	Augmented Common	83.34	88.34	5.0	84.39	87.88	3.5
NL + 21 populations	Common	84.77	88.89	4.1	86.41	87.92	1.5
	Augmented Common	83.68	87.77	4.1	85.04	87.17	2.1
Gains in e_0: 2040 Levels vs. Projected 2006 Values							
NL Lee-Carter	Individual	4.11	4.38	+0.3	4.80	4.62	-0.2
NL Male + Female	Common	4.91	3.99	-0.9	5.89	4.11	-1.8
NL + 10 countries	Common	6.06	5.79	-0.3	6.80	5.80	-1.0
	Augmented Common	6.01	6.09	+0.1	6.98	5.97	-1.0
NL + 21 populations	Common	6.50	5.37	-1.1	7.26	5.47	-1.8
	Augmented Common	6.37	5.71	-0.7	7.55	5.49	-2.1

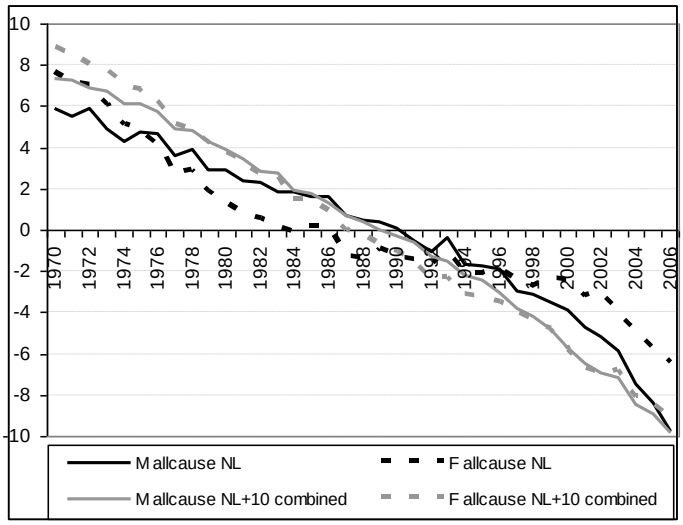
Table 4 Future life expectancy values according to our methodology (including the smoking epidemic in coherent projections based on 22 sex-specific populations) and forecasts for the Netherlands (NL), by sex

	Forecast Year	Males	Females
Our Methodology	2040	85.04	87.17
Statistics NL 2006	2040	80.89	83.67
Statistics NL 2008	2040	82.33	84.82
EUROPOP 2004	2040	79.7	83.2
EUROPOP 2008	2040	79.9	83.2
UN 2006 (medium variant)	2040	81.4	83.8
Uncertain Population of Europe	2049	82.5	86.4
Bongaarts 2006	2050	83.30	88.40
Our Methodology	2049	86.65	88.64
Our Methodology	2050	86.82	88.78

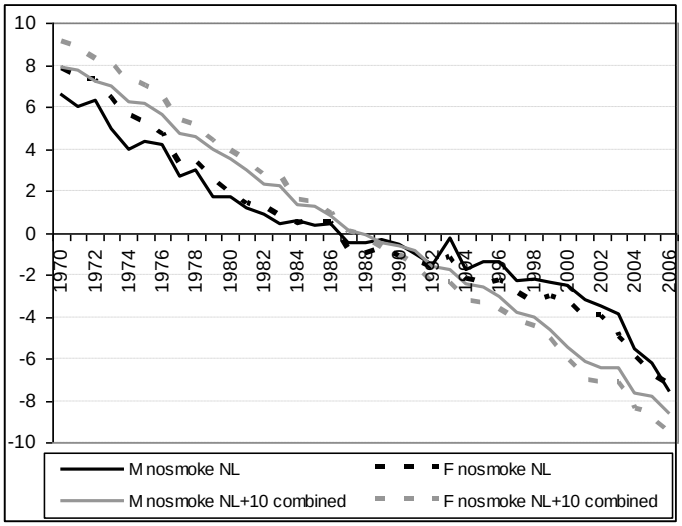
Sources: Alders et al. 2007; van Duin et al. 2006; Eurostat 2010; Giannakouris 2004; van der Meulen et al. 2009; United Nations Population Division 2007

Fig. 1 Past all-cause and non-smoking-related mortality trends for the Netherlands (NL) versus the 11 countries combined, 1970–2006, by sex

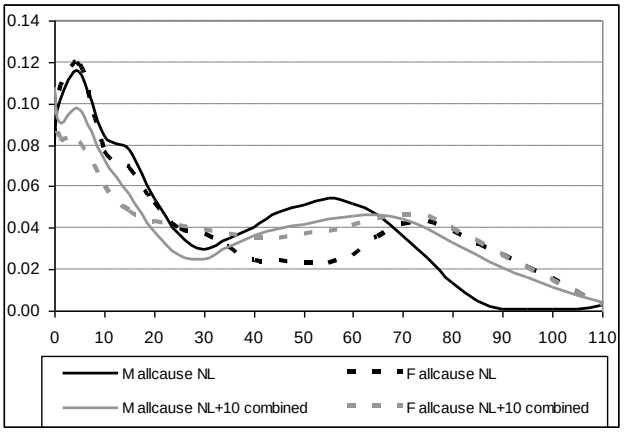
k(*t*) and *K*(*t*) all-cause mortality



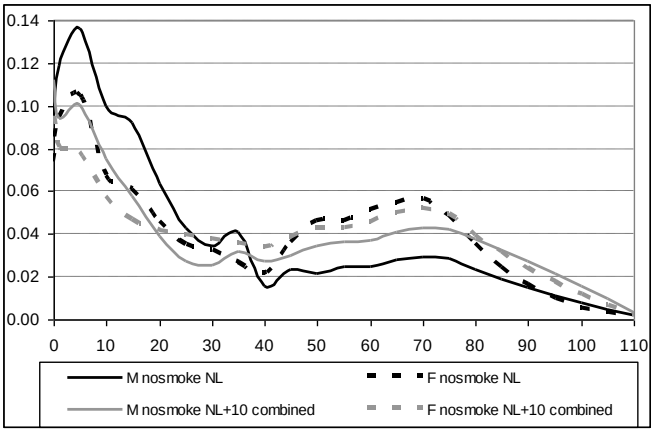
k(*t*) and *K*(*t*) non-smoking-related mortality



b(*x*) and *B*(*x*) all-cause mortality



b(*x*) and *B*(*x*) non-smoking-related mortality



a(*x*) all-cause mortality and non-smoking-related mortality

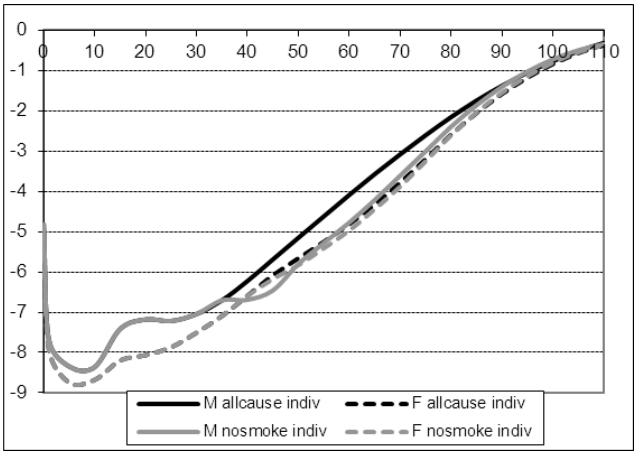


Fig. 2 Observed and projected life expectancy at birth for the projection of all-cause mortality versus the separate projection of non-smoking-related and smoking-related mortality, by sex, the Netherlands, 1970–2040