Working Paper no.: 2014/8

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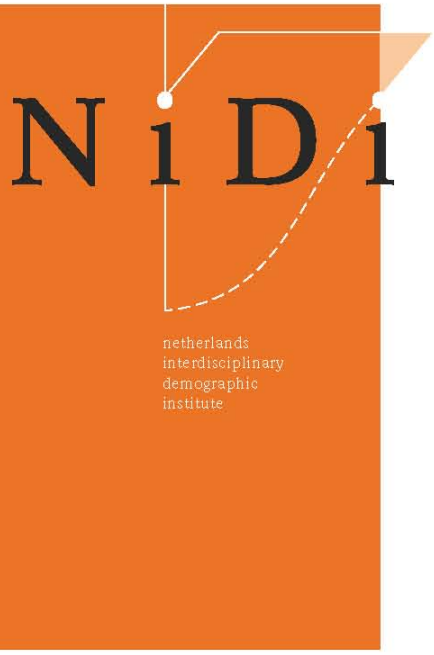

# Multistate scenarios of the impact of prevention and treatment on healthy life expectancy

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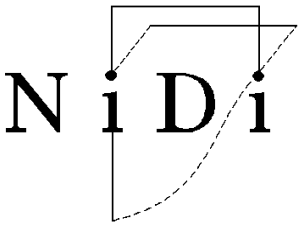


Netherlands Interdisciplinary Demographic Institute (NIDI)
P.O. Box 11650
2502 AR The Hague
Phone: 070 - 3565200
E-mail: beer@nidi.nl for all correspondence

* Statistics Netherlands
** Netherlands Interdisciplinary Demographic Institute (NIDI-KNAW) / University of Groningen
*** Population Research Centre, Faculty of Spatial Sciences, University of Groningen



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ABSTRACT

There is general agreement that life expectancy will continue to increase across European countries. There is less agreement about the extent to which the additional life years will be spent in good or poor health. This paper presents four scenarios of changes in the numbers of years spent in good and poor health for a typical high-income European country based on stylized facts. We estimate the effects of prevention and treatment on healthy life expectancy at age 55 by using a multistate model including three health states: good, fair and bad health. The scenarios show that improved prevention either due to medical progress or due to healthier lifestyles leads to a much larger increase in healthy life expectancy than in total life expectancy. The main effect of better treatment is extended life. Three out of four scenarios imply that the future health status of the older working age population and the younger retirees would not be adversely affected by raising the retirement age by 5 years over a period of 25 years.

KEY WORDS

healthy life expectancy, multi state scenarios, pension reform, compression of morbidity, self assessed health, ageing

## 1. Introduction

The European population is ageing rapidly. The large generations born in the post war baby boom are reaching the age of retirement. In combination with the low birth rates in more recent decades, this leads to an increase of the proportion of older people in the population. Remaining life expectancy at older ages has increased strongly in the last half century and nearly all official projections expect this to continue for the next 50 years. It is therefore likely that a large proportion of the post war generations will survive to very old ages. The longer lifespan of the new elderly adds to the aging of the population. However, if the longer lifespan also implies better health, this dampens the effects of aging. If the onset of the debilitating effects of old age shifts to older ages as life expectancy increases, the age above which we classify people as "elderly" should increase as well. Sanderson and Scherbov (2005) propose to describe ageing in terms of the expected number of remaining lifeyears, which they call prospective age. This indeed introduces a dynamic concept of old age. In a number of EU countries this type of dynamic old age definition has been implemented in the retirement policies. In some countries, the age at retirement is related to estimates of the remaining life expectancy of the birth cohort. In other countries, employees are free to choose their own age of retirement, but the retirement benefits depend on the expected remaining life expectancy of their birth cohort at the chosen retirement age. These dynamic definitions of old age are implemented in terms of the life expectancy, not the healthy life expectancy. Whether the retirement policies are fair, in the sense that successive birth cohorts will enjoy an equal number of years in retirement in good health, or effective, in the sense that age-specific labour force participation can increase along with the official age of retirement, depends on the relative pace of increase of healthy compared to total life expectancy.

In this paper we present health and mortality scenarios for the population aged 55 years and older. Our aim is to examine future developments of healthy and unhealthy life expectancy. All scenarios assume further progress in total life expectancy, but the scenarios differ by assumptions about future changes in morbidity and mortality rates. We construct our scenarios using a multistate model. In contrast with prevalence-based models, multistate models describe how changes in prevalence in a particular state are caused by changes in the inflow and outflow from and to other states. Our multistate model includes four states: self-assessed 'good', 'fair', or 'bad' health, and death. The transitions between these states can be described by a set of morbidity and mortality rates. The morbidity rates are estimated from SILC data (EUROSTAT 2012) for 16 European countries with low mortality levels. Mortality

rates are obtained from the EUROSTAT database. To make the calculations more transparent, we assume simple, stylised forms for the transition rates, which are nevertheless realistic. This allows us to fully specify the model using a small number of parameters. Our scenarios describe the case of a "typical" low-mortality European country. The parameters used are the unweighted averages of the parameters for the 16 individual countries.

Section 2 discusses theories and concepts of healthy life expectancy. In section 3, the model is defined. We discuss how the transition rates are parameterised and estimate the parameter values for the different countries. Multistate health scenarios for a typical low mortality European country are constructed in section 4 and the results for these scenarios are discussed in section 5. Section 6 discusses the possible implications of changes in the health status for participation before and after retirement age. Section 7 summarizes and discusses the main conclusions. Appendix 1 includes a sensitivity analysis that explores the effect of changes in the different morbidity and mortality rates on (healthy) life expectancies. Appendix 2 examines the sensitivity of the results with respect to the inclusion of recovery into the model.

## 2. Health status and participation

Various theories aim to explain the dynamics of healthy and total life expectancy. Howse (2006) gives an insightful characterization of these theories using the concepts primary, secondary and tertiary prevention. Primary prevention is the delay of the onset of chronic degenerative diseases, which could be a result of improving lifestyles, better nutrition, or preventive medicine. Secondary prevention is the delay in the progression of these diseases from weak to severe symptoms, for instance as a result of improving medical treatment. Tertiary prevention is the reduction of fatality of chronic degenerative diseases. The theory of morbidity compression developed by Fries assumed that primary prevention would become the dominant process and the increase in total life years would slow down, resulting in fewer unhealthy life years (Fries 1980). In its more recent form (Fries 2003) the compression of morbidity theory does not rely on a slowdown in the pace of mortality reduction, which is not observed, but only maintains that primary prevention is dominant. The theory of morbidity expansion developed by Gruenberg assumes that tertiary prevention is dominant, resulting in more lifeyears with chronic degenerative diseases with serious symptoms (Gruenberg 1977). More recently, the modified theory of morbidity expansion (Olhansky *et al* 1991) focuses on the distinction between fatal and non-fatal diseases, assuming that there is primary and

secondary prevention of fatal diseases but not, or less so, of non-fatal diseases. The dynamic equilibrium hypothesis (Manton 1982) focuses on secondary prevention. According to this hypothesis, the progression of chronic degenerative diseases is delayed. As a result, the period of life in moderate ill-health is expanded and the period in serious ill-health is compressed.

In this paper we construct scenarios around the concepts of primary, secondary and tertiary prevention. However, we apply these concepts not to chronic degenerative diseases, but to the deterioration with age of self assessed health. We are interested in self assessed health because it has a strong correlation with labour force participation (Cai 2007; Kalwij and Vermeulen 2007). Moreover, it has been found to be a robust predictor of future mortality and of deterioration in objective health measures (Benyami and Idler 1999). The relationship between self assessed health and labour force participation is complex. The health status influences labour participation, but labour participation also influences the health status (Mete and Schulz 2002). Moreover, reporting behaviour will be different for those working and not working. The "justification hypothesis" (Parsons 1992) maintains that those not working will be more likely to report bad health, to justify their inactivity. On the other hand, retirees may be confronted less by their physical limitations than those working, which could positively bias their self reported health.

Despite these problems, we expect that self assessed health is the most useful health concept for use in scenarios of labour and social participation in old age. When self reported data on physical limitations is used instead, one also faces the problem of endogeneity and selective reporting bias. Moreover, for western European countries, prevalence of self reported limitations is still very low at age 55. This suggests that much information is hidden in the group reporting "no limitations". Choosing early retirement may be a result of an expectation of limitations arising in the future, brought on by worsening self assessed general health. Therefore, general health could be a more sensitive predictor of labour participation, at least at the older middle ages, than self reported limitations. Combining self reported health with more objective health indicators can be a way to improve the predictive value for labour participation (Kalwij and Vermeulen 2007).

We study possible implications of changes in the health status for the participation potential of the older labour force, those in the last ten years before retirement, and the young retirees, those in the first ten years after retirement. Especially for the last group, participation potential should be interpreted not only as the ability to perform paid labour, but also other forms of participation in society, such as informal care or volunteer work.

In order to assess whether new retirement policies based on prospective age are fair, we compare the number of remaining years after retirement in good or fair health for different generations under the various scenarios. If we want to assess whether they will be effective at increasing labour participation at older ages, this indicator is less useful, since we are mainly interested in the health situation of the younger old. For this reason, we use partial healthy life expectancies (PHLE) to monitor the health status of the population in different age groups (Jagger et al. 2010 ). To assess the impact of a hypothetical 5 year increase in the age of retirement on the health-composition of the older workforce, we compare the future PHLE at ages 60-69 to the current one at ages 55-64. To assess the impact on the health composition of those in the first decade of their retirement, we compare the future PHLE at ages 70-79 to the current one at ages 65-74.

## 3. Model definition and parameter estimates

We build our scenarios using an illness-death model (ID) (fig. 1). This ID model has 4 states: Good health (G), Fair health (F), Bad health (B) and Dead (D). The transitions between these states can be explained by morbidity rates (θ) and mortality rates ($\mu$). Our ID model is unidirectional. Returning to a previous state is not possible. In section 4 we discuss to what extent including recovery (transition from bad to fair or from fair to good health) in the model may lead to different results. In a model without recovery the morbidity rates in fig. 1 should be interpreted as describing the incidence of "net morbidity" (Bijwaard 2011 ). This is based on the number of transitions from the healthier to the unhealthier state minus the number of reverse transitions.

An exponential age-dependence is assumed for the primary mortality rate, i.e. the mortality rate of persons in good health. This type of age-dependence typically yields a good fit to mortality rates in the age range 55-80 years, on which our analysis will focus:

$$\mu_G(x) = \mu_G(55)e^{a(x-55)} \qquad \text{for } x \geq 55 \tag{1}$$

where $\mu_G(x)$ is the mortality rate of a person with good health at age $x$ and $a$ is a parameter to be estimated. It is assumed that the mortality rates for those in fair or bad health differ from that for people in good health by an age-independent relative risk which is larger than 1:

$$\mu_F(x) = r_F \mu_G(x). \tag{2}$$

$$\mu_B(x) = r_B \mu_G(x). \tag{3}$$

where $r_F$ and $r_B$ are the relative mortality risks of persons with fair and bad health respectively. The (net) morbidity rates are also assumed to have an exponential age-dependence, but with a different slope than the mortality rates:

$$\theta_G(x) = \theta_G(55)e^{b_G(x-55)}. \quad (4)$$

$$\theta_F(x) = \theta_F(55)e^{b_F(x-55)}. \quad (5)$$

where $\theta_G$ and $\theta_F$ are the primary and secondary morbidity rates respectively. Using the stylised forms eq. (1)-(5), the transition rates in the ID model depend on the values of 8 parameters: $\mu_G(55)$, $a$, $r_F$, $r_B$, $\theta_G(55)$, $\theta_F(55)$, $b_G$ and $b_F$.

To find realistic values for these parameters we look at the prevalence of self reported health in the European SILC survey. Five health states are distinguished in this survey ("very good", "good", "fair", "bad", "very bad"). We associate the highest 2 categories with the state *G*, the middle category with the state *F*, the lowest two with the state *B*. In the EUROSTAT database, the SILC data is aggregated in (mostly) 10-year age groups. To obtain an estimate for the prevalences $Q_i(x)$ for one-year age groups, we have fitted the logit of $Q_B$ and of $Q_B + Q_F$ to a linear function of age for the age intervals 35-44,45-54, 55-64, 65-75 and 75-84 years, assuming that the health prevalence for each age-interval corresponds to the age at the centre of the interval. We have used the data for 2009. The estimates were made for Belgium, Denmark, Finland, France, Germany, Greece, Ireland , Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Figure 2 shows the fit for Switzerland (low morbidity), Germany (intermediary morbidity) and Portugal (high morbidity).

We use the procedure described in Bijwaard (2011) and Májer (2012) to derive consistent (net) morbidity incidence rates from the health-prevalence data for a single year, which we have generalized to be used for a model with three health states. This estimation procedure relies on a stationarity assumption for the net morbidity incidence. It assumes that the age-profile of prevalence in the observed period is the same as within birth cohorts. It has the property that the healthy life expectancies computed from a multistate life table using the rates that are derived from the procedure are the same as those computed with the commonly used Sullivan method (Sullivan 1971).

We estimate the model rates from the observed morbidity prevalences and mortaltiy rates using the following equations

$$
\begin{aligned}
\hat{\theta}_G(x) &= 2\frac{Q_G(x)\left[1-\hat{\mu}_G(x)/2\right]\left[1+\mu(x)/2\right]-Q_G(x+1)\left[1+\hat{\mu}_G(x)/2\right]\left[1-\mu(x)/2\right]}{Q_G(x)\left[1+\mu(x)/2\right]+Q_G(x+1))\left[1-\mu(x)/2\right]},\\
\hat{\theta}_F(x) &= 2\frac{Q_F(x)\left(1-r_F\hat{\mu}_G(x)/2\right)\left[1+\mu(x)/2\right]-Q_F(x+1)\left[1+r_F\hat{\mu}_G(x)/2\right]\left[1-\mu(x)/2\right]}{Q_F(x)\left[1+\mu(x)/2\right]+Q_F(x+1)\left[1-\mu(x)/2\right]}+\\
&\quad+\hat{\theta}_G(x)\frac{Q_G(x)\left[1+\mu(x)/2\right]+Q_G(x+1)\left[1-\mu(x)/2\right]}{Q_F(x)\left[1+\mu(x)/2\right]+Q_F(x+1)\left[1-\mu(x)/2\right]},\\
\hat{\mu}_G(x) &= \frac{2\mu(x)}{\lambda(x)\left[1+\mu(x)/2\right]+\lambda(x+1)\left[1-\mu(x)/2\right]},
\end{aligned}
\tag{6}
$$

where $\mu(x)$ is the observed total mortality rate, $Q_G(x)$ is the prevalence of good health at age $x$, $Q_F(x)$ is the prevalence of fair health, and

$$\lambda(x)=Q_G(x)+r_FQ_F(x)+r_BQ_B(x). \tag{7}$$

These expressions are derived using the linear multistate cohort-component model, which assumes that events are evenly spaced within a year. This has the advantage that we obtain a closed form expression for the estimate. Bijwaard (2011) uses the exponential model, which is somewhat more accurate at high ages but requires an iterative procedure to estimate the incidence rate. For our purpose, the difference between the two approximations is not important. Bijwaard and Májer consider the case where there are only two health states, healthy and disabled, whereas we use 3. The expression for the morbidity rate estimator in the 2-state case is the same as for $\hat{\theta}_G(x)$ in eq. (6).

The stationarity assumption is not essential for the estimation. If data from consecutive years is available for one-year age intervals, an estimate can be made by taking all the prevalences at age $x$ in eq. (6) from year $t$ and those at age x+1 from year $t$+1. To improve stability, larger age-intervals could also be used, using data from years that are farther apart. If morbidity rates have fallen in the past, such an estimate would result in lower morbidity rates and higher healthy life expectancies. We are mainly interested in the changes in healthy life expectancy and not in the level. Therefore we have used the simpler estimate based on the stationarity assumption.

To estimate the morbidity incidence using eq. (6-7), we need to first obtain values for $r_F$ and $r_B$. In a meta analysis of 8 studies from the US, France, Sweden and Israel, where 2 health categories (various wordings) were used, DeSalvo et al. (2005) find a mortality odds ratio of 1.99 (1.64, 2.42) for the worst compared to the best health category (numbers in brackets indicate 95% confidence interval). In a meta-analysis of 13 studies with a graded response category for health ("excellent", "good", "fair", "poor") they find odds ratios of 1.23 (1.09, 1.39), 1.44 (1.21, 1.72) and 1.92 (1.64, 2.25) for those reporting "good", "fair" or "poor"

health respectively compared to those reporting "excellent" health. These studies used data from the US, Spain, Australia, Italy, Finland, UK, France and Denmark. For the second set of studies, DeSalvo et al. found a somewhat higher relative mortality risk for men than women for the health category "poor", but this difference was not significant. Some of the underlying studies did find a significantly higher relative risk for men than women, others did not.

For our analysis, we use $r_F = 1.5$ and $r_B = 2$, somewhat higher than the results from the second meta-analysis suggest, but lower than suggested by the first analysis. We use the same relative risks for men and women and for all countries. Figure 3 shows the estimated transition rates for Switzerland, Germany and Portugal and the fit to the exponential forms (1), (2) and (3). The parameters in the exponential forms were estimated by ordinary least square minimization on the log transition rates.

The parameter estimates for 16 European countries and the unweighted average (geometric averages in the case of the incidence rates at age 55) are shown in table 1. The morbidity rates are quite similar for men and women, but the mortality rate at good health at 55 is twice higher for men than for women.

Figure 4 shows the morbidity rates at age 55 $\theta_G(55)$ and $\theta_F(55)$ and the mortality rate $\mu_G(55)$, by country, ordered from left to right with increasing male primary morbidity rate. There is much larger cross-country variation in the morbidity than in the mortality rates. For men, the standard deviation of the log primary morbidity rate across the countries is 14 % of the mean and for the secondary morbidity rate 10 %. For the log mortality rate at good health, the coefficient of variation is only 3 %. The cross-country variation for women is very similar (15, 11 and 4 % respectively for the coefficients of variation of the three (log-)rates). Generally, Southern European countries are found to have higher primary and secondary morbidity rates (at age 55) and, for women, lower mortality rates at good health. For men, the mortality rate at good health is similar for Southern and Northern/Western European countries.

We use the unweighted averages of the parameters for men and women to represent the case of a "typical" low mortality European country. Table 2 shows the health indicators for males and females for this typical country. The remaining life expectancy at age 55 is 25 years for men and 31 years for women. Both men and women have 13 years in good health after age 55. Two thirds of the unhealthy years, 12 for men and 18 for women, are in fair health, a third is in bad health. About half the population at age 70 is in good health.

## 4. Scenarios

In the last century, life expectancy in Europe has increased strongly. Better living conditions, nutrition and hygiene have clearly played a part, as have rising levels of education and wealth, creating better access to medical care and healthier lifestyles. It is also clear that progress in medical knowledge and technology has made a very important contribution. The development of antibiotics greatly reduced the fatality of infectious diseases. Many types of cancer that were once fatal are now treatable. There have been significant improvements in the prevention and treatment of cardiovascular diseases. In a few decades, AIDS was turned from a fatal into a chronic, if still very detrimental disease. Throughout the EU, official mortality projections predict a continuing increase in life expectancy over the next half century. Implicitly, this assumes that there will be significant further improvements in medical technology or health promotion. We follow this assumption in specifying the future development of the parameters in the ID model.

In developing scenarios we distinguish the effects of treatment and prevention on future changes in health and mortality (Siegel 2012). Two effects of treatment can be distinguished: (1) reduction of fatality of acute diseases and (2) delayed progression of and improved recovery from chronic diseases. Three types of prevention can be distinguished: (1) health protection (e.g. safety measures); (2) disease prevention (e.g. vaccination, screening); (3) health promotion (healthier lifestyles). Table 3 shows the direction of the main effects of these determinants on mortality and morbidity.

Treatment of acute diseases lowers the mortality rate for people in good self-perceived health. Obviously, it also lowers the mortality rate for people in fair or bad self-perceived health. However, the excess mortality risk for this group is partly related to fatality from chronic diseases. Hence, improvement in the treatment of acute diseases would tend to increase the relative mortality risk for those not in good health. A secondary effect of this type of treatment is that it can turn acute diseases into chronic or progressive diseases. AIDS is a striking example, but also treatments of acute cancers or cardiovascular diseases reduce fatality but can lead to a prolonged period in bad health. So, while these types of treatments lower mortality incidence, they may increase primary incidence of morbidity.

Treatment of chronic and progressive diseases slows down their progression. Hence, this type of treatment reduces the secondary morbidity rate and reduces the relative mortality risks for people in fair or bad health (tertiary prevention). The emergence of successful treatments which cure a chronic disease would, in our model without recovery, result in a

reduction of the primary morbidity rate. New treatments that reduce the symptoms to such an extent that they no longer affect self-assessed health (Wilson 2004) would have the same effect, since they also amount to a cure, at least from the limited perspective of self-assessed general health.

We assume that the net effect of improvement in medical treatments will be a reduction of the primary mortality rate, the secondary morbidity rate and the relative mortality risk for those in ill health. Since improvements in treatments for chronic and acute diseases have an opposite effect on the primary morbidity rate, we assume that the net effect of improved treatments on this parameter is small and of uncertain direction. For the relative mortality risk, both types of treatments also have opposite effects, but here we expect the net effect to be a reduction of the relative risk. Those already in ill-health will generally benefit more from improved treatments since they are more likely to receive treatment.

Disease prevention reduces the primary morbidity and mortality rate by treating healthy people. Examples are vaccinations or preventive treatments of people with a high risk of developing a disease. Health protection, for instance measures to reduce the number of traffic accidents or accidental falls, also reduces the primary morbidity and mortality rate. Both disease prevention and health protection benefit the population in general, healthy and unhealthy alike, but since those who are unhealthy have an additional component in their mortality rate which is not affected by such measures, they result in an increase of the relative mortality risk for unhealthy people.

Health promotion, such as measures to promote healthy lifestyles or to reduce unhealthy ingredients in food, reduces the primary morbidity and mortality rates. It also reduces the secondary morbidity rate, since a disease will generally progress more slowly if the patient is in better physical condition. By the same argument, it reduces the progression from ill health to death, and hence the mortality rate for those in fair or bad health. Unlike disease prevention and health protection, there is no reason to assume that it changes the relative mortality risk for unhealthy people.

Taken together, we assume that the net effect of prevention measures is to lower the primary mortality rate and the primary and secondary morbidity rate and to increase the relative mortality risk for unhealthy people.

We construct 4 scenarios. The Effective Prevention (EP) scenario is optimistic about (primary) prevention, the Less Effective Prevention scenario (LEP) pessimistic. The Effective treatment (ET) scenario is optimistic about improvement in treatments for acute and chronic diseases, the Less Effective Treatment (LET) scenario pessimistic. The EP and LEP scenarios

assume moderate improvements along the treatment dimension –midway between optimistic and pessimistic. Likewise, the ET and LET scenarios use moderate assumptions for prevention.

The trends that are assumed for the different parameters in these scenarios are shown in table 4. The scenarios are constructed to describe futures that surround a central scenario, which assumes advances in prevention and treatment in equal measure. In the central scenario the relative mortality risk for those with fair or bad health remains constant and the secondary morbidity rate is reduced at the same pace as the mortality rate at good health, so reductions in the fatality and progression of diseases develop at the same pace. This leaves two parameters for which the trend needs to be specified: the mortality rate at good health and the primary morbidity rate. These are fixed by imposing that (1) total life expectancy at birth increases by the same number of years as assumed in the EUROPOP 2010 convergence scenario (EUROSTAT 2011) and (2) that the total number of expected lifeyears in fair or bad health (after age 55) remains constant in the central scenario. The first condition is imposed to make the central scenario consistent with a plausible future as described by the EUROPOP projections, the second because we want the four scenarios to describe both futures with compression and with expansion of morbidity, which is achieved by making the central scenario describe constant morbidity.

In the central scenario, the mortality rate at good health is reduced by $p$ = 1,7% per year, which implies a reduction by a factor 0.42 over a period of 50 years. The primary morbidity rate is reduced more slowly, by 0.45$p$% per year. The secondary morbidity rate is reduced by $p$% per year and the relative mortality risk for those in fair and bad health are kept constant, as described above. This yields a gain in the life expectancy at birth of 7 years for men, 6 years for women, over a 50 year period. This is the same as for the unweighted average of the 16 countries used in the parameter estimates of the model in the 2010 EUROPOP projections. Life expectancy in poor or bad health at age 55 remains nearly constant: +0,3 years over 50 years for men, -0,2 years over the same period for women.

The Effective Treatment scenario describes a future where advances in medical treatments are rapid and dominate the (moderate) developments in prevention. Medicine is advanced, but reactive. It focuses on the care for those already ill, with less emphasis on early detection and prevention of diseases. Negative health effects that result from unhealthy lifestyles are offset by better treatments for those affected by them. In this scenario, there is a stronger reduction of the primary mortality rate and the secondary morbidity rate than in the central scenario. Both parameters are assumed to decrease 50% more rapidly. For the primary

morbidity rate, the same pace of reduction is used as in the central scenario, as we assumed that improvements in treatment have no net effect on this parameter. The excess mortality risk for those in fair or bad health is reduced by 50% over 50 years ($r_F$=1.25, $r_B$=1.5 in 2059).

In the Less Effective Treatment scenario, improvements in the treatment of diseases are limited and increases in life expectancy are mainly due to (moderate) improvements in prevention. Such a scenario could for instance be realized if the rising costs of medical treatment in combination with an enduring economic slowdown and rising number of elderly leads to a policy decision to limit spending on further improvements in treatment and focus on, less expensive, health promotion. The primary mortality rate and the secondary morbidity rate are reduced 50% less rapidly than in the central scenario. The primary morbidity rate declines at the same pace as in the central scenario. The excess mortality risk is increased by 50% over 50 years ($r_F$=1.75, $r_B$=2.5 in 2059). This means that the mortality rates for those in fair or bad health are still being reduced, but more slowly than for those in good health. For fair health, the reduction is 68% more slowly than in the central scenario, for bad health, 76% more slowly.

In the Effective Prevention scenario, health policies, aided by new technologies, are successful at promoting healthy behaviour and reducing harmful substances in food and the environment. Advances in genetic mapping could for instance lead to personalized risk-profiles, which inform people which activities or foods are particularly harmful or beneficial to their health. Medical progress is strong and focuses on pro-active treatments. Increasingly, preventative treatments are applied to those with a high risk for developing a disease and medical care is extended to include the healthy-but-at-risk (Weston and Hood 2004). The advances in "classical" reactive treatments are moderate in this scenario. Because of the strong improvements in prevention, the primary morbidity rate is reduced twice as fast as in the central scenario. Also, there is a 50 % more rapid decline in the primary mortality and secondary morbidity rate. Those already ill benefit less from the advances in prevention. The excess mortality rate is assumed to increase by 50 % over 50 years.

The Less Effective Prevention scenario describes a situation where unhealthy lifestyles become more widespread and progress in preventive medicine is limited. Further increases in life expectancy are due to (moderate) advances in medical treatment. These treatments focus on extending and improving the lives of those already ill. The primary morbidity rate remains constant. The primary mortality rate is reduced 50% less rapidly than in the central scenario, as is the secondary morbidity rate. Moderate advances in medical care combined with weak reductions of mortality for those in good health mean that ill and healthy

people become more alike in terms of mortality risk. The excess mortality risk is assumed to decrease by 50 % over 50 years. This implies that the mortality rate for those in fair health is reduced 29% less rapidly than in the Central scenario, for those in bad health 17% less rapidly.

The morbidity rates are adjusted by an age-independent factor in our scenarios. This ensures that the results from equivalent scenarios calculated in a model with recovery would be similar to our results for the model without recovery (see appendix 2). For the mortality rates, some rectangularisation of the survival curve is assumed. At ages 55 and older, the reductions of $\mu_G(x)$ are partly compensated by increasing the steepness of the mortality age-pattern in such a way that the mortality rate at age 120 remains unchanged. For the ages up to 55, the adjustments are implemented by an age-independent factor.

The health composition of the population at ages older than 55 depends on the health composition at age 55. The multistate life tables for different scenarios are therefore computed starting from age 0, where everyone is assumed to be in good health. The initial rates for the ages 0-55 that we use are of the form eq. (1)-(5), but with adjusted values for $b_G$ and $b_F$ to reproduce the observed values of $Q_F(55)$ and $Q_B(55)$. In this way, the effect of adjustments in the transition rates on the health prevalence at age 55 are taken into account.

## 5. Results

Table 5 shows the remaining life expectancy at age 55 for the four scenarios. Two scenarios yield high gains in life expectancy, one of which shows expansion, the other compression of morbidity. In the other two scenarios, progress in life expectancy is very limited. Here also the number of unhealthy lifeyears increases in one scenario and decreases in the other. One of the four scenarios yields strong gains in life expectancy in good health, two moderate gains, one very weak improvements.

In the Effective Treatment scenario, strong progress in medical treatment prolongs life. As a result, more people reach the older ages where morbidity prevalence is high, leading to expansion of morbidity. However, improved care also means that the quality of life for those in ill health is strongly improved. Remaining life expectancy at age 55 is increased by approximately 9 years over a period of 50 years. A good two-thirds of the additional lifeyears are in good health. This still means that the period in ill health is expanded by about 3 years. The number of lifeyears in fair health increases, while the number in bad health decreases. The share of unhealthy years spent in bad health for men and women is reduced from 30-32 % to 12-13 %.

In the Less Effective Treatment scenario, improvements in medical treatment are very limited and further gains in life expectancy are driven by prevention. As a result, life expectancy in good health increases quite strongly while total life expectancy stagnates, leading to compression of morbidity. Remaining life expectancy at 55 is increased by 2-3 years, life expectancy in good health by 5 years. Consequently, the number of unhealthy years is reduced by 2-3 years. The quality of these unhealthy years is improved, but less so than in the Effective Treatment scenario. The share of unhealthy years in bad health is reduced to 20-21% in 2059

The Effective Prevention scenario also shows compression of morbidity, but as a result of strong improvements in prevention rather than a lack of improvements in treatment. Remaining life expectancy is increased by 8 years (men) and 7 years (women), remaining life expectancy in good health by 10 years (men) and 11 years (women). The number of unhealthy lifeyears is reduced by 2-4 years. The quality of the remaining unhealthy years is strongly improved, with a reduction of the percentage of unhealthy years in bad health down to 10-11% in 2059.

In the Less Effective Prevention scenario, prevention plays a minor role in improving life expectancy and, as a result, nearly all the lifeyears gained are in ill-health. Remaining life expectancy at 55 increases by 4 years, but remaining life expectancy in good health increases by less than a year. The number of unhealthy lifeyears increases by a bit more than 3 years. Of the four scenarios, the improvement in the quality of the unhealthy years is weakest in the LEP scenario: 25-26% of the unhealthy years are in bad health in 2059. The number of years after 55 in bad health remains nearly unchanged.

Perhaps remarkably, all 4 scenarios result in an improvement of the quality of the unhealthy years. This is mostly due to the assumed trend in the secondary morbidity rate. The rate declines under all scenarios, since both prevention and treatment tend to reduce it. This lowers the proportion of lifeyears in bad health in the total number of unhealthy years. To keep this proportion fixed, the pace of the decline of the secondary morbidity rate should be reduced by a factor less than 0.2 in the LEP scenario, instead of the factor 0.5 that was used. This would mean that the mortality rate for those in bad health at age 55 would be reduced at least 4 times faster than the secondary morbidity rate, instead of 1.7 times faster in the LEP scenario. So, unless the rate of fatality of (chronic) diseases is reduced much more rapidly than their rate of progression, the quality of the unhealthy lifeyears will improve. Other combinations of trends for the secondary morbidity rate and the mortality rates lead to the same conclusion. If we do not adjust the age-gradient of the mortality curve but use an age-

independent reduction factor instead, mortality at the older ages in 2059 is somewhat lower. This increases the proportion of years in bad health in the unhealthy lifeyears, but only by one percentagepoint in the LEP scenario. It therefore does not change these conclusions.

In the three scenarios with moderate or strong improvements in prevention (ET, LET, EP), the prevalence of good health increases at ages 55, 70 and 85 (table 6). If strong improvements in treatment are assumed (ET), the gain in health prevalence, expressed in percentage points, is highest around age 70. In the prevention-dominated scenarios LET and EP, the gain in health prevalence increases with age between the ages 55 and 85. In the Less Effective Prevention scenario, the prevalence of good health remains nearly constant at 55, but declines at the older ages. Although the primary morbidity rate is assumed constant, weaker mortality selection of good health because of the declining mortality rates reduces the health prevalence. This effect is stronger at the older ages, where mortality is higher.

## 6. Possible implications for participation before and after retirement age

In an increasing number of European countries measures have been taken to increase the age at retirement. We will examine whether changes in the health status will make it plausible that these changes will lead to an increase in labour force participation rate before the age at retirement and an increase in social participation after retirement. We asssume that the age at retirement will increase by five years. For each scenario we calculate partial life expectancies by health status, which indicate how many years in good, fair or bad health can be expected for a given age interval. In tables 7 and 8, partial and remaining life expectancies are shown around the ages 65 (current retirement age in many EU countries) and 70 (hypothetical pension age in 25 or 50 years' time).

We are using a period perspective. The (healthy) life expectancies that we compare are calculated from age specific transition rates for single years (2009, 2034 or 2059). Since the morbidity and mortality rates are assumed to decline in the different scenarios, this underestimates the mean number of years lived, total and in good health, for those at the start of the age-interval in that particular year. However, we are interested in the change in (healthy) life expectancy and not the level. We use the change in the period life expectancies as an estimate for the change in the mean (remaining) number of lifeyears.

To assess the effect on the pre-retirement participation potential, we compare the health composition of the older working age population currently and in the future after a 5-year increase in the retirement age. The post-retirement participation potential depends on the health composition for the "young retirees", by which we mean those in the first 10 years after

the age of retirement. This health composition has a bearing on whether retirees of the future will still be able to participate and contribute to society, for instance as volunteers or providers of informal care. Finally, we compare the expected number of remaining years by health status after the age of retirement to determine whether increasing the retirement age would be fair, under a given scenario. We use a somewhat one-sided definition of fair, viz. that younger generations will enjoy at least the same number of years, total and in good health, after retirement as the generations currently entering retirement.

For both men and women, the number of life years in good health for the age interval 60-69 years in 2059 is higher than for the interval 55-64 years in 2009 in the scenarios with optimistic or moderate assumptions for primary prevention (EP, ET and LET). Hence, if the age of retirement would increase from 65 to 70 years over this 50 year period, a worker ten years away from retirement in 2059 would still be expected to have more remaining years of good health in the labour force than one in 2009. So increasing the age of retirement by 5 years would not negatively impact the pre-retirement participation potential, compared to the current situation.

If we compare the number of years in good health for the age interval 65-74 years in 2009 with the interval 70-79 years in 2059, we find for those 3 scenarios that also the health composition for the first 10 years of retirement is still better in 2059 than it was in 2009 if the retirement age is increased by 5 years. So there would be no negative effect on the post-retirement participation potential.

In the high life expectancy scenarios EP and ET, the number of total life years and life years in good health for the interval 70+ years in 2059 is higher than for the interval 65+ years in 2009. So, an increase of the retirement age would be fair, in the sense that future generations will still enjoy more healthy years after retirement than currently, even though retirement starts at a later age. In the LET scenario, the increase in the pension age would be effective but unfair, as the remaining life expectancy at the retirement age would be lower in 2059 than in 2009. Post-retirement life expectancy in good health, however, would be higher than in 2009.

The conclusions regarding the participation potential for the EP, ET and LET scenarios also very nearly hold if the retirement age is increased by 5 years over a 25 year period. The health expectancy for the age interval 60-69 years in 2034 is at most 0.1 year less than for 55-64 years in 2009. The same holds for the post-retirement interval 70-79 years in 2034 compared to 65-74 years in 2009. However, such a rapid increase of the retirement age would not be fair under any of the scenarios.

In the scenario that combines low life expectancy with expansion of morbidity (LEP), the health composition of the older working age population and younger retirees is worse in 2059 than in 2009 if the retirement age is increased by 5 years over that period. So, if, as a result of worsening lifestyles, the primary morbidity rate remains constant despite the advances in medical prevention, raising the retirement rate may not be very effective as a means of increasing participation. If such a policy is to be effective under this scenario, it is crucial that the labour force participation of those in fair health is increased. That would still leave the problem that future generations would enjoy fewer years in retirement, and much fewer in good health.

## 7. Conclusion and discussion

We constructed scenarios for mortality and morbidity using a multistate approach. We used a model with three health states, self-assessed good, fair and bad general health, which allowed us to look both at the prevalence and at the severity of ill-health. Aiming for simplicity and transparency, we used stylised transition rates, based on prevalence and mortality data from 16 European countries.

The model allows us to study the effect that changes in different transition rates, which are linked to prevention and treatment have on (healthy) life expectancy. We find that proportional reductions of the mortality rate for all 3 health states mainly result in more unhealthy life years (Appendix 1). Reductions of the relative mortality risks for those in fair or bad health only result in more unhealthy years. Reductions of the primary morbidity rate lead to more healthy and fewer unhealthy years. Reductions of the secondary morbidity rate extends unhealthy life but reduces the severity. We find that the development of life expectancy in good health mainly depends on the trend for the primary morbidity rate, while the development of total life expectancy mainly depends on the trend in the mortality rate at good health.

Different types of medical progress and developments in healthy lifestyles have different effects on trends in morbidity and mortality rates. We argue that improvements in primary prevention will reduce the primary mortality rate, the primary and secondary morbidity rate and increase the relative mortality risk for those in ill health. Better prevention may be related to healthy lifestyles, but also to new types of preventive medicine. We expect improvements in medical treatments to lead to reductions of the primary mortality rate, the secondary morbidity rate and the relative mortality risk for those in ill health. The effect on

the primary morbidity rate is uncertain and was assumed zero. On the one hand, improved treatment of acute diseases may turn them into chronic diseases, thereby turning fatality into morbidity and increasing the primary morbidity rate. On the other hand, improved treatment of chronic diseases may reduce the symptoms to such an extent that they no longer affect self-assessed health. This would lower the primary morbidity rate.

We developed four scenarios based on alternative assumptions about the relative strength of future improvements in prevention and treatment. One scenario assumes strong and another assumes weak advances in primary prevention, one scenario assumes strong and another weak advances in medical treatment. The scenarios surround a central scenario with moderate advances in primary prevention and medical treatment. The parameters for the central scenario were fine-tuned to reproduce the results for the EUROPOP 2010 projection for total life expectancy and to yield an equal increase for remaining life expectancy and remaining life expectancy in good health at age 55.

In the Effective Prevention (EP) scenario, policies aimed at promoting healthy behaviour are successful and there are strong advances in preventive medicine. Life expectancy increases strongly, life expectancy in good health even more strongly. The Less Effective Prevention (LEP) scenario describes a future where unhealthy lifestyles become more widespread and negate the effects of progress in medical prevention. Further improvements in life expectancy are due to advances in medical treatment. Remaining life expectancy at 55 increases weakly and remaining life expectancy in good health very weakly. In the Effective Treatment (ET) scenario, medical treatments have become much more advanced, like in the EP scenario, but they are still mostly reactive and focus on treating those already suffering from a disease. Advances in prevention are moderate. In this scenario, a strong increases in total life expectancy is combined with expansion of morbidity. In the Less Effective Treatment (LET) scenario, prevention plays the main role in future advances in life expectancy because improvements in treatment stagnate. This scenario is reminiscent of the classical compression of morbidity theory. Life expectancy increases very little, life expectancy in good health increases more strongly, leading to healthier if not (much) longer lives.

Comparing the two Prevention scenarios, we find that improved primary prevention has a stronger impact on life expectancy in good health than on total life expectancy. Remaining life expectancy at 55 in 50 years' time is 4 years higher for men, 3 years higher for women in the EP than in the LEP scenario. The difference in lifeyears in good health is 9 years for men, 11 years for women. Improvements in treatment affect total life expectancy

much more strongly than life expectancy in good health. The difference in remaining total life expectancy between the ET and LET scenarios is 7 years for both men and women. The difference for remaining lifeyears in good health is 2 years for men, 1 year for women. The effect of improved treatment on lifeyears in good health becomes somewhat stronger if recovery in included into the model (Appendix 2).

In all four scenarios, the quality of the unhealthy lifeyears increases. In the future, a larger proportion of the unhealthy years are in fair rather than bad health. If we accept that medical progress will continue in the future and that it will affect both the progression and fatality of diseases, it is likely that the quality of the unhealthy years will improve, even if unhealthy lifestyles become more widespread. We find that the ratio of years in bad compared to fair health will only increase if the rate of fatality of diseases is reduced much more strongly than the rate of progression.

We have assumed that, for each scenario, the morbidity and mortality rates for men and women are reduced by the same yearly percentage. This results in similar trends for (healthy) life expectancies for men and women. In the treatment-dominated scenarios ET and LEP, the gender-differences in total life expectancy and life expectancy in good health remain nearly the same. In the EP and LET scenario there is some convergence in terms of remaining lifeyears and number of unhealthy years.

We have used the scenarios to examine the effect of an increase in the age of retirement on the participation potential of the older working age population and the young retirees. In three out of the four scenarios, the health composition of the ten years before and after retirement would still be better in 2059 than in 2009 if the retirement age were increased from 65 to 70 years. If the increase was effected over a 25 years period, the health composition of these groups in 25 years' time would be nearly the same as currently under these three scenarios. Thus, it is likely that even a strong increase in the retirement age over a relatively short period would have no or little negative effects on the participation potential and could be very effective at increasing the labour force. However, only in the two most optimistic scenarios would younger generations have an equal or greater number of total and healthy lifeyears after retirement than current retirees. If the retirement age was raised by 5 years in 25 instead of 50 years, younger generations would have fewer lifeyears after retirement, or fewer lifeyears in good health, under all four scenarios. Whether a strong increase in the age of retirement would be fair to the younger generations therefore seems more of a concern than whether it would be economically effective.

The optimistic scenario for primary prevention (EP) offers the most scope for raising the age of retirement without negatively affecting the participation potential. The pessimistic scenario for this dimension (LEP) offers the least scope. Thus it may be concluded that improvements in primary prevention are key to ensuring that a policy which links the age of retirement to life expectancy will be successful. So, health policies aimed at raising the participation potential should focus on those still in good health. These could be policies improving working conditions, policies promoting behaviour beneficial to good health, or policies stimulating research into medical prevention, such as screening programs or preventive treatments for people with a high (genetic) risk of specific conditions.

Our analyses are based on self assessed health. However, due to differences in reporting behaviour, the levels of self assessed health are not completely comparable between countries (Jürges 2007). It is therefore to be expected that the impact that a change in self assessed health has on participation will also differ between countries. Therefore, to make a next step and to go from participation potential to actual participation and from a stylized to a real country, it will be necessary to use country-specific data on the relationship between participation and self assessed general health.

A number of simplifying assumptions were made in the derivation of the transition rates in section 2. We assumed age-independent relative mortality risks. There is evidence that the correlation between self rated health and mortality becomes weaker at older ages (Franks et al. 2003; Lyyra et al. 2006). Lower relative risks at older ages would mean weaker mortality selection of good health. This would make reduction of the mortality rate or the relative mortality risks less effective in increasing the number of years in fair or bad health. As a result, expansion of morbidity in the ET and LEP scenarios would be weaker. Our finding that the quality of the unhealthy lifeyears will likely increase, unless the rate fatality of diseases decreases much more rapidly than the rate of progression, is strengthened if the relative risks decline at older ages.

We have also tested whether the findings depend strongly on the assumed values for the relative mortality risks in 2009. This does not seem to be the case. If $r_F$=2, $r_B$=3 are used, both when estimating the parameters for 2009 and in the calculation of the life tables for the scenarios, the results are similar to what was found for $r_F$=1.5, $r_B$=2. The increase in life expectancy for the treatment dominated scenarios ET and LEP is 1 to 2 years higher, with all the additional years being in fair or bad health. The reduction in the ratio of years in bad health compared to fair health for these scenarios is a little weaker. The results for the prevention-dominated scenarios EP and LET are nearly unchanged.

The assumption of zero recovery was found not to have a great influence on the results (see appendix 2). This may be due to the fact that we used age-independent adjustments in the morbidity rates for all scenarios. We find that a model without recovery overestimates the effect that reductions in the morbidity prevalence at younger ages have on morbidity at older ages (for the same cohort). This means that models without recovery are less suitable for studying the effects of age-specific health policies.

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**Appendix 1: sensitivity analysis**

The four scenarios all assume simultaneous changes in different model parameters. In this Appendix we examine the individual effects of changes in the parameters. We look at the effect on remaining (healthy) life expectancy at age 55, as calculated from the multistate lifetable, of a 50 % reduction of the mortality rates, the primary morbidity rate, the secondary morbidity rate or of the excess mortality risks in the unhealthy states. We also look at the effect of halving the prevalence of bad and fair health at age 55 while keeping all transition rates at ages 55 and older unchanged. The change in the mortality rates was implemented in the same way as in the scenarios: for ages 55 and older, the reduction was (partly) balanced by increasing the parameter $a$ in eq. (1) in such a way that the mortality rate at age 120 remained unchanged. In this way, some rectangularization of the survival curve was imposed.

*Figure A1* shows the results for remaining life expectancy age 55 in good, fair and bad health as a result of the various adjustments. We first discuss the effects for the model without recovery. Appendix 2 will examine the effects of recovery.

Reducing the mortality rates leads to expansion of morbidity. For our typical low mortality European country, halving the mortality rates results in a 4 year increase of remaining life expectancy. Most of these additional years are in bad or fair health, more so if the prevalence of good health at the older ages in the initial situation is lower. For men, only 30 % of the additional years are in good health, for women, only 20 %.

Reducing the excess mortality risk expands the morbidity period. Halving the excess mortality risks adds about a year of unhealthy life to the life expectancy at 55 for men and 1.5 years for women. There is only a very small effect on remaining life expectancy in good health. For both sexes, about 40 % of the added life expectancy is in fair and 60 % in bad health.

Reductions in the primary morbidity rate have a much larger positive impact on the remaining life years in good health than on the total remaining lifeyears. Changing the primary morbidity rate mainly exchanges years in bad or fair health for years in good health. Halving this rate leads to approximately 6 and 7 additional years in good health for men and women respectively. Total life expectancy only shows an increase of about 1 year under this change.

A reduction of the secondary morbidity rate improves the quality of the unhealthy years. It mainly exchanges years in bad health for years in fair health, hardly affects

remaining years in good health and has a relatively small effect on the total life expectancy. About 1.5 year of bad health is changed into fair health for men, about 2.5 years for women.

Halving the prevalence of fair and bad health at age 55, while keeping all transition rates ate ages 55 and older unchanged, has a similar effect as reducing the primary morbidity rate at all ages. Remaining life expectancy in good health is increased by approximately 3 years for men, 4 years for women, and life expectancy is fair or bad health is reduced. The effect on total remaining life expectancy is much smaller than the effect on remaining life expectancy in good health.

There are sizeable interaction effects between some of the parameters. Reducing the mortality rate increases the effect of reductions in the morbidity rates. The number of life years in good health that are gained if both the primary morbidity and the mortality rate are halved is about a year higher than the sum of the effects of halving the mortality rate and the primary morbidity rate separately. Reducing the mortality rate means that more people survive to older ages, where morbidity prevalence is high, which makes reductions in the primary morbidity rate more effective. By the same argument a lower mortality rate also makes reductions in the secondary morbidity rate more effective at exchanging years in bad health for years in fair health. This effect amounts to half a year to a year extra in fair health. There is a negative interaction effect of reductions in the primary morbidity rate on reductions in the secondary morbidity rate. Simultaneously halving both morbidity rates results in fewer years in fair and more in bad health than the summed effects of halving either. This interaction effect is of the order of half a year (men) to a year (women). Reducing the primary morbidity rate also negatively affects the impact that reductions of the excess mortality risk have on life expectancy (minus half a year). For their part, reductions of the excess mortality risk enhance the effects of reductions in the secondary morbidity rate on years in fair health (positive) and bad health (negative). This gives an interaction effect of up to half a year. Finally, there is a very small positive interaction effect between reductions of the mortality rate at good health and of the excess mortality risk on total life expectancy.

**Appendix 2: model with recovery**

In this Appendix we analyse to what extent the assumption of zero recovery, that is, of modelling in terms of net morbidity rates instead of 'true' morbidity and recovery, influences the results. To analyse whether the same scenarios computed in a model with recovery would yield different results, we introduce a recovery transition from fair to good and from bad to fair health into the ID model. First, we reproduce the multistate lifetable for 2009 for the model without recovery by imposing that the net morbidity rates for the model with recovery be the same as for the model without recovery

$$\widetilde{\theta}_G(x,2009) = \frac{L_G(x,2009)\theta_G(x,2009) + L_F(x,2009)\rho_F(x,2009)}{L_G(x,2009)},$$
$$\widetilde{\theta}_F(x,2009) = \frac{L_F(x,2009)\theta_F(x,2009) + L_B(x,2009)\rho_B(x,2009)}{L_F(x,2009)}, \qquad (9)$$

where $\widetilde{\theta}_G(x)$ and $\widetilde{\theta}_F(x)$ are the morbidity rates for the model with recovery, $\rho_i$ is the recovery rate in state $i$ and $L_i(x)$ is the number of lifeyears in $i$ in the multistate lifetable for the age-interval between $x$ and $x+1$. We use a simple age-independent recovery rate of 0.05 per year for both transitions. This gives a substantial amount of recovery. Of those in fair health at age 55, approximately half eventually recover under this assumption (the others progress to bad health or die). Of those in bad health at age 55, about 60 % of the men and 70 % of the women recover to fair health. The primary and secondary morbidity rates at ages over 55 are between 1.5 and 2.5 times higher than the net morbidity rates.

Figure A1 shows the effects of halving the various parameters in the model with and without recovery.

The response to halving the mortality rate or the excess mortality risks is very similar for both models. Although such changes influence the health prevalences, which means that the net morbidity rates changes in a model with recovery, this change is small except at high ages where the effect of selective mortality on the health prevalence dominates over the effects of morbidity. Precisely because the effect of mortality dominates, the changes in the net morbidity rates that occur there have little effect on the results.

Halving the prevalence of fair and bad health at age 55, while keeping all transition rates at older ages unchanged, has a much weaker effect in the model with than without recovery. If the net morbidity rate is kept fixed, a change in the health prevalence at a given age affects the health prevalence in that cohort for all older ages. Recovery introduces loss of memory into the system. If there is a high rate of recovery, the prevalence of ill-health at a

given age is only influenced by the morbidity rates at ages closely preceding that age. Therefore, in such a model, changes in the health prevalence at younger ages hardly affect the health composition at the older ages. Recovery rates of 5 % per year nearly halve the sensitivity to changes in the health prevalence at younger ages, both for men and women.

The response to an age-independent adjustment of the primary morbidity rate is more similar for the models with and without recovery. However, halving the primary morbidity rate in the model with recovery still has a weaker effect than halving the net primary morbidity rate in the model without recovery. At young ages, where the prevalence of good health is very high, halving the primary morbidity rate also leads to a nearly 50 % reduction of the net morbidity rate. At older ages, however, the resulting reduction of the net morbidity rate becomes progressively smaller, weakening the effect that lower primary morbidity has on the remaining life expectancy in good health. The number of additional lifeyears in good health is some 10 % lower in the model with recovery.

Changing the (net) secondary morbidity rate hardly affects remaining life expectancy in good health in the model without recovery. Because that model is unidirectional, those that have progressed from good to fair health can no longer add healthy years to their life. In the model with recovery, a reduction of the secondary morbidity rate means that those in fair health have a longer period in which they have a chance of recovering to good health. As a result, halving the secondary morbidity rate in the model with recovery has a positive effect on the number of years in good health: nearly a year. Fewer years in fair health are gained for the model with recovery, the response in terms of years in bad health are nearly the same for both models.

How do these differences affect the results of the four scenarios? Table A1 shows the results if the assumptions for the scenarios are applied to the model with recovery (reductions of the net morbidity rates in the model without recovery are implemented as reductions of the morbidity rates, with the same factor, in the model with recovery). Qualitatively, the results are very similar to those for the model without recovery. In terms of total remaining life expectancy, the differences between the two models are at most 0.2 years, in terms of life expectancy in good health, at most 1.3 years. The interval between the scenario with the highest and lowest life expectancy is smaller for the model with recovery for all health categories. The model with recovery generally yields more lifeyears in good, fewer in fair or bad health. The only exception is the LET scenario, but for this scenario the difference in results between both models is very small (at most 0.2 years). The largest differences are found for the ET scenario.

Partial life expectancy in good health for 10 year intervals around ages 65 and 70 is much less sensitive to the inclusion of recovery in the model than remaining life expectancy in good health at 55. The conclusions from section 6 regarding the effects of raising the age of retirement on pre- and post-retirement participation potential under the different scenarios are the same for the model with and without recovery. The conclusions concerning the fairness of such a measure under the different scenarios are also the same.

*Figure 1: four state illlness-death model*

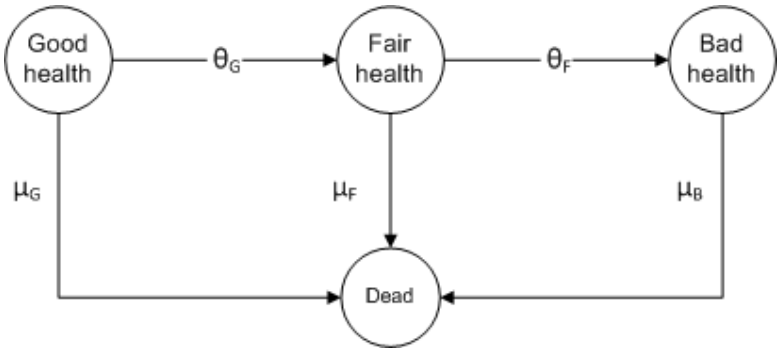



*Figure 2: Prevalence of fair and bad health for Switzerland, Germany and Portugal (2009), observation and fit.*

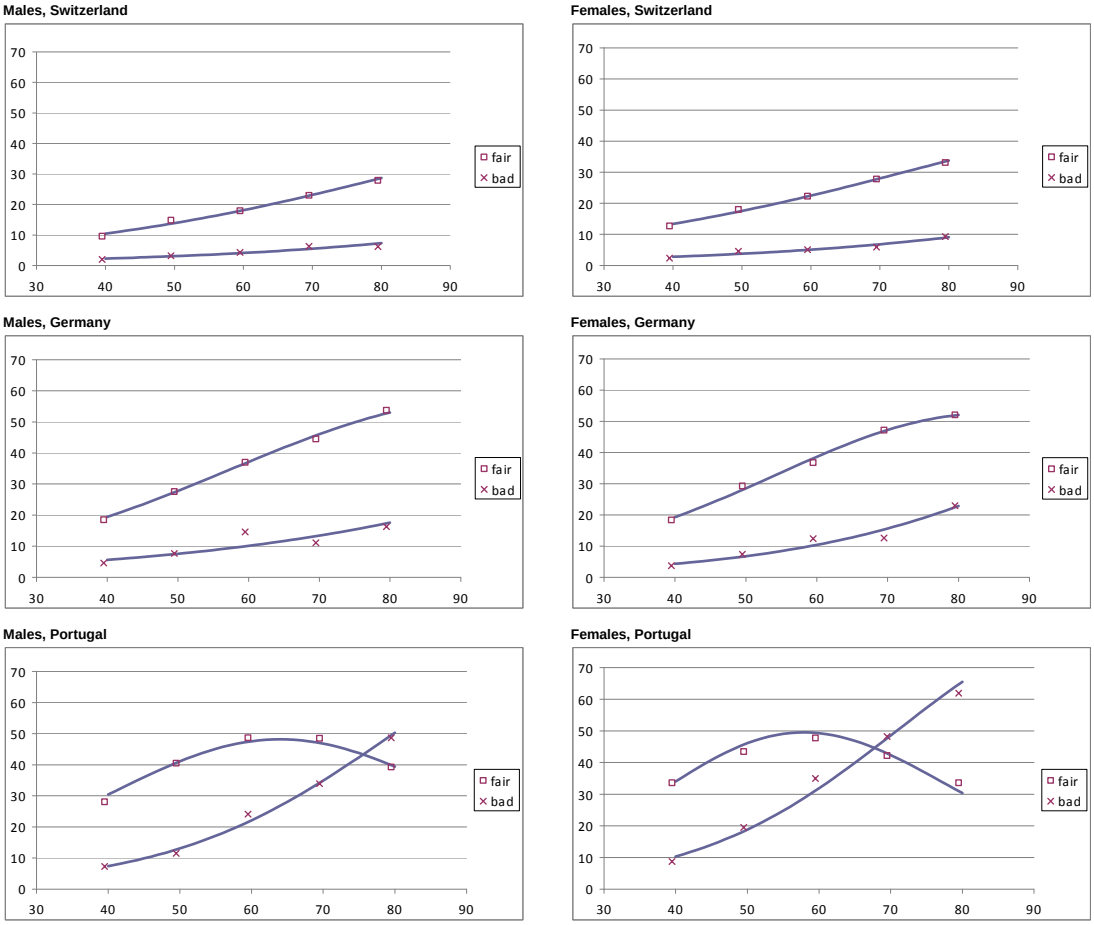


*Figure 3: Mortality and morbidity rates for Switzerland, Germany and Portugal (2009), estimate and exponential fit.*

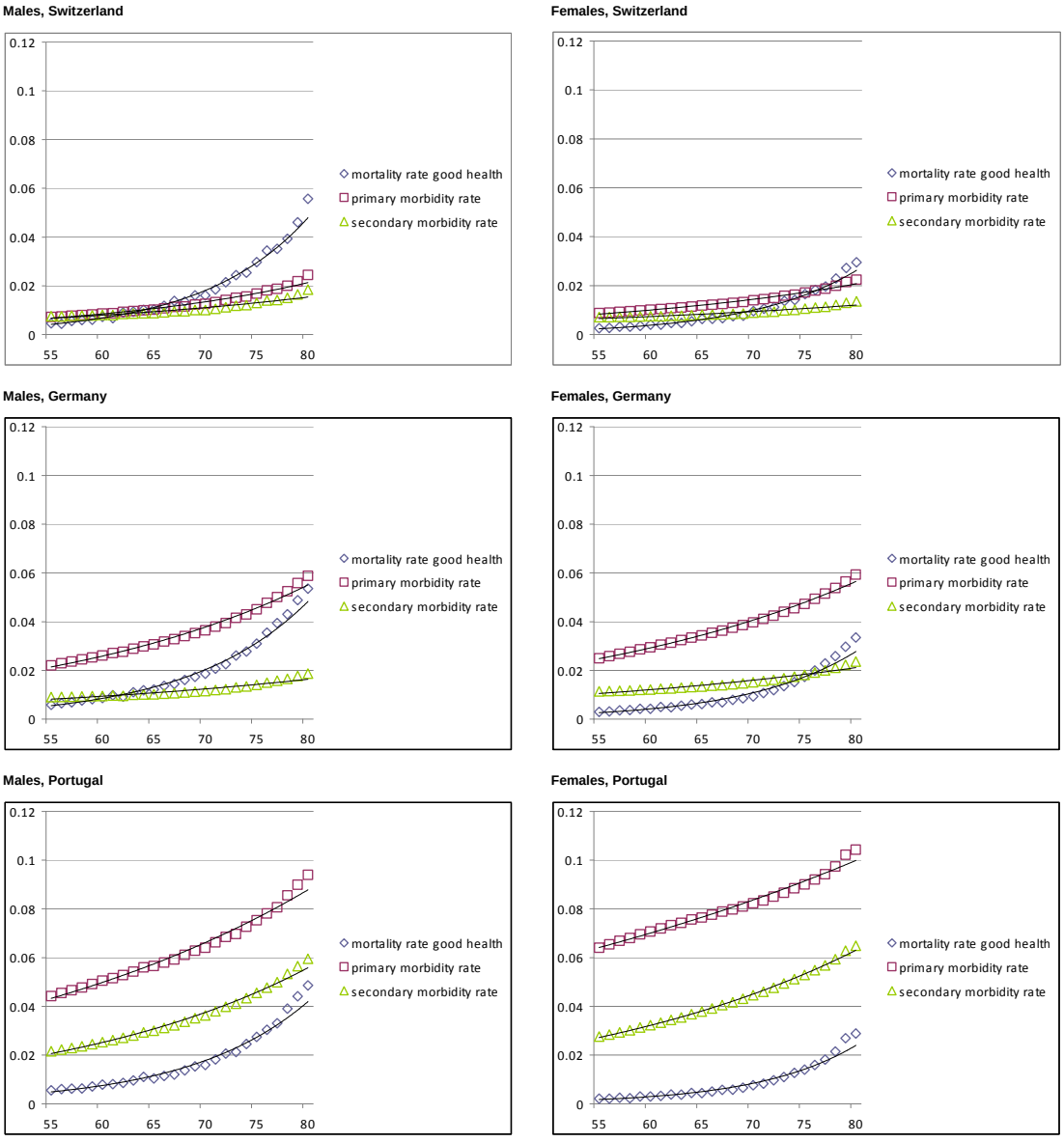
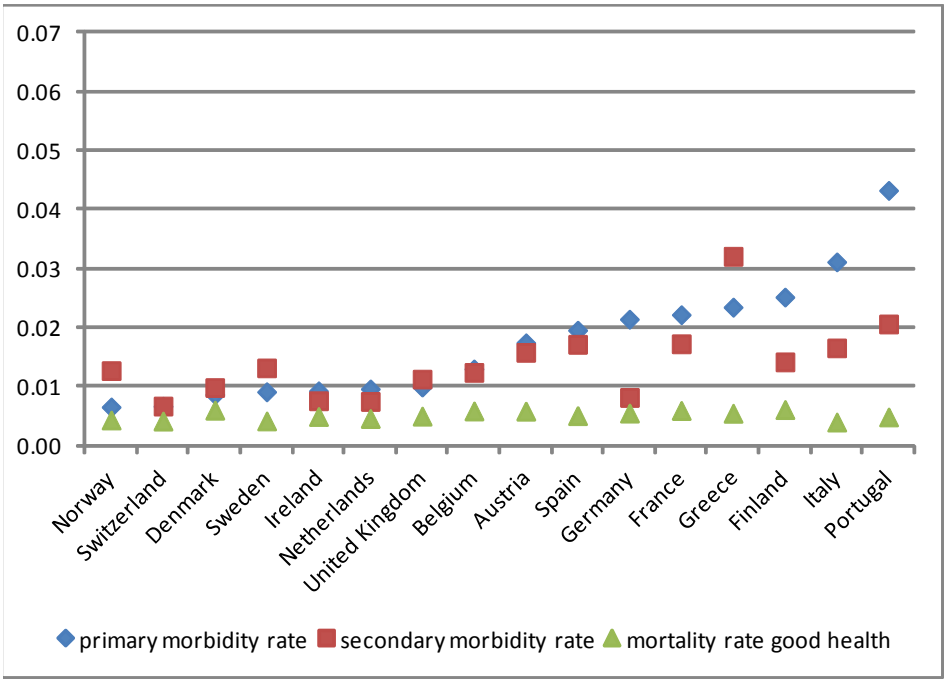


*Figure 4: morbidity and mortality rate at age 55, by country and sex*

Males




Females

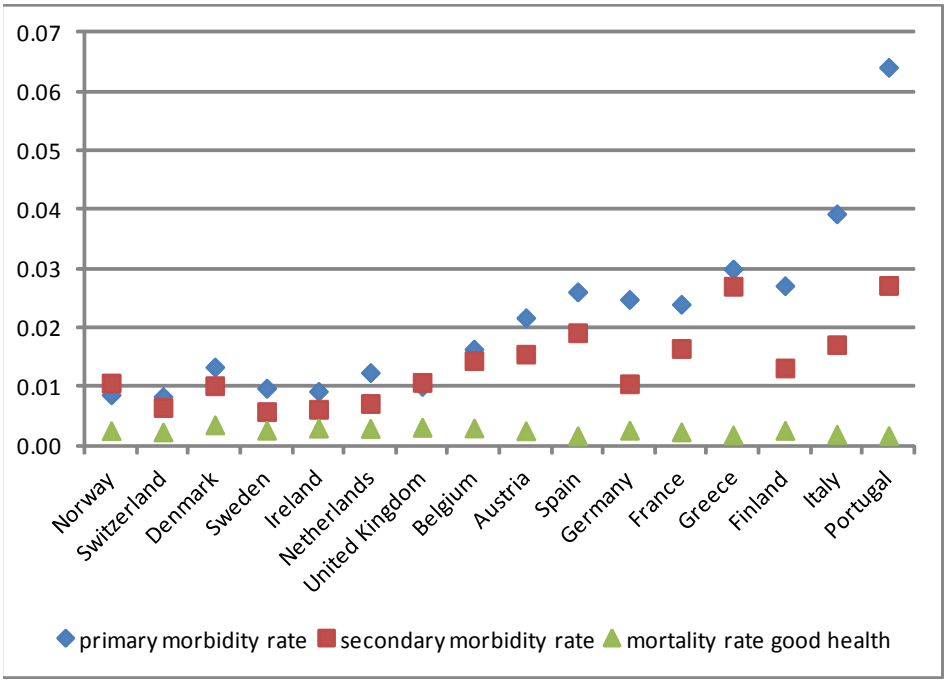


*Table 1: parameter estimates by country and sex*

| | $\theta_G(55)$ | $b_G$ | $\theta_F(55)$ | $b_F$ | $\mu_G(55)$ | $a$ | $Q_F(55)$ | $Q_B(55)$ |
|---|---|---|---|---|---|---|---|---|
| males | | | | | | | | |
| Norway | 0.007 | 0.05 | 0.013 | 0.04 | 0.004 | 0.10 | 0.18 | 0.08 |
| Switzerland | 0.007 | 0.05 | 0.007 | 0.03 | 0.004 | 0.10 | 0.16 | 0.04 |
| Denmark | 0.009 | 0.05 | 0.010 | 0.04 | 0.006 | 0.09 | 0.23 | 0.07 |
| Sweden | 0.009 | 0.05 | 0.013 | 0.03 | 0.004 | 0.10 | 0.15 | 0.05 |
| Ireland | 0.009 | 0.05 | 0.008 | 0.04 | 0.005 | 0.10 | 0.18 | 0.03 |
| Netherlands | 0.010 | 0.05 | 0.008 | 0.03 | 0.005 | 0.10 | 0.18 | 0.05 |
| United Kingdom | 0.010 | 0.05 | 0.011 | 0.03 | 0.005 | 0.09 | 0.17 | 0.07 |
| Belgium | 0.013 | 0.04 | 0.012 | 0.03 | 0.006 | 0.09 | 0.21 | 0.09 |
| Austria | 0.017 | 0.04 | 0.016 | 0.04 | 0.006 | 0.08 | 0.26 | 0.09 |
| Spain | 0.020 | 0.04 | 0.017 | 0.04 | 0.005 | 0.09 | 0.25 | 0.08 |
| Germany | 0.021 | 0.04 | 0.008 | 0.03 | 0.006 | 0.09 | 0.32 | 0.09 |
| France | 0.022 | 0.04 | 0.017 | 0.03 | 0.006 | 0.07 | 0.27 | 0.09 |
| Greece | 0.023 | 0.06 | 0.032 | 0.02 | 0.006 | 0.08 | 0.16 | 0.08 |
| Finland | 0.025 | 0.04 | 0.014 | 0.03 | 0.006 | 0.08 | 0.29 | 0.08 |
| Italy | 0.031 | 0.04 | 0.017 | 0.04 | 0.004 | 0.09 | 0.30 | 0.08 |
| Portugal | 0.043 | 0.03 | 0.021 | 0.04 | 0.005 | 0.09 | 0.45 | 0.17 |
| unweighted mean | 0.015 | 0.04 | 0.013 | 0.03 | 0.005 | 0.09 | 0.24 | 0.08 |
| females | | | | | | | | |
| Norway | 0.009 | 0.04 | 0.011 | 0.02 | 0.003 | 0.10 | 0.19 | 0.10 |
| Switzerland | 0.008 | 0.04 | 0.007 | 0.02 | 0.002 | 0.10 | 0.20 | 0.04 |
| Denmark | 0.013 | 0.04 | 0.010 | 0.02 | 0.004 | 0.10 | 0.22 | 0.10 |
| Sweden | 0.010 | 0.04 | 0.006 | 0.02 | 0.003 | 0.10 | 0.18 | 0.07 |
| Ireland | 0.009 | 0.04 | 0.006 | 0.02 | 0.003 | 0.10 | 0.17 | 0.04 |
| Netherlands | 0.012 | 0.04 | 0.007 | 0.02 | 0.003 | 0.09 | 0.23 | 0.06 |
| United Kingdom | 0.010 | 0.04 | 0.011 | 0.02 | 0.003 | 0.10 | 0.19 | 0.06 |
| Belgium | 0.016 | 0.04 | 0.014 | 0.02 | 0.003 | 0.09 | 0.23 | 0.11 |
| Austria | 0.022 | 0.04 | 0.016 | 0.02 | 0.003 | 0.09 | 0.27 | 0.10 |
| Spain | 0.026 | 0.03 | 0.019 | 0.03 | 0.002 | 0.10 | 0.30 | 0.10 |
| Germany | 0.025 | 0.03 | 0.011 | 0.03 | 0.003 | 0.09 | 0.34 | 0.08 |
| France | 0.024 | 0.03 | 0.017 | 0.03 | 0.002 | 0.08 | 0.29 | 0.10 |
| Greece | 0.030 | 0.05 | 0.027 | 0.03 | 0.002 | 0.11 | 0.21 | 0.09 |
| Finland | 0.027 | 0.04 | 0.013 | 0.03 | 0.003 | 0.09 | 0.28 | 0.06 |
| Italy | 0.039 | 0.03 | 0.017 | 0.04 | 0.002 | 0.10 | 0.36 | 0.10 |
| Portugal | 0.064 | 0.02 | 0.027 | 0.03 | 0.002 | 0.10 | 0.49 | 0.25 |
| unweighted mean | 0.018 | 0.04 | 0.012 | 0.03 | 0.002 | 0.10 | 0.26 | 0.09 |

*Table 2: (healthy) life expectancy at 55 and health prevalence at 70 for a "typical" low mortality European country*

| | Males | Females |
|---|---|---|
| | *years* | |
| lifeyears 55+ | 25.1 | 31.0 |
| | | |
| in good health | 13.2 | 13.3 |
| fair health | 8.2 | 11.9 |
| bad health | 3.6 | 5.7 |
| | | |
| lifetable population aged 70 | | |
| | % | |
| in good health | 52 | 46 |
| fair health | 34 | 38 |
| bad health | 14 | 16 |

Table 3: Effect of different aspects of treatment and prevention on the model parameters

| | $\mu_G$ | $\theta_G$ | $\theta_F$ | $r_F$, $r_B$ |
|---|---|---|---|---|
| **Treatment** | | | | |
| treatment acute diseases | ↓ | ↑ | - | ↑ |
| treatment chronic diseases | - | ↓ | ↓ | ↓ |
| Net effect treatment | ↓ | - | ↓ | ↓ |
| **Prevention** | | | | |
| disease prevention | ↓ | ↓ | - | ↑ |
| health protection | ↓ | ↓ | - | - |
| health promotion | ↓ | ↓ | ↓ | ↑ |
| Net effect prevention | ↓ | ↓ | ↓ | ↑ |

Table4: 50-year adjustment factor in the parameters in the four scenarios (f=0.42)

| Scenario | $\mu_G(55)$ | $\theta_G(x)$ | $\theta_F(x)$ | $r_F - 1$ and $r_B - 1$ |
|---|---|---|---|---|
| Central scenario | f | $f^{0.45}$ | f | 1 |
| Effective Treatment | $f^{1.5}$ | $f^{0.45}$ | $f^{1.5}$ | 0.5 |
| Less Effective Treatment | $f^{0.5}$ | $f^{0.45}$ | $f^{0.5}$ | 1.5 |
| Effective Prevention | $f^{1.5}$ | $f^{0.9}$ | $f^{1.5}$ | 1.5 |
| Less Effective Prevention | $f^{0.5}$ | 1 | $f^{0.5}$ | 0.5 |

*Table 5: remaining life expectancies at age 55 for the 4 scenarios*

| | 2009 | 2059 Effective Treatment | Less Effective Treatment | Effective Prevention | Less Effective Prevention |
|---|---|---|---|---|---|
| | *years* | | | | |
| Males | | | | | |
| lifeyears 55+ | 25.1 | 34.2 | 27.7 | 33.1 | 28.9 |
| in good health | 13.2 | 19.6 | 17.7 | 23.4 | 14.0 |
| fair health | 8.2 | 12.8 | 7.9 | 8.7 | 11.3 |
| bad health | 3.6 | 1.8 | 2.0 | 1.0 | 3.7 |
| unhealty years | 11.8 | 14.6 | 9.9 | 9.7 | 14.9 |
| Females | | | | | |
| lifeyears 55+ | 31.0 | 39.8 | 33.1 | 38.3 | 34.9 |
| in good health | 13.3 | 19.4 | 18.3 | 24.3 | 13.8 |
| fair health | 11.9 | 17.7 | 11.6 | 12.5 | 15.6 |
| bad health | 5.7 | 2.7 | 3.2 | 1.5 | 5.5 |
| unhealty years | 17.6 | 20.4 | 14.8 | 14.0 | 21.2 |

*Table 6. prevalence of good, fair and bad health at selected ages for the 4 scenarios*

| | 2009 | 2059 Effective Treatment | Less Effective Treatment | Effective Prevention | Less Effective Prevention |
|---|---|---|---|---|---|
| | *%* | | | | |
| Males | | | | | |
| lifetable population aged 55 in | | | | | |
| good health | 68 | 76 | 77 | 83 | 68 |
| fair health | 24 | 22 | 19 | 15 | 26 |
| bad health | 8 | 2 | 4 | 1 | 6 |
| aged 70 in | | | | | |
| good health | 52 | 62 | 64 | 73 | 50 |
| fair health | 34 | 34 | 29 | 24 | 39 |
| bad health | 14 | 4 | 7 | 3 | 11 |
| aged 85 in | | | | | |
| good health | 37 | 44 | 53 | 61 | 31 |
| fair health | 41 | 48 | 37 | 35 | 49 |
| bad health | 22 | 8 | 11 | 5 | 20 |
| Females | | | | | |
| lifetable population aged 55 in | | | | | |
| good health | 65 | 74 | 74 | 82 | 64 |
| fair health | 26 | 24 | 21 | 17 | 29 |
| bad health | 9 | 2 | 5 | 2 | 7 |
| aged 70 in | | | | | |
| good health | 46 | 58 | 59 | 69 | 45 |
| fair health | 38 | 38 | 33 | 28 | 43 |
| bad health | 16 | 4 | 8 | 3 | 12 |
| aged 85 in | | | | | |
| good health | 27 | 37 | 42 | 53 | 24 |
| fair health | 46 | 54 | 44 | 41 | 54 |
| bad health | 27 | 8 | 14 | 6 | 22 |

*Table 7. Partial life expectancies around and remaining life expectancies at ages 65 and 70, males*

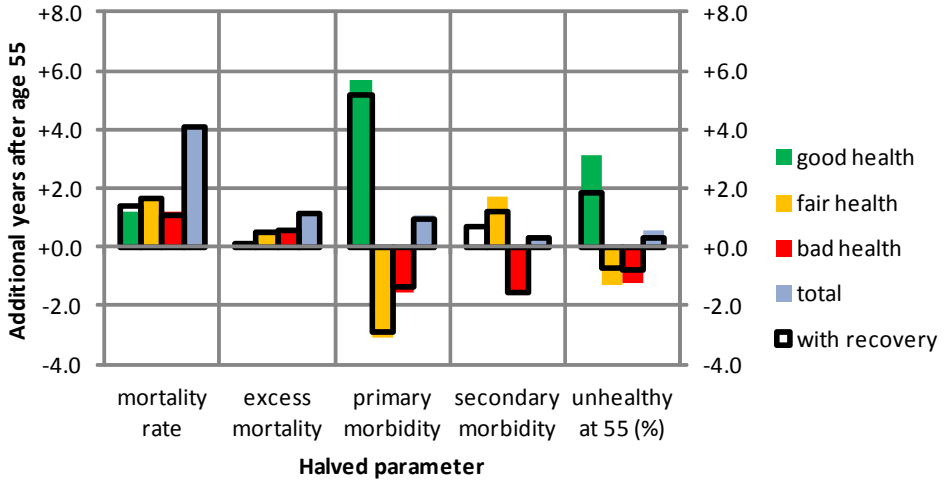
| Males | | | Effective Treatment | | Less Effective Treatment | | Effective Prevention | | Less Effective Prevention | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2009 | 2034 | 2059 | 2034 | 2059 | 2034 | 2059 | 2034 | 2059 |
| | | *life years* | | | | | | | | |
| 55-64 | total | 9.6 | 9.8 | 9.9 | 9.7 | 9.7 | 9.8 | 9.9 | 9.7 | 9.7 |
| | good health | 6.0 | 6.6 | 7.1 | 6.6 | 7.1 | 7.1 | 7.9 | 6.0 | 6.1 |
| | fair health | 2.6 | 2.7 | 2.5 | 2.4 | 2.2 | 2.3 | 1.8 | 2.8 | 3.0 |
| | bad health | 1.0 | 0.5 | 0.2 | 0.7 | 0.5 | 0.4 | 0.2 | 0.8 | 0.7 |
| 60-69 | total | 9.3 | 9.7 | 9.8 | 9.5 | 9.5 | 9.6 | 9.8 | 9.5 | 9.6 |
| | good health | 5.4 | 6.0 | 6.6 | 6.0 | 6.5 | 6.6 | 7.5 | 5.4 | 5.4 |
| | fair health | 2.8 | 3.0 | 2.9 | 2.6 | 2.4 | 2.6 | 2.1 | 3.1 | 3.3 |
| | bad health | 1.1 | 0.6 | 0.3 | 0.8 | 0.6 | 0.5 | 0.2 | 1.0 | 0.9 |
| 65-74 | total | 9.0 | 9.4 | 9.7 | 9.1 | 9.2 | 9.4 | 9.6 | 9.2 | 9.3 |
| | good health | 4.7 | 5.4 | 6.0 | 5.3 | 5.9 | 6.0 | 7.0 | 4.7 | 4.7 |
| | fair health | 3.0 | 3.3 | 3.3 | 2.9 | 2.6 | 2.8 | 2.3 | 3.3 | 3.6 |
| | bad health | 1.3 | 0.7 | 0.4 | 0.9 | 0.7 | 0.6 | 0.3 | 1.2 | 1.0 |
| 70-79 | total | 8.4 | 9.1 | 9.4 | 8.6 | 8.8 | 9.0 | 9.4 | 8.7 | 8.9 |
| | good health | 4.0 | 4.6 | 5.3 | 4.6 | 5.3 | 5.3 | 6.5 | 3.9 | 4.0 |
| | fair health | 3.1 | 3.6 | 3.6 | 3.0 | 2.8 | 3.0 | 2.6 | 3.4 | 3.8 |
| | bad health | 1.4 | 0.9 | 0.5 | 1.0 | 0.8 | 0.7 | 0.3 | 1.3 | 1.2 |
| 65+ | total | 17.1 | 21.2 | 25.0 | 18.2 | 19.2 | 20.6 | 23.9 | 18.8 | 20.4 |
| | good health | 8.0 | 10.2 | 12.8 | 9.7 | 11.4 | 11.8 | 16.0 | 8.2 | 8.4 |
| | fair health | 6.2 | 8.7 | 10.6 | 6.3 | 6.1 | 7.2 | 7.1 | 7.5 | 8.8 |
| | bad health | 2.9 | 2.3 | 1.6 | 2.2 | 1.7 | 1.7 | 0.8 | 3.1 | 3.1 |
| 70+ | total | 13.7 | 17.2 | 20.6 | 14.6 | 15.5 | 16.7 | 19.7 | 15.1 | 16.6 |
| | good health | 5.9 | 7.7 | 9.9 | 7.3 | 8.8 | 9.1 | 12.7 | 6.1 | 6.2 |
| | fair health | 5.2 | 7.4 | 9.3 | 5.3 | 5.2 | 6.1 | 6.2 | 6.3 | 7.5 |
| | bad health | 2.5 | 2.1 | 1.4 | 1.9 | 1.4 | 1.5 | 0.8 | 2.7 | 2.8 |

*Table 8. Partial life expectancies around and remaining life expectancies at ages 65 and 70, females*

| Females | | | Effective Treatment | | Less Effective Treatment | | Effective Prevention | | Less Effective Prevention | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2009 | 2034 | 2059 | 2034 | 2059 | 2034 | 2059 | 2034 | 2059 |
| | | *life years* | | | | | | | | |
| 55-64 | total | 9.8 | 9.9 | 10.0 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 |
| | good health | 5.8 | 6.3 | 6.9 | 6.3 | 6.9 | 6.9 | 7.7 | 5.8 | 5.8 |
| | fair health | 3.0 | 3.0 | 2.8 | 2.7 | 2.5 | 2.6 | 2.0 | 3.2 | 3.3 |
| | bad health | 1.1 | 0.6 | 0.3 | 0.8 | 0.6 | 0.5 | 0.2 | 0.9 | 0.8 |
| 60-69 | total | 9.7 | 9.8 | 9.9 | 9.7 | 9.8 | 9.8 | 9.9 | 9.8 | 9.8 |
| | good health | 5.1 | 5.7 | 6.3 | 5.7 | 6.3 | 6.3 | 7.3 | 5.1 | 5.1 |
| | fair health | 3.3 | 3.4 | 3.3 | 3.1 | 2.8 | 3.0 | 2.4 | 3.6 | 3.8 |
| | bad health | 1.3 | 0.7 | 0.3 | 0.9 | 0.7 | 0.6 | 0.2 | 1.1 | 1.0 |
| 65-74 | total | 9.5 | 9.7 | 9.8 | 9.6 | 9.6 | 9.7 | 9.8 | 9.6 | 9.7 |
| | good health | 4.3 | 5.0 | 5.7 | 5.0 | 5.6 | 5.7 | 6.8 | 4.3 | 4.3 |
| | fair health | 3.6 | 3.9 | 3.8 | 3.4 | 3.2 | 3.4 | 2.8 | 3.9 | 4.2 |
| | bad health | 1.5 | 0.8 | 0.4 | 1.1 | 0.8 | 0.7 | 0.3 | 1.3 | 1.2 |
| 70-79 | total | 9.2 | 9.5 | 9.7 | 9.3 | 9.4 | 9.5 | 9.7 | 9.3 | 9.5 |
| | good health | 3.6 | 4.3 | 5.0 | 4.3 | 4.9 | 4.9 | 6.2 | 3.6 | 3.6 |
| | fair health | 3.8 | 4.2 | 4.2 | 3.7 | 3.5 | 3.7 | 3.1 | 4.2 | 4.5 |
| | bad health | 1.8 | 1.0 | 0.5 | 1.3 | 1.0 | 0.8 | 0.4 | 1.6 | 1.4 |
| 65+ | total | 22.1 | 26.3 | 30.2 | 23.0 | 24.0 | 25.4 | 28.7 | 24.0 | 25.7 |
| | good health | 7.9 | 10.2 | 12.7 | 9.8 | 11.8 | 12.1 | 16.7 | 8.1 | 8.2 |
| | fair health | 9.3 | 12.5 | 15.1 | 9.5 | 9.4 | 10.7 | 10.6 | 11.0 | 12.6 |
| | bad health | 4.8 | 3.6 | 2.4 | 3.7 | 2.8 | 2.7 | 1.3 | 4.9 | 4.8 |
| 70+ | total | 18.0 | 21.9 | 25.6 | 18.8 | 19.7 | 21.1 | 24.1 | 19.7 | 21.4 |
| | good health | 5.8 | 7.7 | 9.8 | 7.4 | 9.1 | 9.3 | 13.4 | 5.9 | 6.0 |
| | fair health | 7.9 | 11.0 | 13.5 | 8.1 | 8.1 | 9.3 | 9.5 | 9.4 | 10.9 |
| | bad health | 4.3 | 3.3 | 2.3 | 3.3 | 2.5 | 2.4 | 1.2 | 4.5 | 4.4 |

*Figure A1: Response of the model with and without recovery to a halving of different parameter-values*

Males




Females

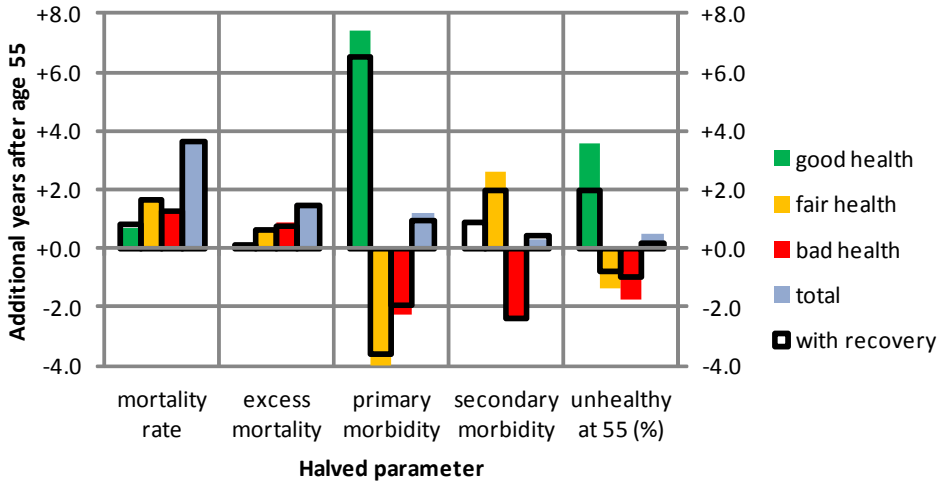


*Table A1: Scenario results for the model with recovery (result without recovery in brackets)*

| | | 2009 | 2059 Effective Treatment | | Less Effective Treatment | | Effective Prevention | | Less Effective Prevention | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *years* | | | | | | | | |
| Males | | | | | | | | | | |
| | lifeyears 55+ | 25.1 | 34.3 | (34.2) | 27.7 | (27.7) | 33.2 | (33.1) | 29.0 | (28.9) |
| | in good health | 13.2 | 20.8 | (19.6) | 17.8 | (17.7) | 23.9 | (23.4) | 14.8 | (14.0) |
| | fair health | 8.2 | 11.8 | (12.8) | 7.8 | (7.9) | 8.3 | (8.7) | 10.8 | (11.3) |
| | bad health | 3.6 | 1.6 | (1.8) | 2.1 | (2.0) | 1.0 | (1.0) | 3.4 | (3.7) |
| | unhealty years | 11.8 | 13.5 | (14.6) | 9.9 | (9.9) | 9.3 | (9.7) | 14.2 | (14.9) |
| Females | | | | | | | | | | |
| | lifeyears 55+ | 31.0 | 40.0 | (39.8) | 33.0 | (33.1) | 38.2 | (38.3) | 35.0 | (34.9) |
| | in good health | 13.3 | 20.6 | (19.4) | 18.2 | (18.3) | 24.4 | (24.3) | 14.6 | (13.8) |
| | fair health | 11.9 | 16.8 | (17.7) | 11.5 | (11.6) | 12.3 | (12.5) | 15.2 | (15.6) |
| | bad health | 5.7 | 2.5 | (2.7) | 3.4 | (3.2) | 1.6 | (1.5) | 5.2 | (5.5) |
| | unhealty years | 17.6 | 19.3 | (20.4) | 14.9 | (14.8) | 13.8 | (14.0) | 20.4 | (21.2) |

There is general agreement that life expectancy will continue to increase across European countries. There is less agreement about the extent to which the additional life years will be spent in good or poor health. This paper presents four scenarios of changes in the numbers of years spent in good and poor health for a typical high-income European country based on stylized facts. We estimate the effects of prevention and treatment on healthy life expectancy at age 55 by using a multistate model including three health states: good, fair and bad health. The scenarios show that improved prevention either due to medical progress or due to healthier lifestyles leads to a much larger increase in healthy life expectancy than in total life expectancy. The main effect of better treatment is extended life. Three out of four scenarios imply that the future health status of the older working age population and the younger retirees would not be adversely affected by raising the retirement age by 5 years over a period of 25 years.

The Netherlands Interdisciplinary Demographic Institute (NIDI) is an institute for the scientific study of population. NIDI research aims to contribute to the description, analysis and explanation of demographic trends in the past, present and future, both on a national and an international scale. The determants and social consequences of these trends are also studied.

NIDI is a research institute of the
Royal Academy of Arts and Sciences (KNAW).