Future mortality in European countries: based on coherent projections of both all-cause mortality and non-smoking-related mortality

Fanny Janssen and Leo van Wissen
Population Research Centre, University of Groningen, the Netherlands

Abstract

In making national mortality projections, it is recommended to take into account the mortality experience of other countries. In this paper, we applied the Li-Lee methodology for coherent mortality projections to the majority of European countries. We extrapolated both past trends in all-cause mortality and non-smoking-related mortality. In addition, we conducted a sensitivity analysis related to the selection of the in- and out-of-group populations. The coherent projections led to a convergence of life expectancy levels between the different countries and the two sexes, which is a likely outcome. Life expectancy levels were higher as predicted for many individual European countries. The selection of in- and out-of-group populations strongly affected the outcomes for all-cause mortality, but is less important for the projection of non-smoking-related mortality. The Lee-Li methodology can therefore best be applied when non-linear effects, such as the effects of the smoking epidemic, are secluded from the past trends.

Background

Mortality projections are highly valuable for social security programs and are often used to predict the sustainability of pension schemes. The level of future mortality levels, especially among the elderly, has important implications for social and health care policies.

In most projections of future mortality patterns, past mortality trends are used as an input (Wilmoth 2000; Bongaarts 2005). These past mortality trends are either extrapolated or used in other ways - e.g., by predicting life-table parameters or their constructs, or by the use of mortality models - to determine future trends (Pollard 1987; Olshansky 1988; Murphy 1990).

However, when projections for separate countries are based on the linear extrapolation of past mortality trends in each individual country, an almost inevitable result is divergence in future mortality levels, even though there may have been convergence in the past (Lundström 2003; Giannakouris 2004; Li and Lee 2005). Although the divergence in mortality levels between countries is in line with what has recently been observed for industrialized countries (Vallin and Meslé 2004) and also at the global level (Wilson 2001; Moser et al. 2005), this is not a likely outcome in the long run for a group of countries for which trends in most determinants of mortality are likely to be similar, thanks to common socio-economic policies, similar progress in medical technology, and similar developments in more specific factors, such as the smoking epidemic. Therefore, the use of the mortality experience of other countries in making national projections might be valuable.

In 2005, Li and Lee developed a method to take into account the mortality experiences of other populations in a group (i.e. other countries or the other sex) when predicting mortality. They do so by extending the well-known Lee-Carter method (Lee and Carter 1992). Li and Lee identify the central tendency within the group, but also preserve inter-country mortality differences in trends in the short term. They do this by giving the historical particularities of each country their due weight when projecting individual-country trends in the short or medium term, while letting them taper off in the long term over which divergence ends. (Li and Lee 2005)

A remaining arbitrary element when applying the Li-Lee methodology is the choice of the in-the-group and out-of-group populations. A crucial question is which countries will determine the

central tendency, or basic mortality trend, that will be applied to the other countries. In this paper, we will therefore also apply a sensitivity analysis, based on different selections of the in-the-group and out-the-group populations.

Important as well is that the Lee-Carter methodology, and therefore also the Li-Lee methodology, applies an age-period framework. Non-linear patterns or cohort effects can therefore not appropriately be captured with this methodology. Non-linear patterns in mortality in Europe seem to a large extent the result of smoking. The long-term trend in old-age mortality might therefore be identified more accurately if the effects of smoking are isolated from the long-term trend. Therefore, we apply the Lee-Li methodology not only to all-cause mortality but also to non-smoking-related mortality. (Janssen and Kunst 2007)

Objective

Our objective is threefold:

1) To apply the Li-Lee methodology for coherent mortality projections to the majority of European countries, for both all-cause mortality and non-smoking-related mortality.
2) To examine the effect of the use of coherent mortality projections over the conventional use of the Lee-Carter methodology.
3) To explore the sensitivity of the outcomes for different selections of the in- and out-of-group populations.

Data & methodology

To address the objective, data was needed on all-cause mortality, exposure, and lung cancer mortality data (to estimate non-smoking-related mortality) for a long enough historical time period to obtain stable results. After exploring the data availability of different sources (Human Mortality Database, the NIDI/Eurostat database on mortality in Europe, WHOSIS), we could select 24 European countries with data for the years 1970-2004, e.g. Austria, Belgium, Bulgaria, Switzerland, Germany East, Germany West, Denmark, Spain, Finland, France, Greece, Hungary, Ireland, Iceland, Italy, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Sweden, United Kingdom. For the majority of countries, data on all-cause mortality and exposure by year, sex and age (0 – 100+) was obtained through the Human Mortality Database (www.mortality.org). For Greece, Ireland, Luxembourg, Malta, Poland and Romania these data were obtained through the NIDI/Eurostat database on mortality in Europe. As part of a project subsidized by the European Commission (Eurostat) ("Decomposition of life expectancy changes by cause of death"), the Netherlands Interdisciplinary Demographic Institute (NIDI) in the Hague constructed a database on mortality in Europe.

Lung-cancer mortality data by year, sex and age (0 – 80+ in five year age groups) were obtained mainly through WHOSIS (http://www.who.int/whosis/en/). For Italy, Belgium, Denmark, Portugal, West Germany and East Germany, additional information on lung cancer mortality needs to be obtained. We will try to obtain these data through the national statistical offices and related institutes.

In some instances, interpolation techniques need to be applied, e.g. for Poland information on the years 1997 and 1998 is missing, and for Romania for 1979.

Levels of smoking-related mortality by age, sex, country, and calendar year were estimated using an adapted version of the indirect Peto-Lopez method (Peto et al. 1992; Ezzati and Lopez 2003; Bonneux et al., 2003). See Appendix I. Non-smoking-related mortality was calculated as total mortality minus smoking-related mortality.

To the all-cause mortality data and the non-smoking-related mortality data, we apply both the Lee-Carter methodology and the Li&Lee methodology, and compare the results. (See Appendix II for a full description of the Lee-Carter and Li&Lee methodology.) In doing so, we take into account the uncertainty in the parameter estimates of the time series models to generate a distribution of outcomes of the model. We thus perform a stochastic prediction. For this purpose, we will use the programme LCFIT by Webb Sprague from UC Berkeley (http://lcfit.demog.berkeley.edu). Note that the programme is still under development, and that the results need to be interpreted with caution.

To obtain future values of life expectancy (2025 and 2050), life tables were applied to the predicted age-specific mortality rates, by sex and country.

Preliminary analysis and findings

Preliminary analysis for a selection of European countries (see Table 1) showed that the common factor model defining all these countries as in-the-group populations gave for the majority of countries a worse fit as compared to the Lee-Carter model. Applying the augmented common factor model (including the common trend and the country-specific deviations from this trend) led to improvements of the fit. The resulting explanation ratios, however, remain low for quite a number of countries. For Italy, Hungary, and Bulgaria strange results appeared. Note, however, again that these findings should be interpreted with caution.

Table 1: Explanation ratios for the Lee-Carter model (LC), the Common model (C) and the Augmented Common model (AC) applied to all-cause mortality for different combinations of country and sex, 1970-2004

country&sex	cluster	LC	C	AC	country&sex	cluster	LC	C	AC
Denmark - M	N	0.69	0.59	0.79					
Denmark - F	N	0.68	0.52	0.74					
Finland - M	N	0.87	0.80	0.84					
Finland - F	N	0.82	0.74	0.84					
Sweden - M	N	0.87	0.80	0.83					
Sweden - F	N	0.86	0.78	0.82					
Austria - M	W	0.94	0.88	0.94					
Austria - F	W	0.91	0.85	0.90	Spain - M	S	0.84	0.79	0.93
Belgium - M	W	0.93	0.88	0.90	Spain - F	S	0.93	0.87	0.93
Belgium - F	W	0.91	0.88	0.88	Italy - M	S	-1.73	-0.77	0.73
Switserland - M	W	0.87	0.82	0.87	Italy - F	S	0.25	-0.29	0.66
Switserland - F	W	0.83	0.78	0.78	Portugal - M	S	0.91	0.82	0.85
West Germany - M	W	0.96	0.90	0.97	Portugal - F	S	0.95	0.85	0.92
West Germany - F	W	0.97	0.90	0.96	East Germany - M	C	0.81	0.79	0.91
France - M	W	0.94	0.92	0.92	East Germany - F	C	0.92	0.83	0.92
France - F	W	0.95	0.92	0.95	Hungary - M	C	-0.99	0.22	0.86
Netherlands - M	W	0.88	0.73	0.88	Hungary - F	C	0.75	0.55	0.82
Netherlands - F	W	0.86	0.71	0.88	Bulgaria - M	E	-0.47	-2.03	0.77
Norway - M	W	0.81	0.72	0.81	Bulgaria - F	E	0.54	-1.50	0.62
Norway - F	W	0.69	0.55	0.74					

Source data: Human mortality database
N = Northern Europe; W = Western Europe; S = Southern Europe; C = Central Europe; E = Eastern Europe

When the populations from Central Europe and Eastern Europe are not selected as in-the-group populations (see Table 2), the explanation ratios are higher. In the large majority of countries, including the country-specific deviations from the common trend leads to an improvement of fit.

Table 2: Explanation ratios for the Lee-Carter model (LC), the Common model (C) and the Augmented Common model (AC) applied to all-cause mortality for different combinations of country and sex, 1970-2004, without the countries for Central and Eastern Europe

country&sex	cluster	LC	C	AC
Denmark - M	N	0.69	0.55	0.80
Denmark - F	N	0.68	0.47	0.74
Finland - M	N	0.87	0.83	0.84
Finland - F	N	0.82	0.74	0.84
Sweden - M	N	0.87	0.81	0.81
Sweden - F	N	0.86	0.78	0.84
Austria - M	W	0.94	0.90	0.95
Austria - F	W	0.91	0.86	0.91
Belgium - M	W	0.93	0.89	0.92
Belgium - F	W	0.91	0.89	0.90
Switserland - M	W	0.87	0.82	0.89
Switserland - F	W	0.83	0.78	0.82
West Germany - M	W	0.96	0.93	0.97
West Germany - F	W	0.97	0.93	0.97
France - M	W	0.94	0.92	0.95
France - F	W	0.95	0.92	0.95
Netherlands - M	W	0.88	0.74	0.91
Netherlands - F	W	0.86	0.68	0.88
Norway - M	W	0.81	0.72	0.83
Norway - F	W	0.69	0.51	0.73
Spain - M	S	0.84	0.77	0.93
Spain - F	S	0.93	0.89	0.92
Italy - M	S	-1.73	-0.99	0.73
Italy - F	S	0.25	-0.47	0.67
Portugal - M	S	0.91	0.82	0.89
Portugal - F	S	0.95	0.87	0.91

Source data: Human mortality database
N = Northern Europe; W = Western Europe; S = Southern Europe

For the Netherlands, we compared the results of applying both the Lee-Carter methodology and the Lee&Li methodology to all-cause mortality data for 1970 to 2004 (HMD), thereby using all countries mentioned in Table 2 as in-the-group populations. The results are shown in Table 3. Applying the LC methodology leads to a substantial improvement of life expectancy at birth over the period 2004 to 2050, with life expectancy values at birth already higher than those predicted by Statistics Netherlands. When mortality experiences from other European countries are taken into account, e.g. when the Li-Lee methodology is applied, the predicted levels of life expectancy at birth in 2050 increase by more than 1 year.

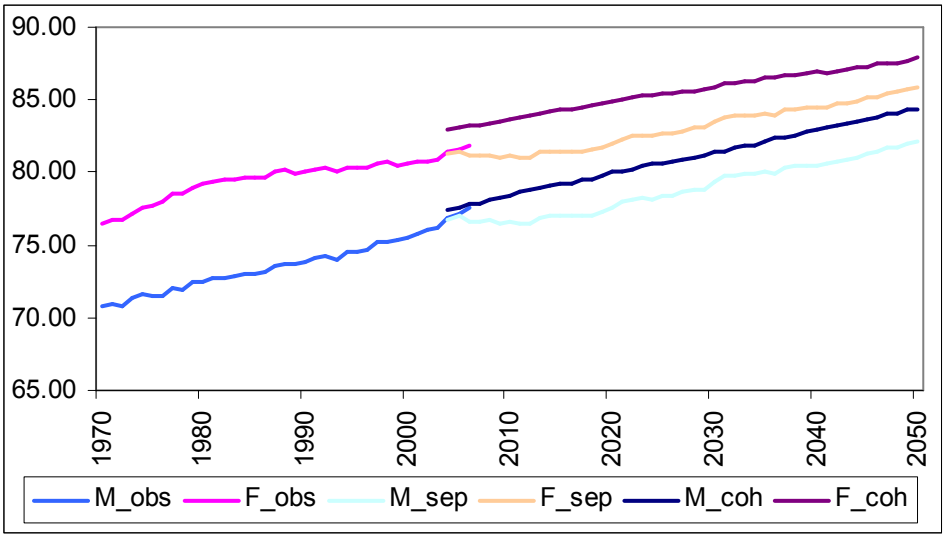
All three different methods lead to a convergence of the sex difference in mortality, especially for the mortality forecast by Statistics Netherlands. This difference is most likely due to the taking into account of smoking trends in the forecast by Statistics Netherlands.

Table 3 Comparisons of the outcomes of the Lee-Carter methodology, the Li&Lee methodology (using all countries mentioned in Table 2 as in-the-group populations) when applied to data for the Netherlands 1970-2004 by sex, and the forecast of Statistics Netherlands

	Life expectancy at birth			
	2004	2050 LC	2050 LL	2050 (CBS, 2006 forecast)
Males	76.87	82.10	84.37	81.49
Females	81.44	85.79	87.90	84.19

Source data: Human Mortality Database and Statistics Netherlands (CBS)

Figure 1 Comparisons of the outcomes of the Lee-Carter methodology (_sep), and the Li&Lee methodology (_coh) (using all countries mentioned in Table 2 as in the group populations) when applied to data for the Netherlands 1970-2004 by sex



Source data: Human Mortality Database

Conclusion

Based on the preliminary analysis and the preliminary findings, we expect that the coherent projections will lead to a convergence of life expectancy levels between the different countries and the two sexes, which is a likely outcome. Life expectancy levels will most likely be higher as predicted for many individual European countries. The selection of in- and out-of-group populations will probably strongly affect the outcomes for all-cause mortality, but will be less important for the projection of non-smoking-related mortality.

Implications

On the basis of the expected findings, we would recommend that the Lee-Li methodology can best be applied when non-linear effects, such as the effects of the smoking epidemic, are secluded from the past trends.

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Appendices

Appendix I: Method to assess levels of smoking-related and non-smoking-related mortality

Levels of smoking-related mortality by age, sex, country, and calendar year were estimated using an adapted version of the indirect Peto-Lopez method (Peto et al. 1992; Ezzati and Lopez 2003; Bonneux et al., 2003). The Peto-Lopez method takes into account the fact that not all mortality from lung cancer is due to smoking and it includes deaths from other causes that could be attributed to smoking.

In the first step, the proportion of the population exposed to smoking in the different populations ("synthetic smoking prevalence") (p) was determined by comparing the mortality rates for lung cancer in these populations with the mortality rates for lung cancer of smokers and never-smokers from the ACS CPS-II study (Peto et al. 1992; Mackenbach et al. 2004). Following Ezzati & Lopez (2003) values for p higher than 1 were set to 1 to avoid any potential overestimation of risk.
In the second step, the etiologic fraction (EF), that is, the proportion of all deaths attributable to smoking, was estimated as a function of the proportion of the population exposed to smoking (p) and the relative risk of dying of smoking (RR), using the formula EF=p(RR-1)/(p(RR-1)-1)). Age and sex specific relative risks were obtained by dividing the all-cause mortality rates for the smokers in the ACS CPS-II study with the all-cause mortality rates for never-smokers from the same study (Peto et al. 1992; Bonneux et al., 2003). To these relative risks we applied smoothing, by using regression analysis with age plus age squared (Bonneux et al., 2003). To take into account residual confounding and to obtain conservative estimates of the numbers of deaths attributable to smoking, the excess risks (RR-1) were reduced by 30 per cent (Ezzati and Lopez 2003).
In the third step, the level of smoking-related mortality by age, sex, country, and calendar year was estimated by multiplying all-cause mortality by age, sex, country, and calendar year by the adjusted etiological fractions. Subsequently, non-smoking-related mortality was calculated as total mortality minus smoking-related mortality.

Appendix II: The Li&Lee method

The Li&Lee method (LL) is an extension of the LC method. The Lee-Carter model (LC) forecasts mortality by age and period. It therefore 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 a vector $b(x)$ denoting the magnitude of the change-specific change over time, which is not captured by the overall time trend $k(t)$. The basic model is:

$$\log[m(x,t)] = a(x) + b(x)k(t)+\varepsilon(x,t)$$

The $a(x)$ are the mean of the $\log[m(x,t)]$ over the observation period. The $b(x)$ and $k(t)$ are found by singular value decomposition of the matrix $\{\log[m(x,t)]-a(x,t)\}$.

The Li-Lee method basically amounts to applying the LC model twice. In the first round, the LC model is applied to the aggregate mortality of all countries, which results in a common time trend, which we denote by *K(t),* and a common age-specific trend factor *B(x)*. The age-pattern *a(x)* is found separately for each subpopulation as the average of the log rates.

In the second round, a country-specific LC model is applied to the residuals from the first round. For each subpopulation these residuals take the form of an age-vector of mortality that changes over time. This second round LC model results in a subpopulation-specific time trend *k(t,i)* and age-specific trend factor *b(t,i),* which is added to the common-factor model from the first round. This so called augmented common factor model is:

$$\log\left[m(x,t,i)\right] = a(x,i) + B(x)K(t) + b(x,i)k(t,i) + \varepsilon(x,t,i) \qquad 0 \le t \le T$$

The *b(x,i)* and *k(t,i)* describe the difference between the rate of change of age *x* of country *i* at time *t* with the rate of change implied by the common factor *B(x)* and *K(t)*.

We assessed the goodness of fit of the LC model, the common factor model and the augmented common factor models by means of the explanation ratio *R*, which is the 'explained' sums of squares as a ratio of the total sums of squares in the rates. (Li and Lee 2005)