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Improving Overall Mortality Forecasts by Analysing Cause-of-Death, Period and Cohort Effects in Trends

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Abstract. The major goal of this study is to propose improvements in the methods for forecasting overall mortality. In order to reach this goal, three types of trend-oriented forecasts have been studied. Each type of forecast is conditional on developments in one of the three factors, period, cohort and cause of death, which are known to represent symptomatic measures of certain causal mechanisms. Mortality projections have been made for four developed European countries: France, Italy, the Netherlands and Norway. The projections are based on observed mortality data over the years 1950–1994 and cohorts born in the nineteenth and twentieth century. The results of the analyses do not show a best solution, though the cause-of-death approach looks the most promising. However, the period and cohort approaches certainly have additional value in the forecasting process. The cause-of-death approach should ideally be used jointly with the overall mortality period (or overall mortality cohort) approach. However, the cause-of-death approach is not optimal for forecasting the mortality of the oldest-old. Another modelling method, for instance parameterization of overall mortality, should be considered for that purpose. The cohort approach can be used to improve forecasting of period mortality.

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Résumé. L'objectif de cette étude est de proposer des améliorations des méthodes de prévision globale de mortalité. Pour atteindre cet objectif trois types de prévisions, basées sur des tendances, sont étudiés. Chaque type de prévision est fondé sur des développements de l'un des trois facteurs connus pour représenter des mesures approchant certains mécanismes causaux: la période, la cohorte et la cause de décès. Ces projections ont été faites pour quatre pays européens: la France, l'Italie, la Hollande et la Norvège. Les projections sont basées sur des données observées sur la mortalité des années 1950–1994 et sur des générations nées aux XIX^e et XX^e siècles. Les résultats des analyses ne donnent pas une solution optimale, bien que l'approche par les causes de décès semble la plus prometteuse. Également l'approche par période et cohorte apporte des précisions supplémentaires au processus de projection. La meilleure solution serait d'utiliser l'approche par causes de décès avec l’approche globale de la mortalité par période (ou par génération). En revanche, l’approche par causes de décès n’est pas la meilleure pour prévoir la mortalité des plus âgés. Une autre modélisation, par exemple utilisant une paramétrisation de la mortalité d’ensemble, devrait être utilisée pour ce faire. L’approche par cohorte peut également être utilisée pour améliorer des prévisions de mortalité par période.

1. The objectives and content of this study

Many recent surveys of methodological developments in mortality forecasting have shown that process-oriented rather than trend-oriented methods are of the greater relevance to mortality forecasting (e.g. Willekens, 1990). This may be attributed to the increasing uncertainty inherent in hypothesizing future changes in mortality. Dealing with uncertainty must include preparing many alternative variants of the future of mortality and/or focussing on single forecasts with well-defined uncertainty measures incorporated in the forecast model. However, process-oriented methods are not very popular nor are they widely used. These methods are not standard, they usually have strict data requirements, they require substantial intellectual efforts and highly skilled forecasters, and finally, they are much more time-consuming than trend-oriented techniques. Therefore, the practice of forecasting mortality is still based on trend methods. In fact, this conclusion was the major argument which promoted the design of a study which would explore the possibilities of improving mortality forecasts using trend methods. The research angle chosen for our study is connected with the types of observations on mortality usually distinguished by demographers: overall mortality over time, overall mortality by birth cohorts, cause-of-death-specific mortality over time or cohort, and overall or cause-specific mortality by period and cohort. In sum, we ask whether mortality forecasts should be by all causes together or by a number of specific causes, and whether they should be by period, by cohort, or by period and cohort.

The ultimate objective of this project was to suggest ways of improving overall mortality forecasts in developed countries by incorporating mortality data by cause of death, if possible by cohort. Any method selected for the analysis should allow us to gain insight into age and sex patterns of (overall and cause-of-death-specific) mortality and their changes over time and among cohorts. Collecting data for such an analysis raises two main problems: mortality data by cohort are not universally available, and cause-of-death statistics have not been harmonized over time and between countries. Improving mortality forecasts by incorporating mortality data by cause of death and cohort is impossible for most countries. The reasons are mainly practical and include a lack of consistency between the successive Revisions of the International Classification of Diseases (ICD), the fact that data have not been collected by cause of death and cohort, and data protection regulations. Also causes of death have changed and the medically defined contents of diseases have evolved during the course of the epidemiological transition. The International Classification of Diseases has also been revised about every ten years since the beginning of this century, often making it difficult to compare the data of different revisions.[1] Thus, for most contemporary causes of death, no consistent historical data, neither period nor cohort, exist. The lack of cohort and cause-specific data is the reason that it is barely possible to keep both the cause-of-death and cohort dimensions when making projections of international mortality.

Assuming that both cause of death and cohort are equally important for improvement of mortality projections, two types of projections are worth investigating: one for causes of death using the period approach, and one for overall mortality using the cohort approach. These two types should be compared with the standard approach, i.e. projections of period total mortality. The comparison could be made in terms of cross-sectional patterns, i.e. over the years 1995–2020. Data necessary for the above approaches are available and were collected. Our analysis comprised all the stages mentioned above.

Four countries were selected for the analysis: France, Italy, the Netherlands, and Norway. The analysis was made mainly (but not exclusively) for ages above 40 years, as causes of death differ among age intervals (infancy, childhood, adolescence, elderly, oldest-old). After age 40, so-called leading causes can be analysed (cardiovascular disease, cancer, violence). Leading causes account for most deaths in the population and are therefore the most important ones. The statistical method selected for projection was a modification of the parameterization technique, i.e. parameterization with time-dependent parameters, also called dynamic parameterization.

In sum, in this contribution we present findings related to the question “How to improve forecasts of mortality in developed countries?”. However, the findings do not offer answers to all possible issues raised by this question. First of all, in section 2, a brief introduction is made regarding the views about forecasting of mortality by cause presented in the literature. In section 3, we discuss data needed to forecast age-specific mortality at the population level: types of data, sources, problems and quality. We continue with a description of the statistical method selected for our forecasts (section 4). In section 5, the three approaches to modelling mortality are discussed in more detail focussing on the most important problems faced in forecasting. In section 6, all forecasts are discussed jointly using life table indicators. Section 7, presents final views as seen from the perspective of this research.

2. Decomposition of mortality by cause and its effects on the estimated trend in mortality

Analysing period and cohort effects belongs to the tradition of mortality forecasting. On the contrary, decomposition of mortality by cause of death has received far less attention from forecasters. Only recently it has become more popular. A few recently published articles devoted to forecasting of mortality by cause of death that are reviewed in this section (i.e. Alho, 1991; Wilmoth, 1995; Caselli, 1996) focus on the differences in the outcomes and accuracy of the overall mortality and cause-of-death based forecasts of total mortality. Interestingly, none of these articles addresses other aspects of the two alternative approaches, such as transparency of assumptions, utility, and consistency with other forecasts in use (e.g. epidemiological). We argue that the other aspects of cause-of-death based forecasts of total mortality are at least equally important as statistical accuracy of prediction and we suggest that more attention be paid to these issues.

In his discussion of the effects of aggregation on the estimation of trend in mortality, Alho (1991) states that it is typical of demography to suggest that changes in vital rates should be analysed by dividing "crude" aggregate phenomena into their components. "To understand mortality it seems natural to go beyond age, sex, and race, to analyse mortality by cause". In his opinion, several factors are, however, capable of influencing the potential for disaggregation-related gains in forecast accuracy. The effects of misclassification of deaths by cause, the cross-correlation between causes, the similarity of auto-correlations in different causes, modelling bias, and expert judgement are all examples of such factors. Using the models for the rate of change in mortality and US mortality data since 1968, Alho also made an empirical contribution to the discussion. Three approaches to analysing and forecasting age-specific mortality were investigated: an analysis of age-specific overall mortality data directly, of each cause-specific mortality separately and adding the results, and of cause-specific mortality jointly and adding the results. He showed that if linear models (in respect of parameters) are used for the rate of decline in mortality for each age distinguished, then the three approaches often give close results, even if cause-specific series are correlated. According to Alho, the results of the different approaches are not close if one or more causes serve as "leading indicators" for the remaining causes, or outside information is incorporated into forecasting either through expert judgement or formal statistical modelling. Also under highly non-linear models or in the presence of modelling error the results may not be close. In some cases, Alho suggests, the aggregate forecasts appear to be the more credible ones.

Wilmoth (1995) continued this line of research. The focus of his work was again on the differences in the outcomes of cause-specific versus total mortality based forecasts. Wilmoth showed analytically for one particular class of forecasting models, (i.e. proportional rate of change models which are linear in parameters), that the forecast of mortality obtained from the aggregation of the forecasts of mortality by cause must eventually exceed the forecast based on mortality data by all causes together (i.e. no decomposition by cause). Using this class of models and mortality data from Japan (1951–90) he demonstrated, the cause of death approach resulted in higher mortality (lower life expectancy) than that of total mortality. In the Japanese example considered by Wilmoth "cancer mortality trends were the most important source of the pessimism inherent in cause-based forecasts". Another important contributor was mortality from heart disease which in Japan, similarly to cancer, had non-declining high-level trends in the whole period 1951–

90. The two causes of death, together with remaining causes, accounted for a vast majority of deaths in Japan in the period studied.

Caselli (1996) prepared cause of death specific-projections of mortality for a number of European countries using age-period-cohort models with an analytical formula expressing the trend in period effects. Data used in her study covered seven causes of death and ages 60 to 85+ in the period 1950–1985. From Caselli's projections another pattern of results has emerged. In general, for all the countries, projections from trends in mortality by cause reduced the advantage enjoyed by females and increased that for men for whom the gains in life expectancy were higher when estimated by cause than those obtained from total mortality based projections. For Dutch men, for example, the increase at age 60 would be 0.9 years *higher* in the cause of death approach than predicted without taking into account differential trends in mortality by cause. For Dutch women the cause of death models gave at age 60 an estimated increase in survival 1.4 years *lower* than that estimated using trends in total mortality average.

Summing up, the major focus of these three recent studies was on differences in the mortality outcomes between cause of death and total mortality approaches. It is rather obvious from the results presented that the general pattern of more pessimism in cause-specific mortality forecasts only appears under certain particular conditions (forecasts obtained as trend extrapolation from linear (or linear in parameters) forecasting models). In all other situations, compared with the overall mortality approach both higher and lower predictions of total mortality can be obtained from the decomposition by cause. An explanation of the differences in the outcomes has been proposed by Alho in terms of sources of bias in the cause of death specific models. Alho concluded that in some cases more aggregate total mortality forecasting models might be more accurate statistically.

Comparing different forecasting methods by only investigating the differences in the forecast outcomes and accuracy would be, however, a poor evaluation approach. Rogers[2] (1995: pp. 200–1) clearly points out that "model performance is a multi-faced concept that involves much more than forecasting accuracy alone. (. . .) Additional attributes such as transparency, utility and face validity, all play an important role in the presentation of population forecasts". This is the reason that the question about the degree of complexity/simplicity of forecasting models cannot be unconditionally answered. In addition to that, "whether simple forecasting models outperform complex models is an empirical issue that depends on the particular historical period observed and the degree of demographic variability exhibited during this period" (ibid., p. 200). The forecast based on simple trend extrapolation of life expectancy at birth is often better in short terms than the forecast obtained from a complex model for mortality dis-aggregated by age and cause of death. However, in long term forecasts the latter may be better than the first.

3. Data types, sources, problems and quality

In the light of the research design of this study, three types of data are required for each of the four countries studied (France, Italy, the Netherlands and Norway): historical (i.e. dating back to as far as the mid-19th century) data on overall mortality in the form of (single-year) age-period-cohort number of deaths and the respective (single-year) population structure, period data on mortality by cause of death with as detailed as possible an age classification, and standard period (single-age) overall mortality data for the years from 1950 up to the present. All data should be sex-specific. An important innovation of our analysis is that mortality of the oldest-old, i.e. those aged 80 years and over up to the last survivor, has been incorporated to the standard data, that is to say, data that usually end with an (aggregated) age category 89+ or 90+ years. These data are only reliable for recent years, i.e. for 1950 onwards, because age confirmation is only possible for people born from the mid-19th century onwards, when the birth registration system started to become operational. In principle, almost all the necessary data exist and could be collected. Several problems related to the data were encountered and must be mentioned. The problems are described below, along with how they were overcome.

3.1. HISTORICAL AGE-PERIOD-COHORT MORTALITY DATA

For France (Meslé and Vallin, 1989), Italy (e.g. Caselli et al., 1987), the Netherlands (Tabeau et al., 1994a) and Norway (Borgan, 1996; personal communication), precise inventories of historical sex-specific (single-year) age-period-cohort mortality data and the respective population structures were compiled at the national level. The inventories were completed to establish a cross-referenced comparative series of life tables and enabled us not only to investigate rough indicators like life expectancy at birth, but also to examine mortality trends in specific age groups. Except for Italy, the above data sets contain the following information: the number of people by sex and age at the start or end of each year, the number of deaths by sex, year of birth, and (single-year of) age at the time of death for each year, and the number of live births by sex for each year. The dual classification of deaths by age at death and year of birth implies the availability of age-period-cohort data. These data can be regrouped in different ways to meet the requirements for cohort and period analysis.

Vallin’s data base for France starts with the year 1899. Although more years are available from Bourgeois-Pichat’s data base (1805–1950), the age intervals are three years and deaths only exist in the form of age-period numbers. Using Vallin’s data, trends in French mortality were examined by Caselli, Vallin, Vaupel, and Yashin (1987), Meslé and Vallin (1989), and Wilmoth, Vallin and Caselli (1989). These studies provide insight into the past and can serve as a starting point for projections of overall mortality in France.

Historical cohort data also exist for Italy but not in the form of a precise inventory or data base. Caselli developed this data set and used it in various studies. The series starts in 1861 and ends in 1985. Mortality (cohort-age) rates are available; absolute (age-period-cohort) numbers are not. As no description of the data set was published, it is not known which operations have been performed on the original data to produce their current form. Nevertheless, the data seem to be reliable, as indicated in several analyses presented in publications (Caselli et al., 1987; Caselli and Capocaccia, 1989; Caselli, 1990, 1994 1994). They are certainly an invaluable source for trends in Italian mortality.

For the Netherlands, the years from 1850 onwards are covered in a data base. Several analyses have been conducted using these data: a descriptive study of trends in Dutch mortality by Van Poppel et al. (1996), and modelling analyses of trends by Tabeau et al. (1994b), Tabeau et al. (1994c), Tabeau and Tabeau (1995). The studies are, once again, a good starting point for new projections.

The Norwegian data base developed by Borgan at Statistics Norway contains data from 1846 onwards. Preliminary analyses of these data indicate that the quality of these data is high. Unfortunately, no published studies of historical mortality trends in Norway have been found. These trends will have to be investigated before projections are made.

3.2. DATA ON MORTALITY BY CAUSE OF DEATH SINCE 1950

Cause-of-death data are usually processed and published as age-period figures. Very occasionally data on causes of death are available from the national statistical offices as age-period-cohort figures which together with population figures, can be used to calculate cohort rates or probabilities. Cohort mortality rates by cause of death are only rarely processed and published by statistical offices. One important reason for this are changes in successive Revisions of the International Classification of Diseases (ICD), as a result of which causes of death in one cohort are reported in different ICD Revisions. For instance, the cohort born in 1900 experienced all nine revisions of the ICD system and will be included in the tenth. Working with age-period data does not solve the problem of changes in the ICD. As we shall see, many more problems are to be expected. We shall discuss them later on in this section, but first the choice of causes of death is made clear and the rationale behind it is explained.

The choice of causes of death was based on two considerations: the scientific requirements of the analysis and deficiencies in the existing data. Only major causes of death with clear age patterns and trends, and known, predictable risk factors were included in projections. Mortality from less significant diseases, usually showing many irregularities, would deteriorate rather than improve forecasting. The following list of ten causes of death (coded according to ICD Revision 9) was selected:

1.	Stomach cancer	151
2.	Trachea/bronchial/lung cancer	162–163
3.	Breast cancer	174
4.	Prostate cancer	185
5.	Coronary heart disease	410–414
6.	Cerebrovascular disease	430–438
7.	Pneumonia and influenza	480–486, 487
8.	Chronic lower respiratory diseases	490–494, 496
9.	External causes	E800–E848, E880–E888, E950–E959
10.	Other	

The World Health Organization (WHO) Data Base, with some necessary support from the countries in question, was used as a source of data. In principle, data on causes of death are available at both the national and international level in a uniform and consistent format. For the sake of consistency, an international form of the medical death certificate was recommended by the WHO and is used in all member states of the European Economic Area (EEA). Furthermore, causes of death are classified on the basis of these certificates according to the ICD. However, in practice many inconsistencies appear within each country and even more between countries. The most important sources of inconsistencies include decennial revisions of the ICD, differences in national interpretations of international rules and differences in the qualifications and training of physicians and the staff who code the causes reported on death certificates (e.g. Rosenberg, 1993; Meslé, 1994).

In order to link the data from different ICD Revisions properly, conversion tables have been developed and used. This was done in a cooperation with the Department of Health Statistics of Statistics Netherlands. In our table, the ultimate links are expressed in terms of the (aggregated) categories of the official WHO short tabulation lists and as the 3- and 4-digit basic categories. On the basis of this table, an aggregation algorithm was developed and used to produce time series of cause-specific mortality data. With respect to the data collection, we had easy access to the WHO data on the Internet. We used the WHO data for Italy and Norway, but not for France (the INED collection of Meslé and Vallin was available to us) and not for the Netherlands (the data from the Health Statistics Department, Statistics Netherlands, were used). A number of single (3- and 4-digit) categories missing from the original WHO files were requested in the countries concerned (i.e. Italy and Norway). These extra data were obtained from the countries and have been incorporated in the WHO data.

Despite of the careful procedure applied, two major inconsistencies were found for Italy and Norway in the time series of mortality by cause, one for mortality from coronary heart disease and one for mortality from chronic lower respiratory diseases, both located around the late years 1960s. In consequence of these distortions, another break was also notable in the trend of mortality from the remaining causes. Mortality from these three causes of death was modelled using shorter time series of observations. For France and the Netherlands the series were consistent as in the past medically oriented projects were conducted in both countries to ensure smooth time series of data on mortality by cause.

3.3. DATA ON MORTALITY OF THE OLDEST-OLD SINCE 1950

Quantification of mortality above age 80 and the evaluation of survival at these ages pose substantial problems, both methodological and practical by nature. The most important are (methodological and practical) deficiencies in the measurement of old-age mortality. As a result mortality of the oldest-old is only moderately recognized in most countries, and projections of mortality after the age of 80 suffer from a lack of reasonable assumptions (Van Poppel and De Beer, 1996).

The proper identification of levels of mortality at the oldest ages depends strongly on data quality (e.g. Kannisto, 1988). The biggest problem is that errors in data have a greater effect in the case of the elderly than in other larger groups of the population. Errors are present in both death and population statistics. One source of errors in death statistics is a general tendency of relatives to overstate the age at death of elderly persons, particularly centenarians. This tendency is more pronounced in countries unaccustomed to keeping records of age, i.e. where no birth registration existed at the time the people in question were born. In addition to age overstatement, heaping round ages such as 100 or 105 can also be observed. Unreliable population statistics largely result from errors in death statistics that served to estimate the population in intercensal periods in the past. The effects of errors are felt most in small population groups such as centenarians. To eliminate errors, two steps are usually undertaken: first, death statistics are improved, then population numbers are re-estimated using the new numbers of deaths. These two steps are at the basis of the development by Kannisto and Thatcher of the Oldest-old Mortality Data Base, a project coordinated by Vaupel at the Odense University Medical School in Denmark. The data from this collection certainly fulfill the criterion of reliability and consistency for all the countries included.

We used the French, Italian, Dutch and Norwegian subsets of this Odense Data Base with data on (age-period-cohort numbers of) deaths and (numbers of) population at (single) age 80 to 119 years for 1950–1993. The data have been incorporated in all the other data we have.

4. Statistical method for projections: Parameterization with time-dependent parameters

4.1. STATIC VERSUS DYNAMIC PARAMETERIZATION

Projections of the future age pattern of demographic processes are an important area of application of parameterization functions. The standard projection procedure comprises a number of elements: specification of a parameterization function, fitting the function to annual data, completing series of annual estimates of function parameters, using these estimates to project future values of parameters, and, finally, incorporating the projected parameters into the original function and producing projections of the phenomenon. This procedure is well known and often applied to demographic processes, such as mortality, fertility, migration (for instance, for mortality McNown and Rogers, 1992; for fertility Knudsen et al., 1993; Thompson et al., 1989). Since this approach is based on annual, i.e. time-independent, estimates of the parameterization model, we call it ‘static parameterization’. A major disadvantage of the above procedure, is that annual estimates of parameters are unstable making the projection of parameters rather difficult.

This obstacle can be overcome by making the parameters time-dependent (Tabeau and Tabeau, 1995). The main advantage of the modification is that it always gives stable estimates of the parameters. Parameterization functions with time-dependent parameters are estimated using an array of age- and time-specific death probabilities/rates. They allow us to fit a number of annual model age schedules to empirical data in a single step. Therefore, this modified approach is also called ‘dynamic parameterization’. The specification of the dynamic function is based on two types of decisions: decisions about the so-called base function to be used for annual age patterns, and about trends to be imposed on the parameters of the base model (the so-called base parameters). The first decision concerns the static structure of the mortality process and the second, their dynamic structures, i.e. changes of the process over time. This decision can be taken on the basis of theories for mortality (e.g. Gompertz-like), and the second using the empirical evidence from annual estimations together with ancillary information from, for instance, longevity research. For causes of death, epidemiological indications concerning a given disease and anticipated trends in the prevalence of relevant risk factors are very important and helpful. Making projections is simple. It is done by giving values to two variables: time and age. As a result, a set of complete age profiles is obtained for selected years in the future.

A static (i.e. base) parameterization model is the following:

$$f_s(x) = f(x, P_1, \ldots, P_k, err(x)) \tag{1}$$

where x is age, P_1 to P_k are (base) parameters to be estimated from a set of annual age-specific death rates/probabilities ($f_s(x)$) and $err(x)$ is the error term. The dynamic function is given below:

$$f_d(x, t) = f(x, P_1(t), \ldots, P_k(t), err(x, t)) \tag{2}$$

where t denotes the time variable and $P_1(t)$ to $P_k(t)$ are trend functions which have replaced the parameters P_1 to P_k. The exact specification of the dynamic model is always based on the static base function selected to describe the age profile of a process in a single period of time. The dynamic nature of the model is obtained by removing time-independent parameters from the static single-year function and replacing them by time-dependent ones in the form of trend functions. The trend functions can be set as linear and/or nonlinear. Their final form depends on how the dynamic model fits the data and what predictive properties it has. Forecasting in the dynamic model is based on only two regressors: age and time.

4.2. MULTICOLLINEARITY

The starting point for dynamic parameterization are estimation results of a static model. Annual estimates of the parameters often show a high correlation with one another. Moreover, irregular changes of annual parameter estimates from one year to another are quite common. They are even observed for mortality in adjoining years with similar levels and patterns of empirical death rates. The annual estimates of coefficients are very sensitive to particular sets of sample data, a problem which arises normally as a consequence of multicollinearity. In the modified dynamic parameterization functions, multicollinearity is also present. It is caused by strong relationships (correlation) between the variables – functions of age – which are present in the linearized version of the nonlinear model. In terms of the fit for particular years, multicollinearity should not introduce negative consequences, i.e. estimation errors of parameters should remain small (and were so in our estimations).

One of the proposed solutions to the multicollinearity problem is to introduce non-sample information into the model estimation. Practically speaking, this can be done by giving a priori values to some parameters. In this case, at least three options are possible:

(a) Some parameters can be assumed to be fixed, i.e. constant over the entire period and not estimated, but set a priori. For instance, based on single-year estimates of the selected static model.
(b) Some parameters can be assumed to be constant, i.e. maintaining no trend; these parameters remain unchanged over all the years in the sample and later in projected profiles, but their values are estimated from data.
(c) Intercepts in hyperbolic trend functions can be considered to be targets for base parameters. Target parameters come from a target age pattern of mortality which can be assumed to be the pattern in a distant future (in the case of overall mortality, this can be the pattern of maximum life expectancy).

Some of these options were used in our estimations.

4.3. ESTIMATION

The model can be estimated iteratively by applying a nonlinear least squares method[3] ((N-L)LS; Johnston, 1984; Pindyck and Rubinfeld, 1990; QMS, 1997). Reasonable starting values must be given to all the parameters. The choice of initial values depends on the specification of trends for the base parameters. In the simplest case, i.e. when all the trends are linear, the constants are identical to the parameters expected in a static model for the first year in the series used for the estimation. The slopes can be assumed to be zeros or small positive or negative numbers, depending on the trends observed in the parameters from individual single-year models. During the estimation, new values for the coefficients are calculated by applying the (N-L) least squares method and the equation is re-estimated around these new sets of coefficient values. This process is repeated until convergence is achieved.

The obtained estimator of the vector of parameters of the model tends to be biassed and usually has an unknown distribution, even if a specific distribution is assumed for the error term of the model. However, under suitable conditions, it is consistent and asymptotically normally distributed (e.g. Judge et al., 1985). The consistent estimate of the variance of the error term can be computed as well, and its asymptotic distribution can be derived. The practical consequence is that under certain assumptions, all the results of the linear regression are asymptotically valid for the nonlinear regression model. Therefore, statistical inference and hypotheses testing can proceed in the same fashion as for the linear model. Some minor problems can arise when evaluating the goodness of fit of the regression. The common measure of fit, i.e. the coefficient of multiple correlation R^2, is no longer guaranteed to be in the range of zero and one, but it still provides some descriptive measure. The sum of squared residuals (SSR) gives better indications.

5. Modelling mortality

Overall mortality at all ages was only modelled within the period overall mortality approach. In the overall cohort and cause-specific approach only mortality after age 40 was analysed. The decision not to include the lower ages in the cohort and cause-specific analysis was prompted by, respectively, a better availability of cohort data and by the choice of (only leading) causes of death for the study.

For overall mortality at all ages, the Heligman-Pollard model was applied as the base model for all countries in the form as proposed for the ratio of death probability q(x) to surviving probability p(x) (Heligman and Pollard, 1980). In this model, the component used for old-age mortality is defined as a modified Gompertz function (see section 5.1). The modification implies that mortality of the oldest-old is assumed not to increase exponentially but more logistic-like with age. The dependent variable in our analysis was, however, different from the odds ratio q(x)/p(x). We modelled the death rate m(x) instead. Consequently, also for this variable we decided to follow not the exponential, but the logistic-like age curve for mortality of the oldest-old. This choice was prompted by the evidence produced in a comparison of goodness of fit from a number of alternative functions estimated for mortality of the oldest-old in cohorts of French women born between 1845 and 1900 (Tabeau, 1996). Two functions seemed to be equally good in this comparison:

the “quadratic” Gompertz function (i.e. a three parameter quadratic function of age for the log death rate) and the modified (two-parameter) Gompertz function. The modified Gompertz function was chosen rather than the “quadratic” Gompertz due to the lower number of parameters. Mortality by cohorts was analysed using the same functional form of the modified Gompertz, and mortality by cause of death by a number of separate models, one model for one distinguished cause and one sex. The total number of models for mortality by cause of death for four countries was eighty. Therefore, with respect to cause-specific mortality it is impossible to discuss all necessary details in this contribution. Readers interested in the subject may refer to Tabeau et al. (1998).

5.1. MODELLING OVERALL MORTALITY BY PERIOD

In the static model, mortality by periods was modelled using a modified Gompertz function as in the Heligman-Pollard model (1980) with the central death rate as a new dependent variable:

$$m(x) = \frac{B * c^x}{1 + B * c^x} + err(x) \tag{3}$$

In the dynamic model, the parameters B and c were replaced by trend functions, e.g. linear and/or hyperbolic. The modified model (3) was re-estimated on the basis of combined age- and period-specific mortality rates (all dynamic model specifications are available from Tabeau et al., 1998). Note that the values and interpretations of the parameters B and c are similar to those in the original Gompertz. B is the initial level of senescent mortality and c the increase in old-age mortality per single year of age. Also, trends in annual estimates of B and c should be similar when estimated from the complex model for all ages and from the Gompertz model for older ages only. They may be slightly different due to the presence of correlations between the parameters of the complex model. A relatively high degree of consistency can be ensured using target estimation of the parameters and fixed and/or constant parameters, as suggested in section 4.2.

We explored long-term historical trends in the Gompertz parameters for mortality observed by periods in three[4] countries with good historical data on mortality: France, the Netherlands and Norway. The estimation was completed on the basis of excellent annual data with single-year age intervals. Only ages 40 and over were included. In effect, we were able to complete clear dynamic trends which for women are shown in Figure 1.

In general, the expectation that useful similarities and/or clear long-term trends would be found for the parameters B and c was not met in the period approach. With the exception of B for women in the three countries, a variety of different national situations were identified. An extrapolated variant of these different trends since 1950 is shown for France in Figure 2. For French men, the trajectories shown in Figure 2 come from the best statistical projection model for age- and period-specific rates. The trajectories for French women are optimal in terms of goodness

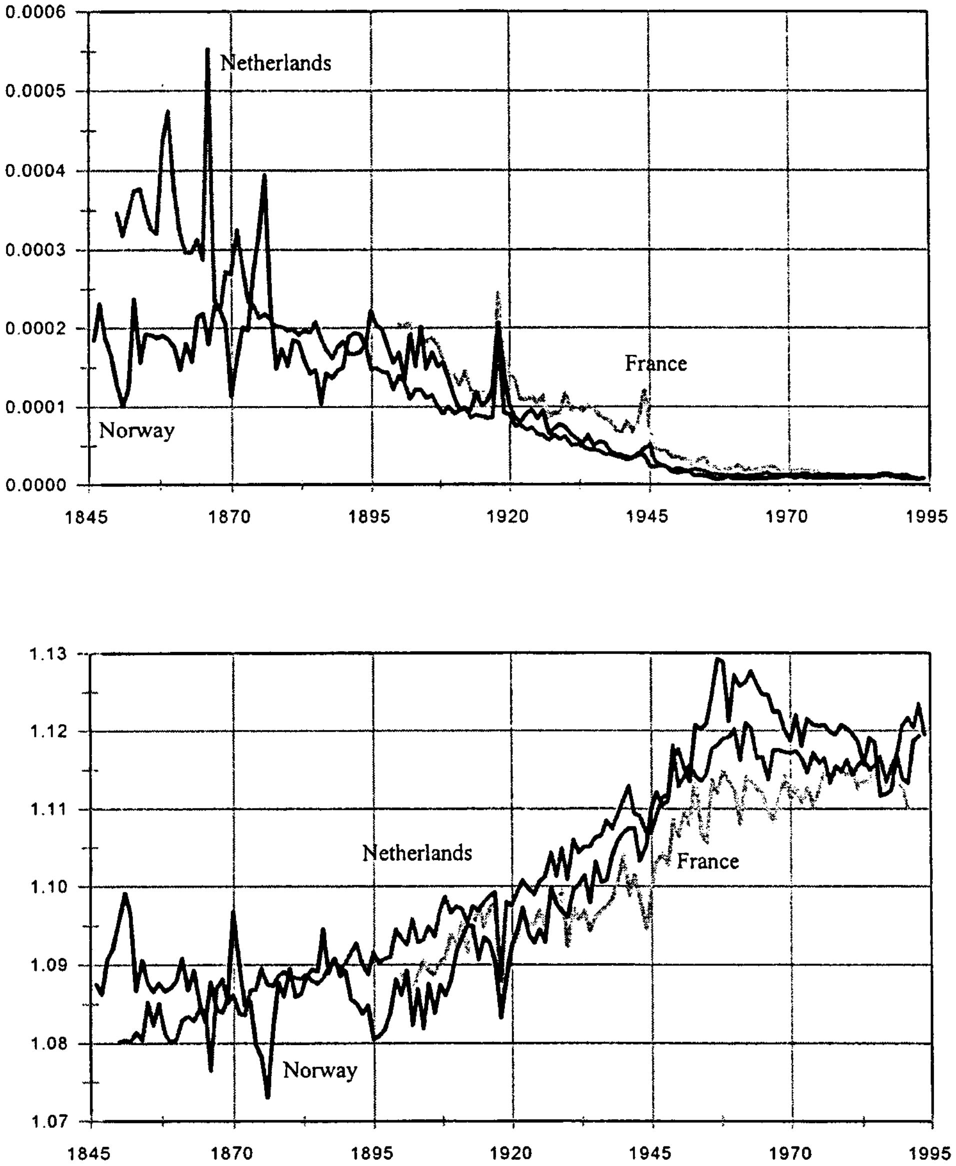


Figure 1. Long-term trends (1846–94) in the Gompertz parameters according to the static period approach estimation, women in France, the Netherlands and Norway.

of fit but do not belong to the best projection model ultimately chosen. The optimal trajectories for French women shown in Figure 2 produced a very low level of life expectancy for women in France. We will show a number of alternative projections of life expectancies for French women and discuss their meaning. Note that they all come from extrapolations similar to that in Figure 2.

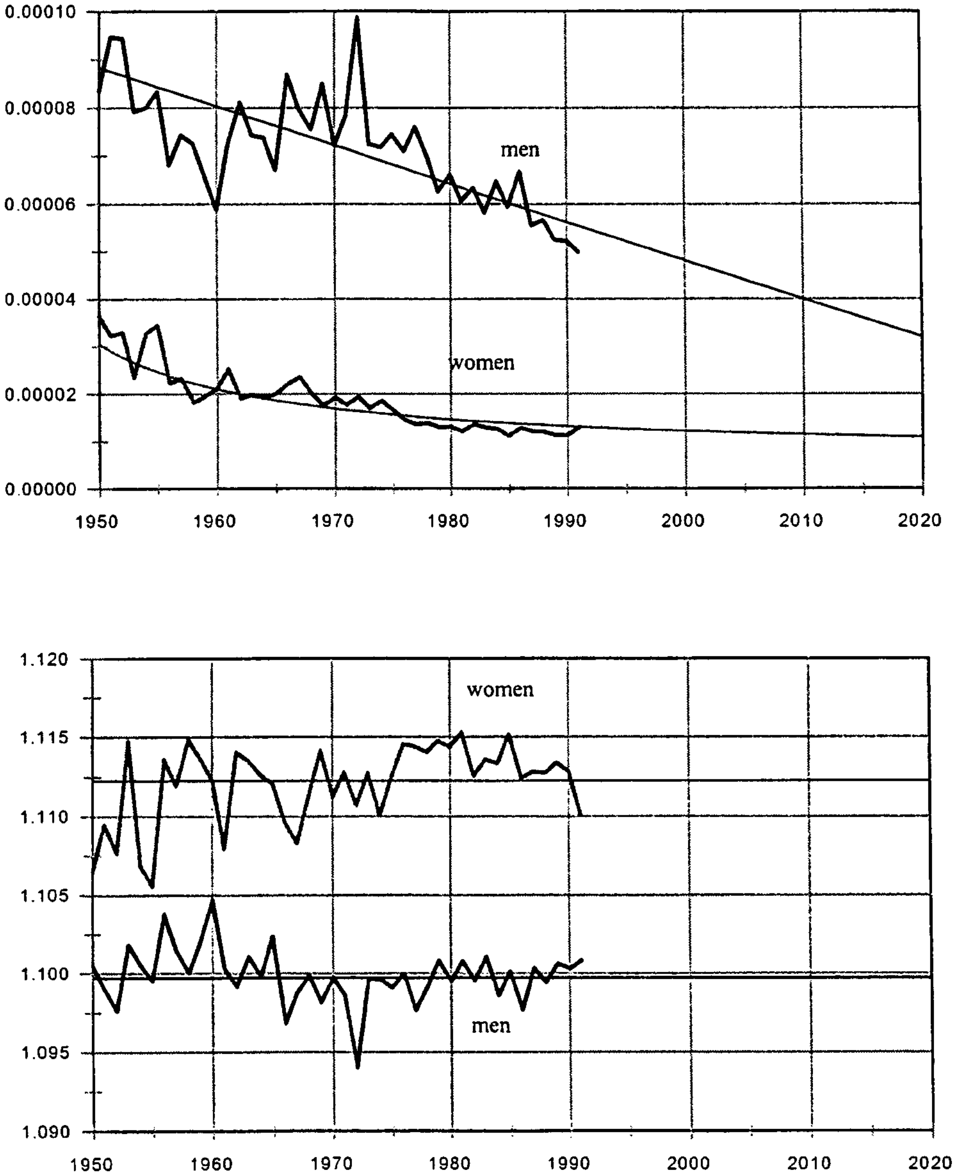


Figure 2. Extrapolation of trends (1995–2020) in the Gompertz parameters according to the static period approach estimation, men and women in France.

Extrapolated trajectories for B and c for French women shown in Figure 2 resulted in projections which were considerably lower than expected by French authorities (82.2 years at birth if no mortality below 40, and 42.2 at age 40; compare with Table I). According to this model minimal declines are foreseen in the general level of old-age mortality as assumed by the hyperbolic trend for B and no change

Table I. Life expectancy at birth in four countries by 2020 according to the latest national forecasts (around 1992–96)

Country	Women	Men
France	86.5	78.0
Italy	84.7	78.3
Netherlands	81.6	77.8
Norway	83.5	77.9

Source: Eurostat Working Document, Annex 2. Presented at Eurostat Working Party on Demographic Projections. September 15–16, 1997. Luxembourg.

in the increase in mortality with age (constant trend for *c*). A second alternative, a medium variant, was obtained assuming a greater decline in the general mortality level whereas the increase with age was kept constant (86 years at birth if no mortality below 40, 46 at age 40). A third variant was much higher than the levels anticipated by French mortality experts in recent years (97.4 years at birth if no mortality below 40, 57.4 at age 40). The only difference between this variant and the previous alternative models is that declines in the level of old-age mortality were assumed to be rapid, declining linearly. Interestingly, the medium variant is close to the projection obtained from the best projection model which is based on a stable trend for *B* (general level in old-age mortality) and a declining trend for *c* (an increase in mortality with age). The stable trend in *B* does not contradict with what we see in Figure 1, but the decline in *c* does not really agree with what has been observed for French women in the past. However, in view of the decline observed among Norwegian women it is by no means improbable. This assumption entails that French women would need a decreasing age-related increase in age-specific death rates in order to reach even higher levels of life expectancy in the future.

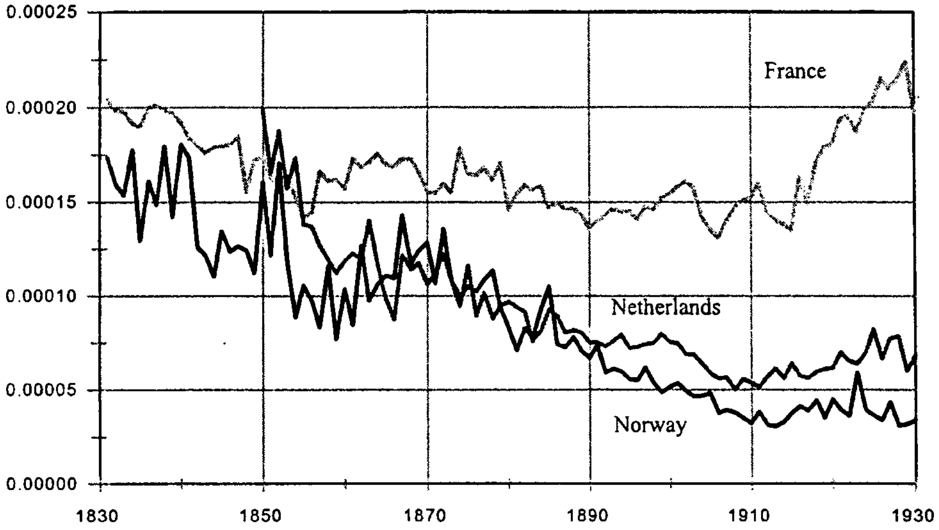
For Dutch men as well two alternatives were almost equally good in a statistical sense. Life expectancy in the first model is 75.4 at birth and in the second 82.2 years. The assumption used for old-age mortality in the first model was that the general level of old-age mortality (B) among Dutch men will gradually decline, but at a lower pace than observed in the past 7–8 years. The increase in mortality with age (c) will continue to increase, as observed recently, only less rapidly than in these past years. The assumptions used for the second model were different with respect to the decline in the general mortality level. In this case, the rapid drops observed in this past period were assumed to continue in the future. Consequently, life expectancy at 40 in these two models is equal to 36.2 and 41.1, respectively. So again it is clear that the method of modelling old-age mortality is crucial to the final form of the projection. The two different ways of modelling old-age mortality are a source of huge differences in future survival. Due to the statistical advantage, the first model was selected rather than the second. However, because the statistical difference between the two models is not very large, a question still remains open: is the selected model the most reliable one?

The above considerations can be generalized. In the period approach, the analysis of historical trends in the Gompertz parameters estimated from mortality statistics for long periods of time does not support hypotheses about future developments in the parameters responsible for old-age mortality changes. The trends after 1950 are quite different from those in the past and are most relevant for projections. The most recent trends in B and c in a country can be used to specify trajectories for the Gompertz parameters and these trajectories can be incorporated in the dynamic projection models. This was possible in five out of six projections made. In the case of too low or too high projections, trends observed in other countries can be used as alternative specifications. This, however, requires the involvement of an expert to make the necessary decisions.

5.2. MODELLING OVERALL MORTALITY BY COHORT

Whereas the modified Gompertz function fits the period patterns rather well, also in the case of mortality in a distant past, the fit by cohorts was bad. This is related to the fact that cohort mortality does not increase exponentially with age for all the ages from 40 onwards. In particular, death rates at ages in the “tails” of the empirical curve, i.e. below 50–60 and after 80–90 years, show the worst fit. Despite the poor fit, the modified Gompertz function, as in the third term of the Heligman-Pollard model, was used in our projections. This function showed a reasonable fit at ages between 60 and 80, having only two parameters which satisfied the requirements of our analysis.

Figure 3 shows that in the cohorts born after 1900, trends in the parameters show rapid jumps. This might be related to the incompleteness of data for these cohorts. Mortality of the oldest-old is missing in the cohorts born after 1900 and perhaps therefore the estimates of the parameter c, the increase in mortality with age based mainly on mortality at lower older ages, become rapidly higher than in the older cohorts. We found the incomplete cohorts born after 1930 (for Dutch and French women after 1890 and 1910 respectively) unreliable and excluded them from the input data for projections. Cohorts born in the first half of the 19th century were also excluded. For cohorts born from approximately 1850 to 1930, relatively clear trends can be identified for the Gompertz parameters. Among women the parameter c, mortality increase with age, declines slightly over cohorts in all countries except for Norway where it is stable. For men, the picture is not that clear-cut. For French and Italian men trends for c decline, whereas for Dutch and Norwegian men they increase slightly. The parameter B illustrates changes in the level of mortality by cohorts. For women in all countries trends in B decline, for France they drop slightly. For men a clear decline can be noted for the Netherlands and Norway but not for France and Italy. For the latter two countries trends are rather stable over the cohorts born between 1850 to 1900.



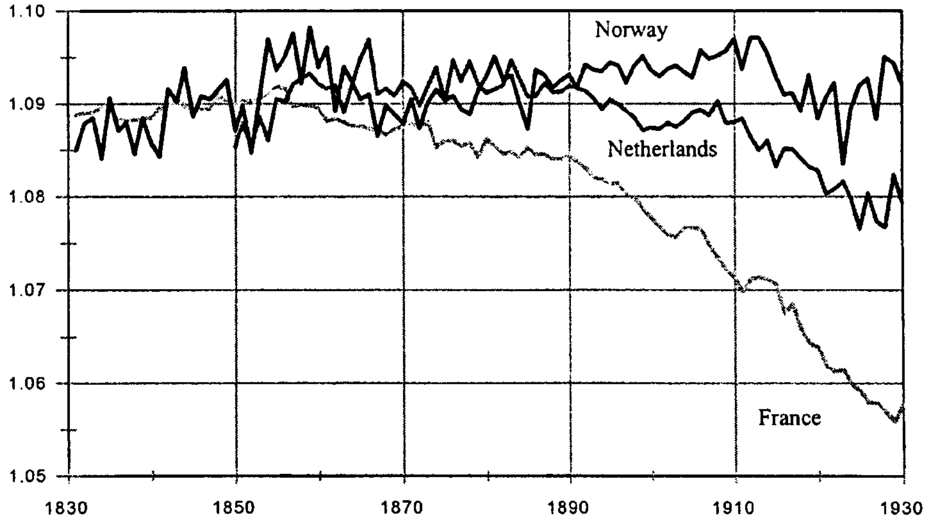


Figure 3. Trends in the Gompertz parameters according to the static cohort approach estimation: women, France, Italy, the Netherlands and Norway.

In order to avoid steep declines in the projections of cohort mortality which would contradict the observed changes, hyperbolic functions were used for trajectories of the base parameters. For both men and women and for all countries only the first Gompertz parameter *B* was assumed to change over cohorts. A target value, equalling 0, needed to be introduced into the (positive) hyperbola for *B* to protect against too rapid unrealistic declines in (standardized) death rates. *c* was always assumed constant over cohorts. This was due to the fact that if both parameters were assumed to be time-dependent, one of the two was non-significant (due to the correlation of the parameters). In fact, for both men and women in all countries it was assumed that cohort mortality would only change its level but not the rate of age-related increase. This assumption could have been unrealistic for younger cohorts but not for those born in the 19th century.

From the above summary of projections of cohort mortality it is clear that the major problem was the choice of a parameterization model and of cohorts for the analysis. Ideally, the selected function should fit the cohort data well and also, more importantly, produce regular trends in the base parameters. This is not the case with the two-parameter Gompertz model. Although the fit of the Gompertz model is acceptable, trends in the parameters are irregular, especially for the younger cohorts, those who have not completed their lives and for whom important declines in mortality after 60 are underway. With respect to the selection of cohorts, from our experience it is clear that cohorts born after 1900 should predominate when making projections. Changes in old-age mortality of these cohorts are of great relevance to the future. These changes are, however, largely unknown since the cohorts are still alive. For cohorts, assumptions must first be made regarding changes in mortality over age, and secondly, using the assumed age patterns, regarding changes in mortality over time. These "double" hypotheses necessary for cohort mortality imply that projections of cohort mortality are particularly uncertain.

5.3. MODELLING MORTALITY BY CAUSE OF DEATH

In order to make projections of overall mortality from mortality by cause of death, eighty parameterization models were applied. At least twice as many models were developed, tested and rejected as non-optimal. The sum of squared residuals, parsimony of model specification, significance of the parameters, and the visual fit (on log as well as on normal scale) were the criteria used for choosing best models. For some models an analysis of ex post forecast errors was completed. Examples of model evaluation and other details about modelling of mortality by cause of death can be found in Tabeau et al. (1998). In this contribution we can only focus on conclusions from our study as the space available here is rather limited.

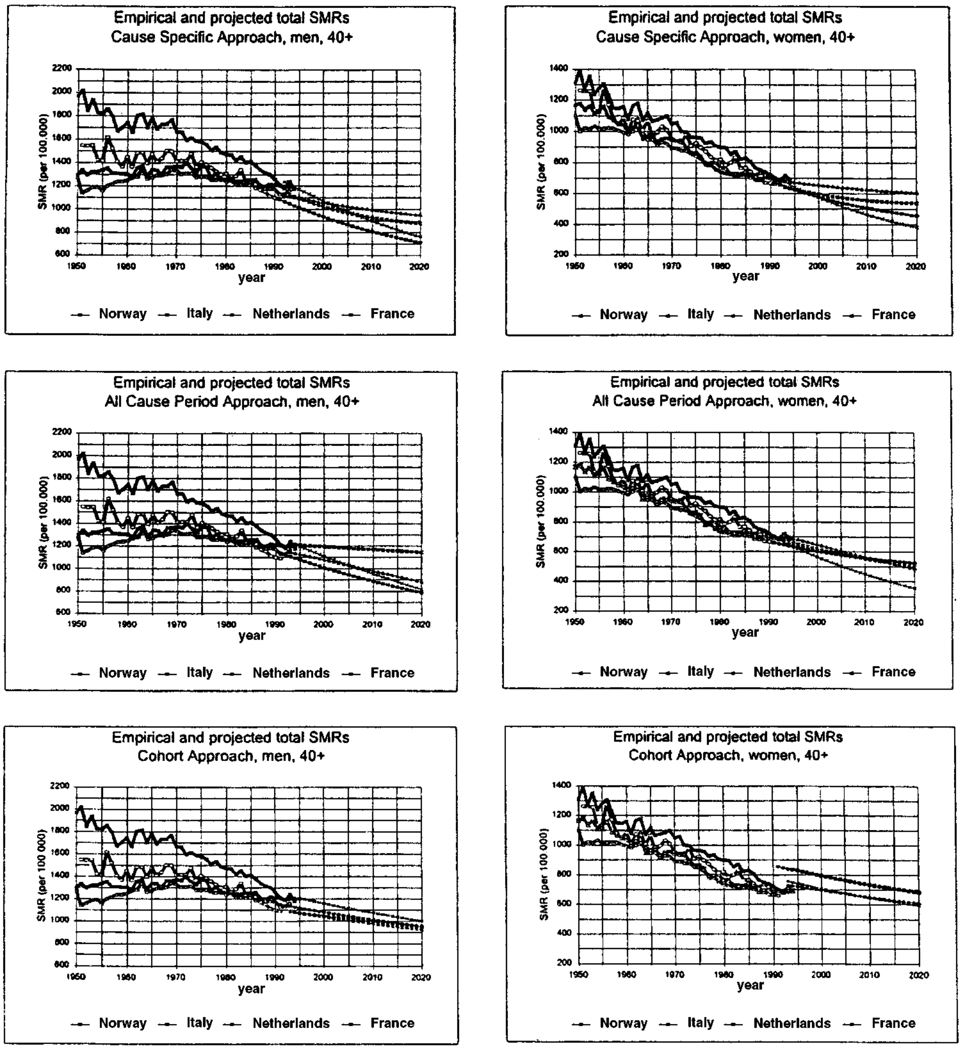
The cause-of-death approach is the least difficult out of the three investigated. Due to the simplicity of empirical age curves, parameterization functions for mortality by cause are simple. They usually include a small number of base parameters. The stability of the base parameters over time is good implying that formulating assumptions for mortality by cause is relatively easy, certainly easier than for overall mortality, whether by period or by cohort. Once the models have been formulated they can be used several times, e.g. for different projections in one country or for a group of countries with similar cause-of-death trends and patterns.

Anyone intending to project mortality by cause of death should, however, be aware of a number of drawbacks of this projection approach. First of all, different causes are relevant to different segments of the population, e.g. children, adults and the elderly. Cause-specific projections can only be made for one sub-population at a time. There is no universal index of causes to be included in projections. The lists of relevant causes may be different for different countries and time periods. Meaningful projections are those based on a good selection of causes of death. There is no use in selecting non-significant causes using the parameterization method. Age patterns of mortality from such causes are very irregular, therefore difficult to parameterize. The impact of such causes on total mortality is minor. A serious problem when projecting mortality by cause of death is related to multiple causes of death for the elderly. The underlying cause of death cannot be easily identified for ages after approximately 90 years which implies that cause-specific projections can only extend up to an (aggregated) relatively low age, such as 90 years and over. Single-year age intervals are to be preferred for the purpose of projecting. When these age intervals are not available, estimating parameterization functions for single ages from mortality rates by longer age intervals is still possible using a proper estimation approach. Finally, age patterns of mortality by cause of death change over time, and more turning points are observed in trends in mortality by cause than in trends in overall mortality, both implying that for some causes relatively short time series must be used in projecting. Note that much more time is needed to complete cause-specific projections than projections of overall mortality.

6. Cross-national comparison of life expectancy by 2020

In the previous section, we showed how projections of mortality in four countries were produced using three different approaches: the overall mortality period, cause-specific period, and overall mortality cohort approach. In this section, differences between the three approaches are discussed.

We begin with Figure 4 which summarizes the differences between the three types of approaches in terms of trends in age-standardized mortality rates (SMRs). In general, the lowest mortality has been predicted for men from the cause-of-death approach and for women from overall mortality by period. The highest variant comes for both men and women from the cohort overall mortality model, for women being particularly high, in some cases higher than recently observed. The absence of international harmonization of the forecasts is obvious. No such attempts were intended and therefore three distinct outcomes were obtained. Convergence or divergence of predicted trends is a purely extrapolation effect. Choosing between the three types of forecasts does not seem to be easy and apparently some more explanation is needed. This is done in sections 6.1 and 6.2 using the concepts of life expectancy and life table surviving population, the measures which are even more informative than SMRs. The cohort approach is discussed separately (6.2) because of its peculiarity and because in many countries historical cohort data on mortality are not available and countries may be interested mainly in the two alternative period approaches.



Empirical and projected total SMRs
Cause Specific Approach, men, 40+

Empirical and projected total SMRs
Cause Specific Approach, women, 40+

Empirical and projected total SMRs
All Cause Period Approach, men, 40+

Empirical and projected total SMRs
All Cause Period Approach, women, 40+

Empirical and projected total SMRs
Cohort Approach, men, 40+

Empirical and projected total SMRs
Cohort Approach, women, 40+

Figure 4. Empirical and projected age-standardized mortality rates for France, Italy, the Netherlands and Norway, by overall period, overall cohort and cause-specific period approach.

6.1. THE OVERALL AND CAUSE-OF-DEATH PERIOD APPROACHES

Around 1993, the level of female life expectancy at birth, e_0, was similar in Italy, the Netherlands and Norway whereas French women had a slightly longer life expectancy (Table II). Due to the dynamic models for all-age mortality by period, in 2020, at the end of the projection horizon, French women still have the longest life expectancy with a gain of 5.2 years, Dutch and Norwegian women score second with gains of about 3 years, and Italian women have a slightly lower life expectancy than women in the two Northern European countries, with a gain of 2.2 years. Except for Italy and the Netherlands, the projections for the other countries (i.e.

France and Norway) are in line with the expectations of national experts given in Table I. The projection for Italy seems to be too low and that for the Netherlands too high.

In 1993 another pattern can be noted in the period mortality patterns for men (Table II). French and Italian men have life expectancies which are similar to (73.1 and 73.6, respectively) and slightly lower than those in the Northern European countries. Dutch and Norwegian men have the same levels of life duration, namely about 74.2 years. By 2020, Italian men have the highest life expectancy, with a gain of 3.7 years. Italian men are followed closely by French and Norwegian men, with respective gains of 3.6 and 2.5 years. Dutch men score last, with a gain of about 1.2 years. In fact, when compared with the latest national forecasts, no projection for men meets the expectations; all of them are far too low. The projection for Dutch men is particularly low and remains so in the whole projection horizon (Figure 4).

Further, it is clear from our investigations that overall mortality period and cause-specific period approaches produce different future levels of mortality, and consequently of life expectancy. For women, in all four countries the overall mortality approach results in higher life expectancies than the cause-specific approach. In France, for instance, the overall mortality approach produces a life expectancy at birth of 86.5 by 2020 whereas the cause-specific approach yields 85.2 years. In Norway, 83.1 and 80.6 years were obtained from the respective approaches by 2020, in the Netherlands 83.2 and 82.2, and in Italy 82.4 and 82.2. This regularity is confirmed at each investigated age, at birth, 40, 60 and at 80.

For men, the findings are also clear, except for Norway. For men in France, Italy and the Netherlands, the overall mortality approach tended to result in lower life expectancies by 2020 than cause-specific projections: for example at birth, 76.7 versus 77.6 for France, and 75.4 versus 77.8 for the Netherlands. Again this general pattern was also confirmed at higher ages. For Norwegian men, the overall mortality approach tended to produce a higher life expectancy than cause-specific projections. This may be attributed to the fact that the projection of overall mortality for Norwegian men is rather high (in terms of life expectancy; low in terms of mortality). In addition, the cause-specific projection (i.e. life expectancy) is relatively low for Norwegian men, a result of past trends in mortality by cause of death, primarily high-level, stable trends in mortality from coronary heart disease and external causes and the ever increasing trend in mortality from lung cancer.

It is worth noting that both the total gains in life expectancy over the entire projection horizon, and the (relative) age distribution of the gains were different in the two approaches. In general, for both men and women in the cause-of-death approach, a larger percentage of the total gain in life expectancy at birth in each country was attributed to changes in mortality after 60.

Important conclusions can be drawn from the above findings when the concept of the (life table) surviving population is applied (Table III). Life expectancy at 80 and the percentage surviving population at this age provide us with two different, in fact complementary, types of information. Whereas life expectancy at age 80

Table II. Life expectancy in France, Italy, the Netherlands and Norway in 1993 and in 2020 according to the period, cause-of-death and cohort projection approaches*

	At birth				At age 40			At age 60			At age 80		
	1993	Period	Cause	Cohort	Period	Cause	Cohort	Period	Cause	Cohort	Period	Cause	Cohort
Women													
France	81.3	86.5	85.2	80.8	48.0	46.7	42.2	29.5	28.1	24.3	13.3	11.0	11.0
Italy	80.2′	82.4	82.2	79.7	43.0	42.8	40.3	24.3	24.2	22.7	9.4	9.0	9.3
Netherlands	80.2	83.2	82.2	80.0	44.1	43.1	40.8	25.6	24.8	22.9	10.8	9.3	9.4
Norway	80.2	83.1	80.6	80.8	44.3	41.8	42.0	25.7	23.6	23.9	11.1	8.6	10.0
Men													
France	73.1	76.7	77.6	73.9	39.0	40.1	36.2	22.0	23.1	19.6	9.5	8.5	8.1
Italy	73.6′	77.3	77.9	74.8	39.3	39.9	36.8	21.2	22.0	20.0	7.8	8.2	8.0
Netherlands	74.2	75.4	77.8	76.5	36.6	39.1	37.1	18.6	20.9	20.3	6.2	7.1	7.9
Norway	74.2	76.7	75.6	75.2	38.4	37.3	36.9	20.7	19.8	19.9	7.9	7.9	8.0

* For mortality by cause (or cohort), life expectancy at birth is based on two types of rates: cause (or cohort) rates for ages above 40, and overall mortality period rates below age 40; note that the rates below 40 are the same in all approaches and equal to overall mortality period rates.

′ = In 1992; source: own calculations.

Table III. Percentage of survivors at age 40, 60 and 80 in France, Italy, the Netherlands and Norway by 2020 according to the period, cause-of-death and cohort projection approaches

	At 40	At age 60			At age 80		
	Period	Period	Cause*	Cohort*	Cause	Cause	Cohort*
Women							
France	95.7	94.0	93.9	89.2	76.5	78.8	59.0
Italy	99.0	94.9	94.5	91.0	65.8	66.4	56.5
Netherlands	98.6	94.1	93.6	91.6	67.1	68.0	57.0
Norway	98.2	93.6	92.5	92.1	67.2	63.3	60.3
Men							
France	95.8	86.2	86.4	83.6	49.7	57.6	40.9
Italy	96.3	89.8	89.4	85.1	51.2	54.4	43.4
Netherlands	97.8	90.0	91.6	88.7	41.1	52.2	46.4
Norway	97.0	89.1	88.4	86.4	48.3	45.2	43.6
Both genders							
France	95.8	90.1	90.2	86.4	63.1	68.2	50.0
Italy	97.6	92.4	92.0	88.1	58.5	60.4	50.0
Netherlands	98.2	92.1	92.6	90.2	54.1	60.1	51.7
Norway	97.6	91.4	90.5	89.3	57.8	54.3	52.0

* This percentage was calculated assuming that the percentage of survivors at 40 is the same as in the overall mortality period model.

characterizes survival chances after this age, the percentage surviving population at age 80 characterises survival chances below this age. So, populations with higher life expectancies at 80 may have lower percentages of survivors at this age. This is the case, for instance, with French, Italian and Dutch women when overall period and cause-of-death projections are compared. For both sexes the overall and cause-specific methods produce (both jointly and separately) similar (or slightly lower in the overall approach) percentages of survivors at age 60 but not at age 80 by 2020. For each country, except Norway, the cause-of-death projections result in larger populations of those aged 80 and over, for both sexes taken together: 6.0% in the Netherlands, 5.1% in France, and about 1.9% in Italy. Norway is again an exception with a smaller percentage of survivors (3.5%) estimated using the cause-specific approach. The differences are certainly not small, in particular for countries with large populations, like France.

The differences between the approaches are also summarized by the projected trends in sex differences in mortality. When sex differences in mortality are measured by the difference between male and female life expectancy at birth (and also at 40 and 60), overall projections produce increasing sex differences for all countries, except for Italy. As the rates of change in the sex differences are not the same in all countries, the effect of the overall mortality approach is that trends in sex differences, starting from similar levels in 1994, differ considerably by 2020. Cause-specific projections produce another set of results. According to this approach, the sex difference at birth (and also at 40 and 60) declines in all the countries between 1994 and 2020, pointing to a convergence of trends rather than a divergence. In the entire projection horizon at age 40, the biggest sex difference can be noted for France, declining gradually to a level of 7 years. For the other countries, sex differences start from about 5.0 years in 1994 and end with levels of 2.5 to 4.5 years by 2020. The opposite trends resulting from the two projection approaches do not help when deciding which approach should be preferred.

6.2. THE COHORT APPROACH

Before any discussion of projections by cohort can start, it must be stated that all cohorts which are most relevant to projections are incomplete. Projections of cohort mortality are therefore particularly uncertain. In this study, mortality levels and patterns of cohorts born in the 19th century were used mainly to project cohort mortality. This decision was prompted by difficulties with the formulation of hypotheses for the Gompertz parameters for cohorts with incomplete life durations, i.e. those born between 1900 and 1930 and later. As a result of a design of this sort, an important turning point in old-age mortality, usually said to occur in the years 1950–1960, is missed, and too high levels of old-age mortality are likely to result.

With respect to the projections obtained by the cohort approach[5] it is clear that cohort life expectancies by 2020 are very low for each sex and each country (Table II). For women at younger ages (i.e. 40, 60), they are not only low, but no more than currently observed levels, or even just under these levels. For instance, for women in 1993, observed life expectancies at 40 were 42.3, 41.3, 41.2 and 40.9 years for France, Italy, the Netherlands and Norway respectively, whereas life expectancies projected by the cohort approach equalled 42.2, 40.3, 40.8 and 42.0 years, respectively. Norwegian women are the only exception, with a reasonable level of the cohort projection, in particular at ages 40 and 60.

The patterns for men are different from those for women and also differ between different countries. The projections for French and Italian men are the lowest of all the three approaches applied. Nevertheless these projections are above the current levels of life expectancy, whether at age 40, 60 or 80. This is an important difference compared with women. The projections for men in the Netherlands, i.e. life expectancies at ages 40 and 60 based on the cohort projections, are clearly higher than projections based on the overall mortality period approach. For Norwegian men, the cohort approach produced patterns similar to those discussed for French and Italian men where the differences are related to the degree of similarity between cohort and cause-of-death projections. For Norwegian men, as opposed to French and Italian men, these two approaches produced very similar levels of life expectancy at age 60 as well as 80 years.

The percentage surviving is very low at any age for each sex in the cohort approach (Table III). This finding illustrates the nature of cohort projections which in turn shows the character of the mortality process in the early stages of the epidemiological transition. In the distant past, deaths increased much more rapidly with age than today. Therefore, the percentage of the population surviving is low compared with current values.

Sex differences in the projections produced by the cohort approach increase slightly in all countries. The level of sex differences is very low in the cohort projections, in fact lower than currently observed. This again shows that mortality is overestimated, in particular for women, by the cohort approach.

7. Summary and discussion

The major goal of this study was to show ways of improving demographic forecasts of overall mortality. In order to reach this goal, we proposed a forecasting method, dynamic parameterization, particularly suitable for mortality decomposed by cause. We applied this method to forecast mortality by ten causes of death in four low mortality European countries, and compared these results with those from two traditional (period and cohort overall mortality) forecasting approaches. The forecasts presented in this paper are mathematically sophisticated but conceptually "naive". They are based on trend extrapolation, and contain a minimal (if any) expert judgement. In order to produce the forecasts, we defined best statistical models, let the past trends continue and showed the outcomes of these "assumptions". In effect, three alternative sets of forecasts are obtained and hardly anyone can be chosen as the "best". This situation is typical for each country.

Our study clearly shows that trend extrapolation of overall mortality by period, cohort and by cause of death produce different levels of mortality, and consequently of life expectancy, percentages of survivors and sex differences in mortality in the future. The method used in our study is highly non-linear. Therefore, one should not expect that a general pattern of higher mortality arising from the use of cause-specific approach shown by Wilmoth (1995) for linear models also emerges from our projections. This does not mean that no pattern at all have been obtained in our study. Our findings are consistent with those presented by Caselli (1996) using age-period-cohort models. When the two period approaches are compared for women, the overall mortality approach results in higher life expectancies in all four countries than the cause-specific approach. This is confirmed at each investigated age, at birth, 40, 60 and at 80. For men, the findings are opposite (Norway is one exception). For men, the overall mortality approach tended to result in lower life expectancies by 2020 than the cause-specific projections, again for ages 40, 60 and 80.

With respect to the projections obtained by the cohort approach it is clear that life expectancies are low for each sex and each country. For women at younger ages (i.e. 40, 60), they are not only low but also at currently observed levels, or just under these levels (except of Norway). This implies that projections of mortality obtained by the overall cohort approach cannot be taken as a reasonable alternative to overall mortality from period or cause-specific period approaches.

So, which approach is preferable and why? This question can be answered in at least two ways: quantitative and qualitative. A quantitative way to choose between the different forecasts would be to look at statistical accuracy of prediction which in the cause of death approach might be worse than in overall mortality period approach due to the reasons summarized by Alho (1991) and reviewed in section 2 of this paper. On the other hand, Rogers (1995) suggests that forecast accuracy is an empirical issue, depending on the particular historical period observed and the degree of demographic variability exhibited in mortality trends in the countries investigated. The accuracy of our models is not necessarily comparable between the three approaches and the countries. The quantitative answer does not seem to be the best way of choosing between the three forecasts.

The qualitative approach pays more attention to transparency of assumptions, options for empirical validation, and utility of the forecasts rather than to statistical accuracy. Formulating assumptions for overall mortality is not an easy task. In the fourth stage of the epidemiological transition observed in the Western European countries, the levels of life expectancy are extremely high and a further change of life expectancy is hardly predictable from the past experience. Some authors (e.g. Olshansky and Carnes, 1994; Carnes and Olshansky, 1993) suggest that the law of diminishing returns will hamper the increase in life expectancy. This is not necessarily the only possible variant of the future as the “enormous plasticity” of the life span is widely seen elsewhere in the animal kingdom (e.g. Finch, 1997). Due to the fact that the number of determinants of mortality is extremely large, empirical validation of assumptions for total mortality, irrespective by period or cohort, is practically not feasible. A simple way of overcoming the difficulties in choosing the assumptions for overall mortality is predicting total mortality from mortality decomposed by causes of death. Trends in mortality by cause of death can be linked with trends in risk factors of diseases – causes of death. Validating assumptions for cause-specific mortality can be done using epidemiological models of health of the populations. This seems to be far simpler, yet is not simple at all, as only joint studies of demographers and epidemiologists can result in realistic forecasts of cause-specific (and, consequently, total) mortality forecasts. Finally, one should also note that the forecasts of mortality by cause of death are urgently needed for many purposes, one example being the estimation of health care costs and, in particular, of the disability costs related to the use of health care services in the ageing populations. The estimates of disability costs must be based on (among other things) future levels of cause-specific mortality. Both demographic and epidemiological forecasts of mortality by cause are of potential use in this estimation. But epidemiological and demographic forecasts of cause-specific mortality show usually considerable conceptual differences and consequently different outcomes. Discrepancies observed between these two types of forecasts of cause-specific mortality should be better understood.

In the view of the above discussion, we are convinced that the qualitative approach to the choice between different forecasting approaches is more useful to forecasters than the quantitative. The qualitatively chosen approach in this study would be by cause of death which, however, should be supplemented by overall mortality (period and/or cohort) prediction. A simple reason for using multiple forecasting approaches found in our study is that the variant closest to the national expectations summarized in Table I was for men, the cause-of-death approach and for women, the overall mortality period approach.

In order to explain more generally the need for multiple-approach forecasts it is useful to examine the three forecasting approaches in terms of their advantages and disadvantages. Regarding the cause-of-death forecasts we argue that, conceptually, this forecasting approach should be considered as a technique to improve forecasting of mortality in terms of predicting structural (age and cause) patterns and not necessarily in terms of the statistical quality of prediction. The importance of forecasting of mortality by cause of death is mainly related to the transparency of assumptions, availability of options for empirical validations of the forecasts and their high utility. However, the cause-of-death approach is not optimal for forecasting of mortality of the oldest-old. This is because the underlying cause of death cannot be easily identified for ages after approximately 90 years which implies that cause-specific projections can only extend up to an (aggregated) relatively low age such as 90 years and over. Another modelling method, for instance parameterization of overall mortality, should be considered for that. It is worth noting that old-age mortality, i.e. mortality after age 60 and in particular after 80, is the key component of any projection model. Hypotheses chosen for this component are crucial to the outcome of projections, but their formulation is difficult. The hypotheses can no longer be chosen on the basis of past experience but using longevity research or research on the expectations of future trends in risk factors. In order to formulate good hypotheses, we need explanatory models for mortality of the oldest old. These models could be used to prepare simulations, each conditional on different values of the explanatory variables. We could also use explanatory models for mortality to make retrospective projections of risk factor levels necessary to achieve certain levels of mortality. These two types of models would tell us more about the "worth" of projections obtained by extrapolating trends. Unfortunately, this approach is hardly applied in current mortality projections.

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Notes

[1] France is one exception where reclassified data could perhaps serve to reconstruct rough estimates (based on five-year age groups) of cohort- and cause-specific mortality since 1925 (Vallin and Meslé, 1990). The Netherlands is the second exception with reclassified data (since 1875) for a rather small number of mainly historically relevant causes of death (Van den Bosch et al., 1996). For recent years, i.e. since 1950, (single-year) age, period, and cohort-specific data for causes of death are available, in a few countries with best mortality statistics, like the Netherlands. These data are not easily accessible, first because they require time-consuming and expensive preparation, and, secondly because strict data protection regulations have to be obeyed. In addition, the time series from 1950 onwards must be seen as extremely short for the needs of cohort analysis.

[2] Despite of the fact that the remarks at Rogers and the whole discussion of simplicity versus complexity in forecasting models presented recently in special issues of *Mathematical Population Studies 5(3)*, 1995, and *International Journal of Forecasting 8(3)*, 1992, were all made in the context of the population forecasting, their relevance to forecasting of any demographic process, including mortality, is unquestionable. These two editions offer a lot of useful material about forecasting in general.

[3] The method is available in the standard software packages such as EViews, SPSS and others. Estimation can be also done by the likelihood maximization, using for instance GLIM.

[4] Italy was not included since Italy was the only country for which we were not able to collect single-year mortality data, even for the years after 1950, and had to use five-year age intervals instead.

[5] In this section the term “cohort forecasts” is used for period patterns obtained from transformed cohort death rates. Cohort death rates by age are normally situated on the diagonals of the Lexis diagram. We used them to construct the columns of the Lexis. The columns served to calculate new life tables for the years 1994–2020, called “cohort approach”.

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