Determinants of trends in old-age mortality in seven European countries, 1950-1999*

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ABSTRACT

This paper presents an overview of old-age mortality trends in seven European countries and the role of smoking, mortality selection, socio-economic developments throughout the life-course, and medical end-of-life decisions herein. Poisson regression and correlation analyses were applied to all-cause and cause-specific mortality among the elderly (60+/80+) and to empirical data on determinants in Denmark, England and Wales, Finland, France, The Netherlands, Norway, and Sweden, 1950-1999. We found large heterogeneity in the pace of decline, with stagnation since the 1980s in Denmark, The Netherlands, and among Norwegian men. Both period patterns and cohort patterns were observed. Smoking, an important cohort factor, has had a marked influence on old-age mortality trends, but can not fully explain the observed stagnation. Mortality selection has not been a driving factor behind old-age mortality trends. Next to the effect of current economic growth an effect of economic developments during earlier ages of the cohort was found. Cross-national differences in old-age mortality might to some extent be the result of differences in attitudes concerning appropriate medical treatment for the elderly.

BACKGROUND

The twentieth century has witnessed an enormous increase in life expectancy. Whereas in the early 1900s, people from low-mortality countries could expect to live on average approximately 50 years from birth,[1] in 2000, life expectancy at birth in record-holding country Japan rose to over 77 years among men, and almost 85 years among women.[2]

The epidemiological transition that lies behind this increase in life expectancy is characterized by different phases.[3] The early increases in life expectancy, up to about 1930, were the result of "receding pandemics", i.e. huge declines in mortality from communicable diseases at younger ages.[3,4] These declines in mortality among younger ages gradually led to a shift in mortality towards older ages, with more weight to non-communicable, or "degenerative and man-made" diseases. As a result, the development in life expectancy became more and more determined by trends in mortality at older ages.[5]

In low-mortality countries, mortality at older ages has generally declined since the 1950s,[6-11] due to decreasing mortality rates from mainly cardiovascular diseases.[12] This decline in old-age mortality did not only contribute to the general increase in life expectancy; it was also partly responsible for the current increase in the number, the proportion and the mean age of elderly people in these populations, i.e. the ageing of these populations. The far-reaching consequences of population ageing for demands of health care services and old-age benefit systems are widely known.

Due to the increasing effect of old-age mortality trends on the current and future course of life expectancy, and due to its role in the ageing of populations,[13-15] it is increasingly being recognized that old-age mortality should receive more attention in research. Next to emphasis on the age-trajectory of mortality among the elderly population,[16-19] a number of questions on possible future trends in life expectancy have gained interest. With respect to the latter, particularly the extent to which today's populations are approaching a limit to human life expectancy is extensively being debated upon. On the one hand, proponents of 'the limited-lifespan paradigm' state that biological and practical constraints to reducing old-age mortality imply that future gains in life expectancy will occur at a slower pace, and that the limit to life expectancy is almost reached.[20-22] On the other hand, 'the mortality-reduction paradigm' is adhered to by researchers who argue that life expectancy will continue to increase for some time to come.[2,23,24] They support their view by referring to mortality developments in sub-populations with extreme good health, to foreseen biomedical progress, and to historical observations that old-age mortality has been decreasing continuously.

In order to make inferences about possible future trends in old-age mortality, it is important to carefully study past trends and, even more importantly, to study the determinants of past trends. The growing research focus on mortality among elderly populations, however, has until recently led to mostly descriptive studies on trends in old-age mortality.[8-10,25-27] Although, these studies reported important cross-national variations in the pace of mortality decline among the elderly, with even stagnation of the mortality decline in the 1980s in the Netherlands and Norway,[9,28] little is known about the mechanisms behind the observed trends.

Aim of the current study is to carefully describe trends in old-age mortality in seven European low-mortality countries from 1950 to 1999, and to assess the role of specific factors in explaining the observed trends.

Approach

For this purpose, we study both trends in all-cause mortality and trends in specific causes of death. Because many of the intermediate factors or risk factors that could determine mortality trends among the elderly are related to specific causes of death, studying the trends in cause-

specific mortality can generate evidence on the determinants of the trends in all-cause mortality among the elderly.

In addition, we adopt a life-course perspective, with emphasis on determinants occurring not only in late life but also in earlier phases of the life course.[29,30] For the present population study, adopting a life-course perspective implies the study of not only period patterns in old-age mortality, but also its cohort patterns. Whereas period patterns indicate immediate and modifiable effects of conditions occurring in late life, cohort patterns may reflect unmodifiable long-lasting effects of determinants located earlier in life. This distinction is of crucial importance for making projections of future developments in mortality. If cohort effects prove to be important, cohort-wise projections may be used to explore possible future mortality trends.

Parallel analyses for seven selected countries are performed in order to reveal general patterns and possible country-specific deviations from these general patterns. We included seven low-mortality countries in north western Europe, i.e. Denmark, England and Wales, Finland, France, the Netherlands, Norway, and Sweden. For these countries, differences both in old-age mortality trends,[8] and in the levels and trends of several potential determinants have been observed. In addition, these countries are among the few countries with the most accurate data on old-age mortality from 1950 onwards.[9]

With regard to the determinants, we focus on the role of smoking, mortality selection, socio-economic developments throughout the life-course, and medical end-of-life decision-making. Smoking is known for its strong negative effect on survival. Moreover, the impact of smoking on mortality trends may vary considerably between countries,[31] due to, for example, cross-national differences in the development of lifetime exposure to smoking across the birth cohorts.[32] Mortality selection implies that when mortality decreases at younger ages, the increasing proportion of the elderly population might be expected to be less healthy when compared to survivors of earlier cohorts.[15] Subsequently this elderly population could experience relatively higher morbidity and mortality. Socio-economic developments may be a key factor in influencing mortality levels and trends.[33] During the 20th century, all European countries experienced dramatic increases in both economic prosperity and life expectancy. Cross-national differences in medical end-of-life decision-making[34] could possibly contribute to cross-national differences in old-age mortality.

Research questions

Applying our approach to the aim of this article we formulated two main research questions:

1. How did old-age mortality develop over the period 1950 to 1999 in seven European countries?
2. Which role do smoking, mortality selection, socio-economic developments throughout the life-course, and medical end-of-life decision-making have in explaining the observed trends?

DATA AND METHODS

Data

We included aggregate data on total mortality, the underlying cause of death, and population at risk, by year of death (1950-1999), sex, and five-year age groups (60+/80+) for Denmark, England and Wales, Finland, France, The Netherlands, Norway, and Sweden. These data were obtained from national statistical offices, and related institutes, the Kannisto-Thatcher Database on Old Age Mortality (http://www.demogr.mpg.de/databases/ktdb),[9] and the Human Mortality Database (http://www.mortality.org).

With respect to the causes of death, we selected 26 specific causes of death. We focussed especially on smoking-related causes of death, cardiovascular diseases, and diseases specifically related to old age.

To study the role of socio-economic developments throughout the life-course, we reconstructed trends in Gross-Domestic Product per capita and infant mortality from 1865 onwards, based on historical overviews.[35-38] To assess the role of medical end-of-life decision-making, we included recent data on physicians' practices and attitudes concerning medical end-of-life decisions from the EURELD consortium.[34,39]

Methods

To these data, we applied different descriptive and analytical techniques. The old-age mortality trends were described by means of Poisson regression. The dependent variable was the number of deaths, with the person-years at risk as offset variable. As independent variables, we used age group and period splines. Spline functions divide the overall trend into a number of separate, adjacent segments,[40] and enabled us to study trends within specific decades instead of broader periods, and to identify changes in the overall trend, such as a stagnation in mortality decline. The analysis using splines yielded estimates of annual mortality changes within each decade.

To reconstruct trends in cause-specific mortality between 1950 and 1999 we had to bridge five different revisions of the International Classification of Diseases (ICD-6 to ICD-10), for all countries, except France for which coherent series of causes of death were already available.[41] For this purpose, we constructed a general concordance table on the basis of three-digit codes. Subsequently, we evaluated the occurrence of mortality discontinuities by visually inspecting cause-specific trends, by using country-specific background information on these trends, and by the quantification of the discontinuities in cause-specific Poisson regression models. (See Janssen et al., 2004).[42] Mortality discontinuities that were regarded as due to changes in coding rules were controlled for on the basis of sex- and cause-specific transition coefficients. These transition coefficients are the parameter estimates of variables associated with a coding change (e.g. ICD-8toICD-9), and obtained through sex-specific regression models. In these regression models, cause-specific mortality was the dependent variable and age, period splines and variables associated with a coding change were independent variables.

To assess the role of period and cohort effects in old-age mortality trends we performed age-period-cohort analyses. In age-period-cohort models it is impossible to identify the role of age, period, and cohort separately, due to the linear dependency between the variables (period – age = cohort).[43-45] To overcome this identification problem we used the Clayton and Schifflers approach, which decomposes mortality in a common linear trend, non-linear cohort effects, and non-linear period effects.[44,45] We measured the contribution of drift, the non-linear period effects, and the non-linear cohort effects in the mortality trends by assessing the reduction in scaled deviances (a measure of unexplained variance) when comparing the subsequent models (i) age-drift with age, (ii) age-period with age-drift, and (iii) age-period-cohort with age-period, respectively. We expressed these reductions as percentages of the reduction in scaled deviance observed between the model with age only and the full APC model.

The role of smoking was studied by comparing trends in all-cause old-age mortality with trends in non-smoking related mortality. Non-smoking related mortality was estimated based on a simpler application of the indirect Peto-Lopez method.[46,47] The prevalence of smoking in the different populations was determined by relating the lung cancer rates in these populations to the smoothed lung cancer rates among the never smokers of the ACS CPS-II study. In

addition, the fact was used that the etiologic fraction (EF) is a function of the proportion of the population that is exposed (p) and the relative risk (RR), i.e. EF = p(RR-1)/(p(RR-1)+1). The relative risk for smoking of total mortality was set at 2. To remove residual confounding and to obtain conservative estimates of the numbers of deaths attributable to smoking the etiological fractions were adjusted by 30 %.[48] The adjusted etiological fractions were used to calculate non-smoking related mortality, i.e. all-cause mortality * (1-EF). The trends were expressed in percentage annual mortality changes.

To test whether mortality selection was a dominant factor in determining trends in old-age mortality, we studied the possible existence of a negative correlation between trends in late middle-age mortality (ages 55-69) and trends in old-age mortality (ages 80-89) among the cohorts centralised around 1895, 1900, 1905, and 1910. Next to all-cause mortality, we focused on cardiovascular diseases and diseases typically related to old age, i.e. causes of death that are especially susceptible to mortality selection. Mortality declines in cardiovascular diseases, predominantly ischaemic heart diseases, have been shown to lead to increased prevalence of chronic heart diseases at older ages,[49] with subsequently higher mortality risks of related diseases.[50] Diseases typically related to old age, might be related to the level of among the elderly.

A possible role of socio-economic developments throughout the life-course was assessed by studying both univariate and multivariate associations across five-year birth cohorts (i.e. those born between 1865 and 1924) between old-age mortality (65+) and gross domestic product (GDP) prevailing at time of death, and at earlier ages of these cohorts. Through Poisson regression analyses, we measured the reduction in scaled deviances (i.e. a measure of goodness-of-fit) when GDP prevailing at different ages, is added to a model with age as the only covariate. This reduction in scaled deviances was expressed as a percentage of the reduction observed for a full age-period-cohort model.

In a final analysis, we examined the association between physicians' practices and attitudes concerning end-of-life decision-making and mortality by age and cause of death across six European countries, i.e. Belgium, Denmark, Italy, The Netherlands, Sweden, and Switzerland. We did so by means of correlation analyses.

RESULTS

Trends in old-age mortality in seven European countries, over the period 1950 to 1999

The period patterns showed an overall decline in mortality among those aged 80 and over from 1950 to 1999, with a convergence in the mortality level between countries over time. However, there was large heterogeneity in the pace of decline, with periods of stagnation being widespread. From the 1980s onwards, small mortality declines or even increases were observed in Denmark, The Netherlands, and among Norwegian men. In contrast, old-age mortality decline continued in England and Wales and France. (Figure 1)

In Figure 2, the main results of our age-period-cohort analysis are displayed. Drift (the linear component of both period effects and cohort effects) contributed to a large extent to the systematic trends, especially among elderly women. However, for men in Denmark, The Netherlands, and Norway, non-linear cohort effects and non-linear period effects contributed substantially to old-age mortality trends. For both sexes, and all countries, the effect of adding the non-linear cohort effect to the model including age and period, was statistically significant, indicating that the trends in old-age mortality can be described by a combination of period and cohort patterns.

For the subsequent cohorts (1865 to 1935), all-cause mortality among those aged 60 and over generally declined. This decline, however, stagnated among Danish, Dutch and Norwegian

men born between 1890 and 1915, and among women from all countries born after 1920. (Figure 3)

The role of the different determinants in explaining the observed trends

Smoking

In Table 1, the trends for total mortality and mortality from non-smoking related diseases are displayed, by means of annual changes. For all-cause mortality the heterogeneity in the pace of old-age mortality decline between the countries clearly shows. Comparison of the trends for total mortality with the trends for mortality from non-smoking related diseases showed quite different trends, indicating that smoking has had a marked influence on old-age mortality trends. When, however, the mortality trends in non-smoking related diseases are compared between the different countries, the differences in the pace of the mortality decline between the countries only partially disappear. Recent trends in the Netherlands and among Danish men remain unfavourable, particularly in the 1990s, whereas recent mortality trends in non-smoking related diseases continue to be very favourable in France. The stagnation of old-age mortality decline in the Netherlands and among Danish men thus cannot be fully explained by smoking. The disappearance of the stagnation among Norwegian men and even more so among Danish women implies that the stagnation in Danish women and among Norwegian men is more closely related to smoking. (Table 1)

Mortality selection

All-cause mortality changes at ages 80-89 were strongly positively correlated with all-cause mortality changes at ages 55-69 among the cohorts born between 1895 and 1910 (correlation coefficient of 0.61), and especially among men (correlation coefficient of 0.71). For causes of death that are especially susceptible to old age, i.e. circulatory disease mortality at ages 55-69, and mortality at ages 80-89 from diseases specifically related to old age, positive correlations or no clear negative correlations were observed with all-cause mortality trends at later or younger ages, respectively. Virtually the same correlations were seen between all-cause mortality changes at ages 80-89 and changes in circulatory disease mortality at ages 55-69 (correlation coefficient of 0.61 overall). Mortality trends at ages 80-89 from diseases specifically related to old age – that is infectious diseases, pneumonia, diabetes mellitus, symptoms and external causes, showed no clear negative correlations with all-cause mortality trends at ages 55-69. Mortality selection, thus, does not seem to be a driving factor behind old-age mortality trends in the countries under study. (Table 2)

Socio-economic developments

Figure 4 displays the main results on the role of socio-economic developments throughout the life-course on old-age mortality trends. The black columns show that for the cohorts born between 1865 and 1924, levels of GDP at time of death were strongly associated with all-cause mortality at ages 65-99, especially among women, and among men in England and Wales, Finland, and France. In these instances, the reduction in scaled deviance when the variable GDP at time of death is added to the model including only age was relatively high. In most countries, the reduction in scaled deviances was even higher when in addition GDP variables prevailing at earlier ages were added to the regression model. The associations were merely inverse, as expected. That is, increasing levels of GDP led to decreasing old-age mortality rates, and vice versa. Thus, next to the inverse effects of current economic developments on old-age mortality trends, independent inverse effects of economic developments during earlier ages of the cohort were found. GDP prevailing at ages 20-49 (men) and 50-64 (women) showed the strongest associations with old-age mortality for the majority of countries. Thus, socio-economic circumstances during adulthood and middle age

seem more important in determining old-age mortality trends than those during infancy or childhood.

Medical end-of-life decision-making

Based on physicians' estimates of the life-shortening effect of medical end-of-life decision-making on the individual, a rather small effect of medical end-of-life decisions on national life expectancy was observed (results not shown). However, across six European countries, physicians' practices tended to correlate positively with old-age mortality (0.39 men; 0.55 women), and the share of physicians who feel they should unconditionally preserve their patients' lives tended to correlate negatively with old-age mortality (-0.55 men; -0.65 women). Cross-national differences in old-age mortality, thus, might to some extent be affected by differences in attitudes concerning appropriate medical treatment for the elderly.

DISCUSSION

The aim of this article was to carefully describe trends in old-age mortality in seven European low-mortality countries from 1950 to 1999, and to assess the role of specific factors in explaining the observed trends.

For this purpose, we studied both all-cause mortality and cause-specific mortality, we applied a life-course perspective, and we performed parallel analyses to seven countries, i.e. Denmark, England and Wales, Finland, France, the Netherlands, Norway, and Sweden. In a series of separate analyses, we assessed the role of smoking, mortality selection, socio-economic developments over the life course, and medical end-of-life decision-making.

Our results indicate large heterogeneity in the pace of mortality decline among the elderly in seven European countries, with stagnation since the 1980s in Denmark, The Netherlands, and among Norwegian men. Mortality decline continued, however, in England and Wales and especially France. In determining these trends, both period patterns and cohort patterns seem important. Smoking, an important cohort factor, has had a marked influence on old-age mortality trends, but can not fully explain the observed stagnation. The consistently positive correlations observed between trends in late middle-age mortality and old-age mortality among the same cohorts, indicate that mortality selection has not been a driving factor behind old-age mortality trends in the countries under study. Next to a period effect of current economic developments on old-age mortality trends, a cohort effect of economic developments during earlier ages of the cohort, predominantly during adulthood and middle age, was found. Cross-national differences in old-age mortality might to some extent be affected by differences in attitudes concerning appropriate medical treatment for the elderly.

The consistently positive correlations between trends in late middle-age mortality and old-age mortality among the same cohorts, and the observation of an independent, mostly negative effect of GDP prevailing at earlier ages of subsequent cohorts on old-age mortality, both seem to suggest effects of early life circumstances carried throughout life, and, even more importantly, effects of prolonged exposure to, or long-lasting effects of risk factors, such as smoking, emerging in adult life.

Old-age mortality thus seems susceptible to both favourable and unfavourable circumstances either prevailing at old ages, or originating earlier in life, predominantly in adulthood or middle age.

Evaluation of the data and the methodological approach

The mortality and population data used in this study stem from countries considered to have good or excellent population and vital registries.[8,9] Reported survivorship counts are highly

accurate.[9,51] Comparison of our mortality data to the mortality data from the Kannisto-Thatcher Database—in which the data was checked for age-heaping and were subjected to a number of checks for plausibility[9]—showed only small discrepancies, that had no appreciable effects on our results.

Our approach of studying determinants of trends in old-age mortality trends was characterised by its emphasis on cause of death patterns, its life-course perspective, and the use of parallel analyses for seven countries. The usefulness and limitations of this approach will be discussed below.

Studying the trends in cause-specific mortality generated clues on the determinants of all-cause mortality trends. Examining specific causes of death helped to identify intermediate factors or risk factors that could determine mortality trends. Our differentiation into causes of death also informed us about causal mechanisms. It should however be acknowledged that especially among elderly populations, the identification of a single underlying cause of death is complicated by the presence of more than one chronic disease contributing to death.[52,53] Particularly at older ages, the validity of the underlying cause of death may thus be questioned. Studying multiple causes of death has been proposed as an alternative.[52-54] However, in addition to the difficulty of obtaining these data, these studies are also limited because of the differences in the extent to which physicians list more than one cause on the death certificate.[52] Moreover, numerous methodological problems are involved due to the abundance of the data.[54] Studying multiple causes of death thus is not by definition the better solution.

In studying long-term trends in causes of death, the comparability over time may be affected by the many revisions of the International Classification of Diseases (ICD) leading to changes in coding rules in the period under study. We made considerable effort to bridge these ICD revisions by carefully constructing a concordance table based on three-digit codes and by identifying and controlling for the remaining biases due to coding changes both within and between ICD revisions. However, remaining problems, such as changes in the reporting of cause of death by physicians,[55,56] may result in gradual shifts that are more difficult to detect and to control for.[56] These problems could have especially influenced the trends for diabetes mellitus, pneumonia, dementia, and "symptoms and ill-defined conditions". The trends for diseases that have a more straightforward diagnosis, such as smoking-related cancers, and for broad groups of causes of death such as cardiovascular diseases, are less likely to be affected.

By adopting a life-course perspective, we could distinguish between determinants occurring in late life (period determinants) and determinants originating in earlier phases of the life course (cohort determinants).[29,30] Age-period-cohort analyses are a useful method when the life-course perspective is applied to aggregate mortality data. Not only can age-period-cohort analyses help in estimating the importance of period versus cohort effects in mortality trends, which is important for making projections of future developments in mortality, they can also contribute to the assessment of the role of specific determinants throughout the life-course. However, a persistent problem in age-period-cohort analyses is the identification of the separate roles of age, period and cohort, due to the interdependency between these variables (period – age = cohort). This is referred to as the identification problem.[43-45] To overcome this problem, we used the Clayton and Schifflers approach n which mortality is decomposed into a common linear trend (drift), a non-linear cohort effect, and a non-linear period effect.[44,45] Focus on non-linear patterns, however, will yield a conservative estimate of the contribution of the cohort and period effects, respectively. Moreover, it should be noted that the identification problem could only be dealt with adequately if clear non-linear patterns exist.

Our parallel analyses of seven selected European countries proved very useful as it informed us about generalities of patterns, and possible country-specific deviations from these general patterns. Furthermore, this approach enabled us to examine both determinants unique to

specific countries, and general determinants of old-age mortality trends. An important limitation of our ecological study-design is that conclusions could only be formulated at the aggregate level, and cannot be simply generated to individuals. Furthermore, the use of aggregate data complicated the demonstration of causal mechanisms in our analyses, especially when both the trends in possible determinants and the trends in the outcome variable mortality were highly linear.

Determinants of stagnation in old-age mortality decline in the Netherlands

Stagnation of old-age mortality decline since the 1980s was observed in Denmark, the Netherlands, and among Norwegian men. Our comparison of all-cause mortality trends with trends in non-smoking related mortality revealed that the stagnation of old-age mortality decline among Danish women and among Norwegian men seemed closely related to smoking, whereas the stagnation in old-age mortality decline in the Netherlands and among Danish men cannot be fully explained by smoking.

Further analyses of the possible additional explanations for the stagnation of mortality decline among Dutch elderly revealed stagnating trends in GDP in the Netherlands from 1890 to 1915 (results not shown). All-cause mortality decline among elderly men also stagnated for these cohorts, which could indicate that stagnating socio-economic developments in infancy and childhood might have contributed to the observed stagnation. The same conclusion, however, does not seem to prevail for women. Furthermore, the mechanisms behind the possible effect of socio-economic developments in infancy and childhood on old-age mortality trends are still not fully understood.

Mortality increases from ischaemic heart diseases (IHD) among the middle aged in the 1950s to the early 1970s,[57] and the associated uptake of adverse risk behaviour,[57] could have contributed to the stagnation of mortality decline among Dutch elderly in the 1980s and 1990s, as they all belong to the same cohorts born roughly between 1890 and 1915. These mortality increases from IHD were higher in the Netherlands and Norway than in the remaining countries, at least among men.[58]

Turning to possible period determinants, the increasing prevalence of medical end-of-life decisions in the Netherlands in the early 1990s,[59] and the intensification of the ongoing public debate on euthanasia in the Netherlands during the 1980s,[60] might indicate changes in attitudes concerning appropriate medical treatment for the elderly in the Netherlands since the 1980s, which could have contributed to some extent to the observed stagnation.

In addition, an effect of changes in health care and social services available to the elderly together with an increase in the number of elderly living alone and a possible decline in social support cannot be completely ruled out. Since 1975, Dutch policies shifted from institutionalisation and intramural care for the elderly, towards de-institutionalisation. Although de-institutionalisation can enhance active ageing, de-institutionalisation combined with the increase in the number of elderly living alone[61] and the decrease in social support with age,[62] may have resulted in more elderly people without sufficient care, which might have had a negative effect on their length of life. Recent data showed that of those aged 65 and over the proportion of disabled older people living in the community is fairly high in the Netherlands (12.6 %) as compared to other countries (e.g. France 8.0 % and Sweden 9.37 %).[61]

What can we expect for the future?

An important current debate is the extent to which today's populations are approaching a limit to human life expectancy.[2,20-24] Stagnation of mortality decline in the Netherlands has sometimes been seen as a sign of such a limit, but our parallel analyses among seven

European countries provide no evidence that a limit to life expectancy is within reach. Although mortality decline stagnated since the 1980s in the Netherlands, Denmark, and among Norwegian men, further improvements in old-age mortality decline occurred England and Wales and France, i.e. countries that reached the same low level of mortality as Denmark, The Netherlands, and Norway around 1980. In addition, other interpretations (e.g. effects of smoking, socio-economic developments in early life, trends in cardiovascular risk factors, etc.) seem more likely for the stagnation of mortality decline in the Netherlands.

Given the strong positive association between mortality trends in late middle age and those among the elderly, which we observed for the birth cohorts centred around 1895 to 1910, considering recent changes in mortality at younger ages may be a useful approach to inform projections of future old-age mortality trends. Mortality trends in late middle age among Dutch men over the period 1975-1999 turned out to be quite favourable (-1.7 %), and could be taken as an indication that the stagnation in old-age mortality trends is temporary. For women, however, recent trends in late middle age mortality were somewhat less favourable (-0.69 %). This could imply that the stagnation of old-age mortality decline among Dutch women is likely to continue for some time to come, unless its negative effects are counterbalanced.

The exact prediction of future old-age mortality patterns or future developments in life expectancy, however, remains a difficult task. Past mortality predictions have repeatedly been proven too pessimistic[2] due to the occurrence of unforeseen positive developments. For example, the huge reduction in cardiovascular disease mortality from 1970 onwards, as a result mainly of major advances in medical care and behavioural change, was not anticipated upon.[58] The chance certainly exists that in the future medical and biomedical progress will again lead to large mortality declines. From the analyses performed in our study, it can be concluded that most gains from possible medical and biomedical progress will likely to be obtained from the further reduction of the case fatality of cardiovascular diseases and cancers, i.e. still the most important causes of death at old ages, but potentially also from reducing mortality from diseases specifically related to old age, for which recent mortality increases were observed. We would like to stress, however, that it is important to realize that not only favourable developments, but also unfavourable developments might occur. After all, the stagnation in old-age mortality decline as observed in Denmark, the Netherlands and Norway (men only) indicates that old-age mortality seems highly plastic and susceptible not only to factors with favourable effects, but also to factors with possible unfavourable effects. A current increasing threat is the obesity epidemic among young adults.[63] In addition, unfavourable developments might occur from the re-emergence of infectious diseases,[64] wars, and health effects of ecological changes.[63]

Recommendations for further research

Studying old-age mortality trends and its possible determinants remains important to inform politicians and health care professionals on possible mortality developments in the future. Our approach that focused on cause of death patterns, adopted a life-course perspective, and used parallel analyses of different countries, proved very useful for generating and testing relevant hypotheses on explanations of old-age mortality trends. The further study of the determinants of old-age mortality trends could be aided by a more detailed description of cause-specific mortality trends, in a larger number of countries. To study more specifically the factors that discriminate a country or a region with favourable mortality experiences from those with less favourable mortality, more in-depth comparative research is recommended in which cohort-specific risk factor levels are reconstructed from existing surveys both among the elderly and among the younger population, in earlier times. Studying regional variations within a country could also provide additional clues on the determinants of old-age mortality decline. To demonstrate the exact causal mechanisms and the pathways in which determinants operate on mortality, and the exact impact of a possible determinant on old-age mortality, and its

changes over time, long-term prospective studies – using individual-level data – would be ideal. An alternative approach is the linkage of the national cause of death registries with individual characteristics. As a final step, further research should try to incorporate the effects of different determinants on mortality trends into a more comprehensive explanatory model.

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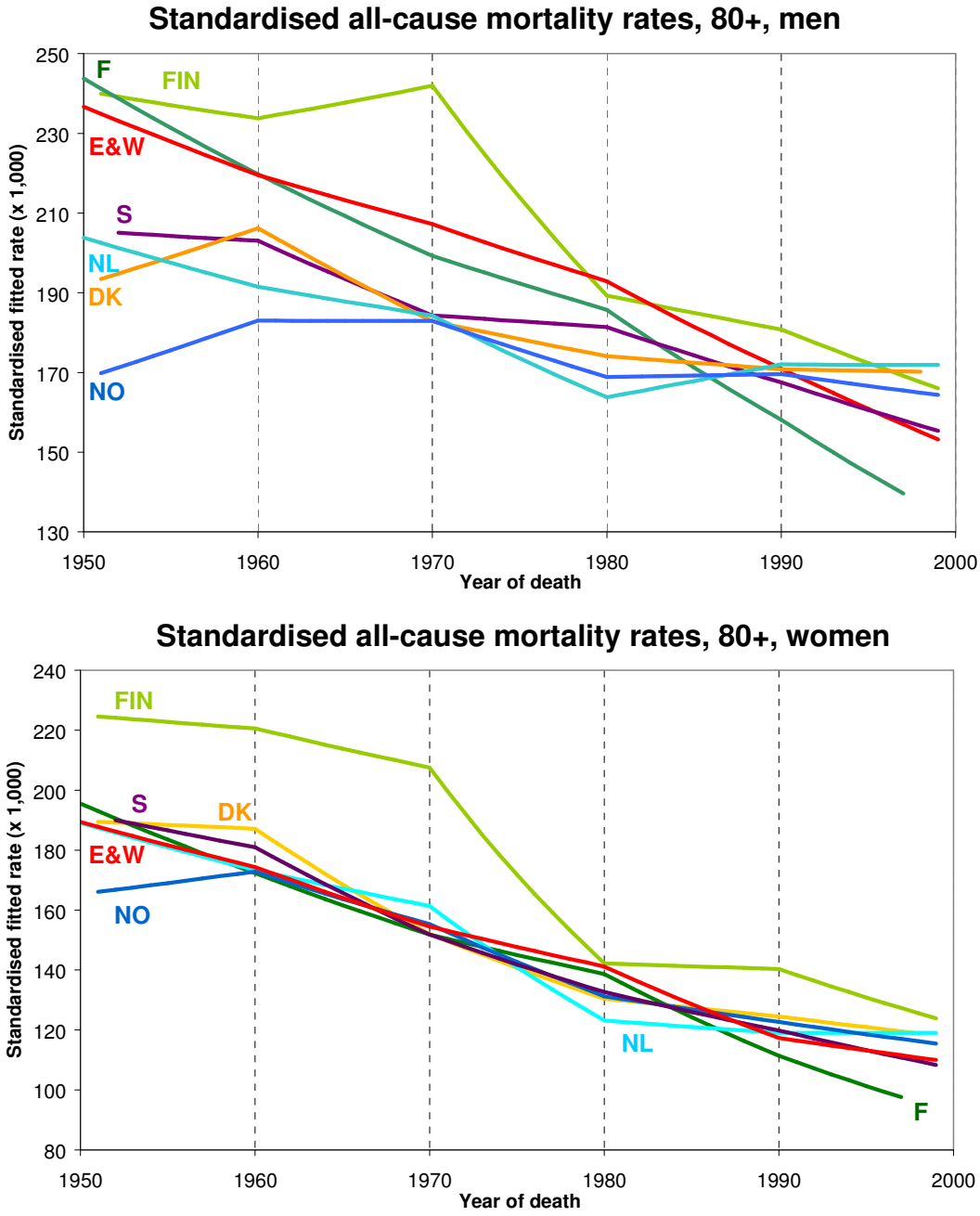

Figure 1. Trends in standardised all-cause mortality rates in seven countries, 1950-1999, males, aged 80 and over

DK = Denmark; E&W = England and Wales; FIN = Finland; F = France; NL = the Netherlands; NO = Norway; S = Sweden

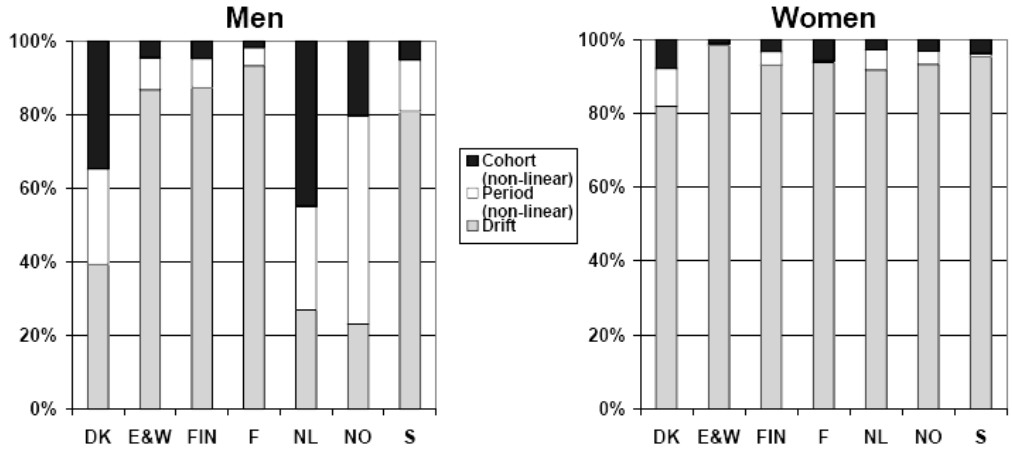

Figure 2. The contribution of drift, non-linear period effects and non-linear cohort effects to all-cause mortality trends, by sex and country

Notes: Drift = the reduction in scaled deviance by adding drift to the model including only age; Period (non-linear) = the reduction in scaled deviance by adding the non-linear period effect to the age-drift model; Cohort (non-linear) = the reduction in scaled deviance by adding the non-linear cohort effect to the age-period model; We measured the reduction in scaled deviance relative to the total reduction in scaled deviance of the full age-drift-period-cohort model compared with the model including only age. All effects are significant at the p = 0.05 level (one-tailed). DK = Denmark; E&W = England and Wales; FIN = Finland; F = France; NL = The Netherlands; NO = Norway; S = Sweden.

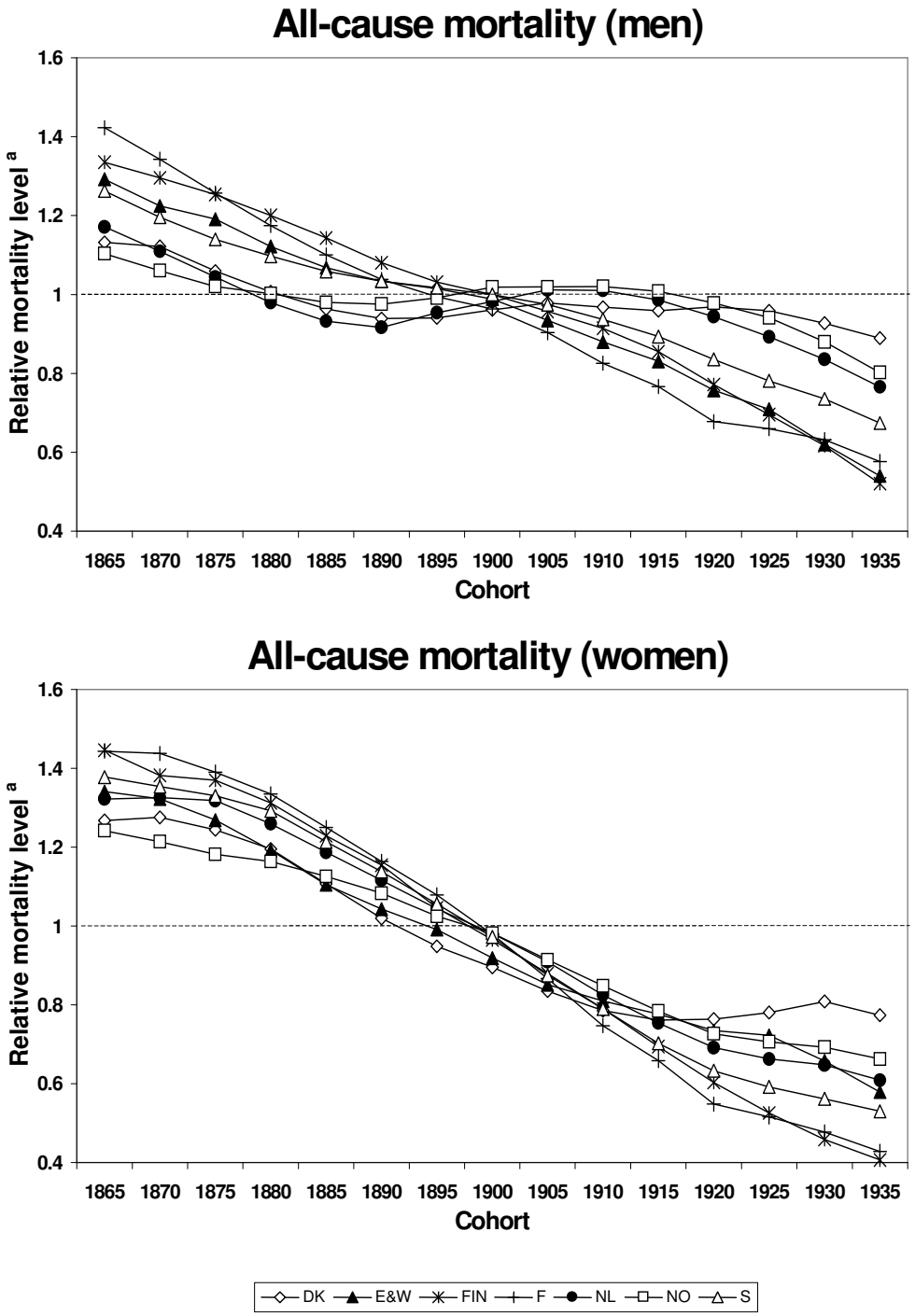

Figure 3. Cohort trends (including drift) for all-cause mortality by country and sex, for those aged 60 and over

[a] Mortality level of each individual cohort relative to the unweighted average of the mortality levels of all cohorts together.
DK = Denmark; E&W = England and Wales; FIN = Finland; F = France; NL = The Netherlands; NO = Norway; S = Sweden.

Table 1. Annual changes (%) for total mortality and mortality from non-smoking related diseases, by country and sex, for those aged 80 and over

	Mortality									
	All causes					Non-smoking related mortality[a]				
	1950-59	1960-69	1970-79	1980-89	1990-99	1950-59	1960-69	1970-79	1980-89	1990-99
Men										
Denmark	**0.58**	**-1.16**	**-0.45**	**-0.19**	**-0.20**	**-0.49**	**-1.54**	**-1.42**	**-0.45**	**-0.23**
England and Wales	-0.65	-0.79	-0.44	-1.44	-1.20	-0.56	-1.96	-1.27	-1.61	-0.51
Finland	-0.53	0.26	-2.45	-0.55	-1.11	-1.72	-0.41	-2.99	-0.40	-0.69
France	-1.27	-0.98	-0.73	-1.82	-1.66	-1.47	-1.45	-1.42	-2.18	-1.27
Netherlands	**-0.60**	**-0.35**	**-0.93**	**0.38**	**-0.19**	**-1.03**	**-1.47**	**-2.09**	**-0.39**	**0.06**
Norway	**0.76**	**0.14**	**-0.82**	**0.02**	**-0.51**	**0.42**	**-0.05**	**-0.91**	**-1.09**	**-0.45**
Sweden	-0.17	-0.85	-0.20	-0.92	-0.98	-0.64	-1.26	-1.02	-0.66	-0.86
Women										
Denmark	**-0.09**	**-2.25**	**-1.67**	**-0.47**	**-0.56**	**-0.72**	**-2.37**	**-2.09**	**-0.79**	**-1.30**
England and Wales	-0.96	-1.30	-0.88	-1.90	-0.65	-1.18	-1.51	-1.48	-2.56	-0.99
Finland	-0.18	-0.70	-3.85	-0.34	-1.47	-0.29	-0.61	-3.95	-0.46	-1.89
France	-1.42	-1.40	-1.07	-2.23	-1.72	-1.45	-1.25	-1.29	-2.49	-1.59
Netherlands	**-1.11**	**-0.85**	**-2.72**	**-0.47**	**0.01**	**-1.18**	**-0.88**	**-2.79**	**-0.86**	**-0.49**
Norway	0.43	-0.97	-1.80	-0.74	-0.71	0.25	-0.70	-1.38	-1.51	-0.94
Sweden	-0.61	-1.86	-1.51	-1.14	-1.05	-0.86	-2.00	-1.92	-0.94	-1.41

Table 2. Correlation relative mortality changes for men and women born to the centralised birth cohorts 1895-1910 among seven European countries

Cause of death ages 55-69	Cause of death ages 80-89	All N=42	Men N=21	Women N=21
All-cause mortality	All-cause mortality	0.61**	0.71**	0.33
All circulatory mortality	All-cause mortality	0.61**	0.70*	0.40
All-cause mortality	Infectious diseases	0.01	0.15	0.26
All-cause mortality	Pneumonia	-0.03	-0.14	-0.23
All-cause mortality	Diabetes mellitus	0.44**	0.11	0.42
All-cause mortality	Dementia	0.18	0.25	0.21
All-cause mortality	All symptoms and ill-defined conditions	0.07	-0.12	0.62**
All-cause mortality	All external causes of death	0.39*	0.33	-0.09

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

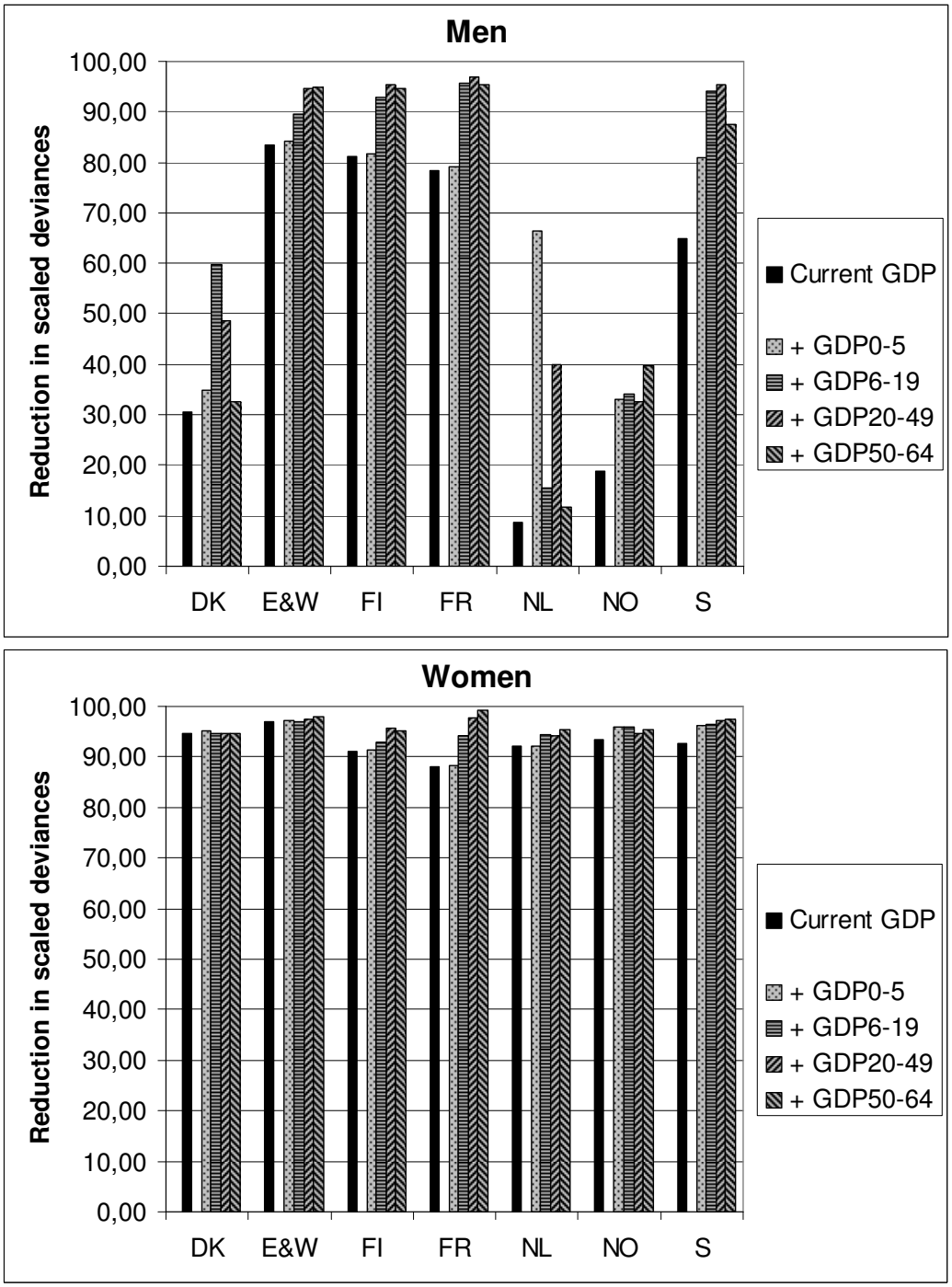

Figure 4. Comparison of the independent association of GDP[a] measured at different ages of the cohort with all-cause mortality among those aged 65-99, by country and sex

[a] With log transformation of the GDP variables

Reduction in scaled deviance for the stepwise inclusion of GDP at time of death, GDP at ages 0-5, 6-19, 20-49, and 50-64 in the model, compared to the model with age only. This reduction is expressed as percentage of the total reduction in scaled deviances between the model with age only and the model with age, period and cohort terms.

All reductions in scaled deviances are statistically significant ($p = 0.05$). DK = Denmark; E&W = England and Wales; FIN = Finland; FR = France; NL = the Netherlands; NO = Norway; S = Sweden. Current GDP = GDP at time of death.