Netspar

Network for Studies on Pensions, Aging and Retirement

NETSPAR INDUSTRY SERIES

Do life expectancy projections need to account for the impact of smoking?

Frederik Peters
Johan Mackenbach
Wilma Nusselder

DESIGN 52

Frederik Peters, Johan Mackenbach en Wilma Nusselder

Do life expectancy projections need to account for the impact of smoking?

DESIGN PAPER 52

NETSPAR INDUSTRY PAPER SERIES

Design Papers, part of the Industry Paper Series, discuss the design of a component of a pension system or product. A Netspar Design Paper analyzes the objective of a component and the possibilities for improving its efficacy. These papers are easily accessible for industry specialists who are responsible for designing the component being discussed. Design Papers are published by Netspar both digitally, on its website, and in print.

Colophon
March 2016

Design
B-more Design

Lay-out
Bladvulling, Tilburg

Printing
Prisma Print, Tilburg University

Editors
Frans Kooymans
Netspar

CONTENTS

Affiliations
Frederik Peters – Erasmus University Rotterdam
Johan Mackenbach – Erasmus University Rotterdam
Wilma Nusselder – Erasmus University Rotterdam

Acknowledgements
We thank Anja de Waegenaere and Fanny Janssen for their valuable advice and comments on an earlier version of this paper.

DO LIFE EXPECTANCY PROJECTIONS NEED TO ACCOUNT FOR THE IMPACT OF SMOKING?

Summary

In the past, gains in life expectancy have been consistently underestimated, resulting in a considerable longevity risk that jeopardizes the financial stability of pension funds, life insurers, and public budgets. The goal of this paper is to assess whether consideration of the distorting impact of smoking on mortality trends helps to obtain more reliable projections of life expectancy and thus reduces the longevity risk. For this purpose, we review the international literature on that topic and illustrate the impact of smoking on mortality trends and projections, using the Netherlands as an example. In this context, we compare and evaluate the outcomes of the most recent projection models of the Dutch Actuarial Association (AG) and Statistics Netherlands (CBS) in 2014, which differ in their treatment of smoking. Our results confirmed earlier studies in other countries, which demonstrated that non-smoking trends in life expectancy were more linear and more similar among men and women than all-cause mortality trends in life expectancy. Projections of Dutch life expectancy that accounted for the impact of smoking were less sensitive towards the choice of the fitting period and thus resulted in more coherent estimates for men and women. The multi-country projection models of AG and CBS arrived at compa-

rable outcomes in 2060 as an isolated Dutch projectionwhere smoking-associated mortality was removed . Based on the findings presented in the international literature and our own results, we clearly suggest that smoking should be taken into account to avoid implausible and diverging long-run projections. However, taking smoking into account involves costs, particularly due to additional model assumptions. The comparison of the outcomes of the AG and CBS models suggests that modelling mortality trends simultaneously for a group of countries potentially represents a parsimonious and generic alternative to explicitly modelling smoking. Further studies should test this hypothesis in more detail.

1. Introduction

Reliable projections of life expectancy are becoming increasingly important since the costs of pensions, healthcare and life insurance products depend to a large extent on the probability that people reach very high ages. The uncertainty around this probability, termed as the "longevity risk", affects the capital requirements of insurance companies and pension funds to ensure their solvency, aside from the risks arising from the stock markets and interest rates (Hári, De Waegenaere et al. 2008). Particularly sudden and unexpected changes in mortality probabilities over time, termed as "mortality shocks", pose a threat to companies in this sector as such a risk is often not covered by adequate capital reserves. Moreover, ongoing increases in life expectancy challenge the sustainability of public budgets required for the payment of state pensions, fueling debates about the increase of the statutory retirement age.

In general, for most of the Western world the changes in mortality probabilities developed steadily in the past. Trends could thus be modeled easily by means of simple extrapolation. For this reason statistical offices in many European countries based their forecasts of life expectancy for many years on variants of the Lee-Carter model, one of the most popular extrapolative forecasting approaches (Stoeldraijer, Duin et al. 2013).

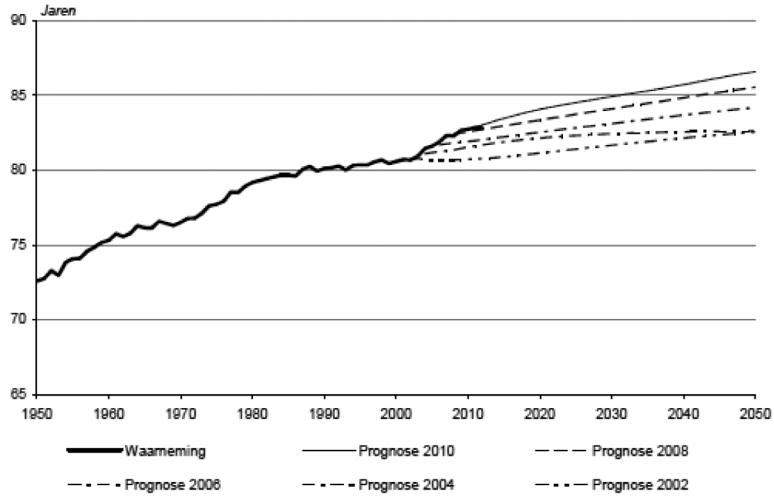
However, the seemingly easy task of predicting life expectancy trends repeatedly failed in the past – despite its so steadily and linearly evolving past trend – usually due to further longevity gains being considerably underestimated (Keilman 2008). In the Netherlands this failure dates back to the 17th century, where Johannes Hudde demonstrated that inhabitants of Amsterdam lived longer than expected, causing the price of life annuities

sold by the city government to turn out to be much too low (Ham 2005). More than three centuries later, a similar situation occurred when the Actuarial Association (*Actuarieel Genootschap*, AG) realized that the mortality probabilities in its 2005 projection table were much too pessimistic (Genootschap 2010). In fact, life expectancy gains in the Netherlands accelerated rapidly since 2001 after restrictions on hospital budgets were relaxed (Mackenbach, Slobbe et al. 2011, Peters, Nusselder et al. 2015).

This sharp increase in life expectancy was neither anticipated by the actuaries nor by official estimates of Statistics Netherlands (*Centraal Bureau voor de Statistiek*, CBS). For instance, the life expectancy predicted in 2000 to be reached by Dutch women in 2050 (83 years) was already surpassed in 2013. As depicted in Figure 1, every new official estimate of Dutch life expectancy – performed every two years by Statistics Netherlands (CBS) – represents a considerable upward revision of the preceding estimate (Janssen 2014). The most recent estimate, published in 2014, expects a more than five year larger gain in Dutch life expectancy than was the case in 2000 (Janssen 2014). But even the apparently much more optimistic estimate of 88.5 years for life expectancy of Dutch women in 2050 may actually turn out to be too pessimistic, given that such a high value is almost reached by Japanese women today.

The failure to establish reliable projections of life expectancy poses a risk to the pension and life insurance sector, termed "longevity risk". In case of an underestimation of the progress in life expectancy, pension funds must pay life annuities longer than originally budgeted, thereby negatively impacting their solvency and possibly resulting in bankruptcy. Likewise, with a too pessimistic forecast of their expected lifespan, individuals are likely not to invest sufficiently in private pension plans. With an over-

Figure 1. Biannual official projections of Statistics Netherlands (CBS) of female Dutch life expectancy at birth between 2000 and 2010. Source: (Stoeldraijer, van Duin et al. 2013)



estimation of the gain in life expectancy, the pension sector and individuals may decide on more austere measures than strictly needed.

In the Netherlands, the longevity risk has been typically higher than in other countries because its mortality trends deviated from the general pattern of a steady mortality decline with longer periods of slow progress in life expectancy followed by a more rapid progress recently (Janssen, Nusselder et al. 2003, Mackenbach, Slobbe et al. 2011). Thus, there are no stable historical Dutch mortality trends that could be directly extrapolated into the future. This extrapolation problem was highlighted already in 1971 by the famous demographer Nathan Keyfitz. He noted that "as long as a series changes uniformly, extrapolation will give a perfectly good forecast" (Keyfitz 1971). However, if turning points

in mortality time series occur – as was the case in the Netherlands –, then, according to Keyfitz, an adequate forecast "...requires a model incorporating the mechanism that causes the turning point" (Keyfitz 1971).

Since it was realized that Dutch trends in life expectancy fundamentally differed from those observed in other countries, researchers were hunting for the mechanism(s) that caused the deviation. Until today this hunt has been only partially successful. So far there is only consensus that at least one factor can be taken into account when it comes to predicting Dutch life expectancy: the distorting impact of the smoking epidemic (Janssen, van Wissen et al. 2013). Contrary to most other factors influencing mortality trends, information on smoking has the unique characteristic that it meets Keyfitz's condition "to predict the demographic future before the future happens" so that future trend changes could be anticipated (Keyfitz 1971). This is because for smoking – contrary to most other mortality risk factors – there is a clear causal link to mortality, there are reliable approaches to quantify its impact, and the distorting effect on mortality trends follows a regular pattern (Bongaarts 2014). Due to the delay of the effect of current smoking on mortality by about 25–30 years, information on that risk factor could indeed help to anticipate future trend changes.

Despite the important impact of smoking on mortality trends, actuarial life tables – such as the one published by the AG – ignored its influence so far, thereby potentially increasing the longevity risk considerably. For this reason, this paper seeks to answer the question whether smoking should be taken into account in actuarial mortality projections to reduce the longevity risk. We therefore review the international literature on this topic and then demonstrate the effect that the smoking epidemic has

had both for past mortality trends and future projections. Against this background, we finally compare the outcomes of the most recent projection of the AG, which did not account for smoking, with a projection outside of the actuarial field obtained by the CBS, which explicitly modelled the impact of smoking.

2. Theory: Why care about smoking?

2.1 The relevance of smoking as a mortality risk factor

Smoking is much more than a normal mortality risk factor. Unlike for other factors, there exists strong evidence of a causal link between tobacco smoking and death, and it thereby represents the "single most important preventable cause of premature mortality" (Rogers, Hummer et al. 2005). The World Health Organization estimated that during the twentieth century about 100 million people died worldwide of causes related to smoking, whereas for the twenty-first century as many as one billion deaths are held possible (World Health Organization 2008). The risk for smokers to die prematurely compared to non-smokers is about three times higher. Smoking is not only the dominant cause of lung cancer but is also strongly linked to many other cancers and to virtually every respiratory and cardiovascular disease (Doll, Peto et al. 1994, Doll, Peto et al. 2004, US Surgeon General 2014). The life expectancy of smokers is impaired by up to ten years compared to people who have never smoked (US Surgeon General 2014). There is a long time lag of up to 30 years for the harms of endured smoking but also for the benefits of smoking cessation to come to light, (Lopez, Collishaw et al. 1994, Oza, Thun et al. 2011). This means that the currently observed smoking-associated mortality roots in behavior of decades ago, so that the current smoking prevalence already determines smoking-associated deaths for the coming decades. Finally, a substantial fraction of all deaths could be directly attributed to smoking. Currently, this amounts to about a quarter of all male deaths and about an eight of all female deaths worldwide, lowering life expectancy on average by 2.4 years for men and 1 year for women (Rentería, Jha et al. 2015). In many Western countries, the smoking epidemic

has had a disastrous impact on life expectancy. For instance in Denmark and the USA, the loss in life expectancy at age 40 due to smoking amounted up to 4 years for men and 3 years for women (Rentería, Jha et al. 2015).

2.2 Two milestones that pave the way for inclusion of smoking in mortality projections

In 1992 two seminal papers were published that revolutionized the state of research in their respective fields, paving the way for the inclusion of smoking in mortality projections. Initially published for different goals, about two decades later, in 2013, the synthesis of both articles formed the new modern paradigm in the research on the projection of mortality trends, particularly emphasizing the merit of accounting for the impact of smoking. The first paper, authored by Ron Lee and Lawrence Carter, demonstrated that the central time trend of log-transformed age-specific mortality rates "declines at a roughly constant rate and has a roughly constant variability" (Lee and Carter 1992), allowing a simple extrapolation of such trends into the future (see Box 1). Until today the approach proposed by Lee and Carter, i.e. to decompose the matrix of mortality rates over time in an age component and an age-time interaction, is referred as the "gold standard" of mortality projection and often used as a benchmark to evaluate new projection techniques (Li and Chan 2007). The advantage of the Lee-Carter model over other approaches is its simplicity, the intuitive interpretation of its parameters, and the possibility of estimating the uncertainty around the outcomes.

The second paper, authored by Richard Peto, Alan Lopez et al., provided the first indirect quantification of the total impact of smoking on mortality at a population level, based on the comparison of the observed number of lung cancer deaths in a given year and country and the expected number of lung-cancer deaths in a population of people who had never smoked (see Box 2) (Peto,

Box 1. The Lee-Carter method to extrapolate mortality rates

1. Basic assumption: A time-series of age-specific mortality rates shares a common linear time trend.
2. Fitting of a linear model with a factor for age and an age-time interaction to a matrix of mortality rates over age and time transformed by the natural logarithm.
3. Forecasting the time component of the model by using a random walk with drift.
4. Estimating 95% confidence intervals based on the error term in step 3.

Boreham et al. 1992). This represented an important innovation in the field as, prior to the publication, the damage of smoking was usually assessed on the basis of self-reported smoking prevalence, which is known to underestimate the true smoking intensity, or on the basis of cigarette sales, which does not reliably reflect the numbers of cigarettes smoked per smoker and does not discriminate smoking behavior by age and sex (Lopez, Collishaw et al. 1994). Although lung cancer itself accounts only for about a third of all smoking-associated deaths, the ratio of observed and expected lung cancer deaths represents reliable information about the cumulative damage of past smoking in a population, providing a solid basis for estimating also other causes of death due to smoking. The indirect Peto-Lopez approach enabled reliable and universal estimates of the impact of smoking on mortality, merely requiring information on lung-cancer deaths, data that were routinely collected anyway for many countries in the world within the WHO causes-of-death database (currently about 100 countries) (Mathers, Boerma et al. 2009).

The Lee-Carter approach and the Peto-Lopez approach each turned out to be useful in many applications and have been recurrently adapted and improved since their first publication.

Box 2. The Peto-Lopez Approach to estimate smoking-attributable mortality

1. Basic assumption: Lung cancer is a reliable indicator for the cumulative damage of smoking.
2. Estimation of the proportion of smokers and non-smokers that would result in the sex- and age-specific lung cancer death rate that was observed in the population of interest. For that purpose, known lung cancer death rates of smokers and non-smokers were applied, taken from the American Cancer Society Preventive Study II (CPS-II), a large prospective cohort study from the mid-1980s with more than 1 million participants.
3. Multiplication of the estimated proportion of smokers in the population of interest with relative risks of dying separately for seven different groups of causes of death (lung cancer, upper aerodigestive cancer, other cancer, respiratory disease, vascular disease, cirrhosis/accidents/violence, other medical causes), resulting in smoking-attributable fractions by sex and age.
4. The smoking-attributable fractions are multiplied by the age- and sex-specific mortality rates to get smoking-associated mortality rates and smoking-free mortality rates.

The major improvement of the Lee-Carter model was the insight that high-income countries share a common trend in the decline of mortality rates, that could be utilized to perform more robust estimations of country-specific trends (Li and Lee 2005). A major improvement over the Peto-Lopez approach, replacing the several quite arbitrary assumptions involved in the original method, was the regression-based procedure suggested by Preston et al., to estimate the total damage from smoking based on observed lung-cancer death rates (Preston, Glei et al. 2010).

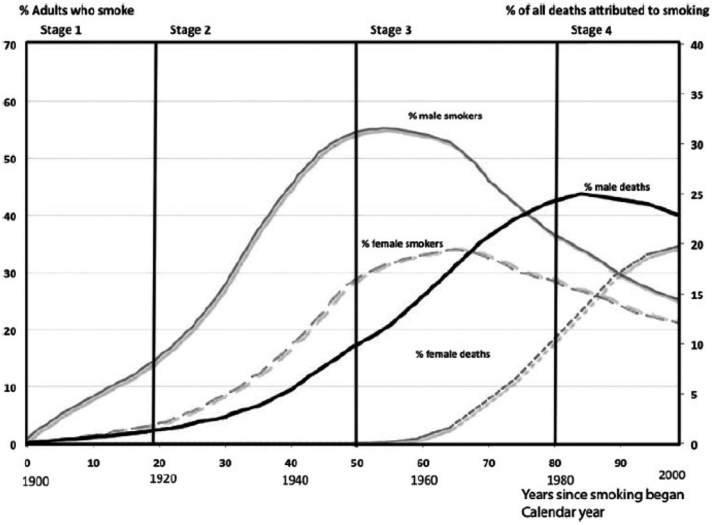
The two approaches were used in isolation from each other for quite a while until evidence was accumulating that the Peto-Lopez approach could solve a distinctive drawback of the Lee-Carter approach.

2.3 Smoking as a likely cause of irregularities in mortality trends

Although the Lee-Carter model is still one of the most widely used mortality-projection techniques, its outcomes are particularly sensitive to the choice of historical data employed to fit the model, unless the central time trend in the data is perfectly linear (Booth, Maindonald et al. 2002, Janssen and Kunst 2007). While for many countries such a linear trend has been identified, there have also been striking exceptions, among them the Netherlands, with stagnating improvements in mortality observed for males during the 1950s and 1960s and for females during the 1980s and 1990s (Janssen, Nusselder et al. 2003). Other prominent exceptions to the linear decline in mortality reported in the literature are Denmark, Norway, Australia, England and Wales and the United States, where mortality trends increased slowly if at all for longer periods of time (Juel, Bjerregaard et al. 2000, Booth, Maindonald et al. 2002, Meslé and Vallin 2006). More recently, a number of papers assessed systematically whether there were trend breaks in the series of the time index of the Lee-Carter model. Such break points were detected in virtually all high-income countries, especially during the 1970s and 1980s in males. The presence of such trend breaks poses a tough challenge for the linear extrapolation of mortality rates, requiring a clear decision on the length of the historic data included in the projection model (Janssen and Kunst 2007). For some countries, such as England and Wales, it was found that the non-linearities rooted in cohort effects posed additional challenges to the original Lee-Carter model, which only specified age and period effects (Willets 2006).

Parallel to the literature reporting irregularities in mortality trends at country level, an increasing number of articles dealt with the description of the so-called "tobacco epidemic" (Lopez, Collishaw et al. 1994) by using the Peto-Lopez approach and its

Figure 2. Stages of the cigarette epidemic in developed countries. Source: (Thun, Peto et al. 2012)



variants. A central insight of the latter literature is that mortality due to smoking evolved in a regular bell-shaped pattern, with different timing for men and women. The timing of the impact of this epidemic was subdivided into four stages. This provided a stylized description of the progression of the epidemic, characterized by a lagged spread of the prevalence in smoking in women compared to men, followed by a lagged spread of sex-specific lung-cancer mortality peaking about 30 years later than the smoking prevalence (see Figure 2) (Thun, Peto et al. 2012). The regularity of this pattern enables prediction of the future of smoking-attributable mortality, by utilizing trends in observed lung-cancer rates to complete the bell-shaped pattern of the impact of smoking for successive age groups (Stoeldraijer, Bonneux et al. 2014). The application of such models proved to be useful to resolve important research problems, such as the

dramatic increase of the gender gap in life expectancy during the second part of the 20th century, which arose from the earlier adoption of smoking by men (Luy and Wegner-Siegmundt 2014).

Interestingly, the mortality-projection world ignored the findings of the more public-health oriented literature on the impact of smoking for a long time.[1] Rather than thinking about ways to include this knowledge in projection models, forecasters tried to tackle the irregularities by including additional parameters in their models, such as additional factors for time or cohort (Renshaw and Haberman 2006). However, such more flexible models often suffered robustness problems, plus they created the additional problem of lack of clarity as to how the non-linear components of the trends should be extrapolated into the future. Another attempt to cope with the irregularities aimed at identification of the most recent linear segment of trends in mortality rates that could be linearly extrapolated (Li, Chan et al. 2011). Again, this did not provide a sufficient solution since the number of years covering the most recent linear segment is often a much too short time span to enable robust long-term projections. Furthermore, such trend-detection approaches potentially extrapolate temporary unusual trends too far into the future.

2.4 Emergence of a new modern paradigm in mortality projection

About ten years ago, demographers that experimented with the adjustment of smoking-attributable mortality in series of

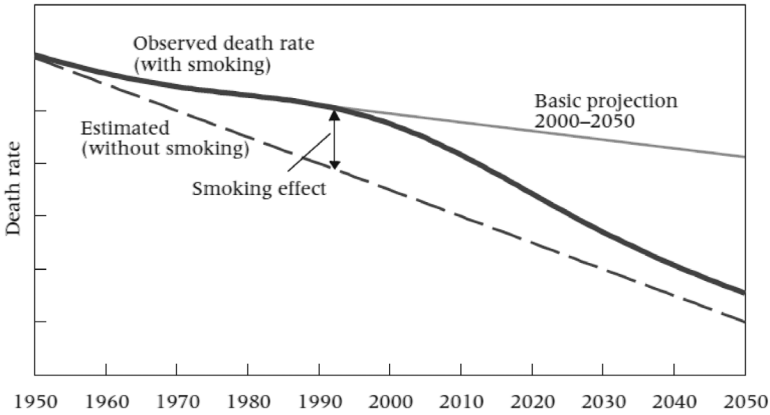
1 Except for approaches that aimed at projecting life expectancy disaggregated by cause of death, where in some cases factors driving these trends, among them smoking, were included in the model mostly in the form of more or less arbitrary assumptions about its future impact. However, the practice of mortality projection by cause of death did not gain wide acceptance due to methodological problems.

mortality rates realized that the irregular mortality trends in the group of Western countries became much more regular and more similar to each other after removal of the impact of smoking (Bongaarts 2006). Over the years evidence on the leading role of smoking to explain variations in mortality trends accumulated, partly explaining why the decline in mortality rates slowed down in females in the second part of the 20th century, why Denmark performed much worse than Sweden in terms of gains in life expectancy, and why survival among Dutch men improved faster in the 1990s than among Dutch women (Janssen, Kunst et al. 2007, Staetsky 2009, Christensen, Davidsen et al. 2010, Rostron and Wilmoth 2011).

The success of the smoking factor, in combination with its wide applicability, provoked attempts to directly include the contribution of smoking into mortality-projection models. This is undoubtedly a promising enterprise given that smoking explains non-linear trends, cohort patterns, and trend differentials among countries and between men and women (Pampel 2005, Janssen, Kunst et al. 2007, Janssen and Kunst 2007, Bongaarts 2014). Furthermore, the progression of the impact of smoking is highly regular and thus predictable, and the current prevalence of smoking – no matter if inferred directly from survey data or indirectly from excess lung-cancer mortality – already determines the smoking-associated mortality for the coming decades (Janssen and Kunst 2007, Stoeldraijer, Bonneux et al. 2014).

The basic idea of how smoking distorts the projection of mortality trends is schematically shown in Figure 3. This shows that the effect of smoking first slows down and later accelerates the otherwise perfectly linearly declining trends in mortality. If projections are based on the period during which the spread of the smoking epidemic temporarily slowed down the decline in

Figure 3. Distorting impact of smoking on the projection of mortality rates. Source: (Bongaarts 2014)



mortality, the resulting forecasts automatically become too pessimistic. Likewise, if projections are based on the periods where the abatement of the smoking epidemic temporarily accelerated the decline in mortality, the resulting forecasts become too optimistic. By contrast, the ideal projection model would extrapolate the linearly declining non-smoking mortality trend and then add to that the likely development of smoking-associated mortality (Janssen, van Wissen et al. 2013).

One of the earliest inclusions of smoking in a mortality projection was by Pampel, who applied the Peto-Lopez approach to estimate the damage from smoking to finally improve forecasts of sex-differences in mortality (Pampel 2005). Taking smoking into account revealed that in many countries a current increase in sex-gap in mortality will soon reverse since women catch up with men in terms of smoking-associated mortality. While Pampel focused on sex differentials in mortality trends, in the years following his publication various approaches targeted explicitly on

incorporating smoking in projections of life expectancy. The most important contributions are summarized in Table 1.

Bongaarts was the first to adjust mortality rates for the impact of smoking to improve long-term projections of life expectancy, arriving at more optimistic trends in particular for females (see Table 1) (Bongaarts 2006). Bongaarts' analyses demonstrated a surprising degree of similarity of trends in smoking-free senescent life expectancy among a group of 16 high-income countries. The analysis by Janssen and Kunst focused on the impact of smoking on trends in remaining life expectancy at age 80, thus at older ages (Janssen and Kunst 2007). Taking smoking into account resulted in more optimistic long-term projections of life expectancy at age 80, particularly for males. In line with the analysis of Bongaarts (2006), smoking-free mortality trends among the countries studied were more similar to each other, except for Norway.

Stewart et al. simulated the impact of changes in smoking trends and obesity on the change in life expectancy at age 18 (Stewart, Cutler et al. 2009). They found only a modest effect when taking smoking into account, probably because they did not differentiate between females and males and because they projected life expectancy only up to 2020.

Building on survey data about smoking prevalence, Wang and Preston demonstrated the usefulness of including the years spent as current smoker until age 40 as covariate in a Lee-Carter model that led to more optimistic forecasts of survival, especially for males (Wang and Preston 2009). These results, based on a direct measure of smoking intensity, were later confirmed by Preston et al. by using an indirect method based on a variant of the Peto-Lopez approach (Preston, Stokes et al. 2014).

Table 1. Approaches to incorporate smoking in the projection of mortality trends

Basic information on projection					How smoking was incorporated
Author(s)	**Year**	**Sample**	**Time Frame**	**Target Year**	**Indicator**
Bongaarts	2006	USA	1950–2000	2050	Smoking-attributable mortality (Peto/Lopez)
Janssen/Kunst	2007	7 European Countries	1950–1999	2050	Smoking-attributable mortality (Peto/Lopez)
Stewart et al.	2009	USA	1973–2005	2020	Distribution of smokers in 4 categories
Wang/Preston	2009	USA	1969–2003	2035	Years spent as current smoker at age 40
King/Soneji	2011	USA	1970–2007	2030	Current smoking prevalence
Janssen et al.	2013	Netherlands	1970–2006	2040	Smoking-attributable mortality (Peto/Lopez)
Preston et al.	2014	USA	1969–2003	2040	Years spent as current smoker at age 40, lung cancer mortality (PGW)

The idea that the current smoking prevalence helps to predict mortality several decades later was adopted by King and Soneji within a Bayesian framework (King and Soneji 2011). Due to the additional inclusion of obesity, the estimates were more optimistic only for men compared to the projection of the Social Security Administration. They were not optimistic for women, as the negative effects of the obesity epidemic counterbalanced the gains from lower damage due to smoking.

in the projection of mortality trends		Principal findings	
Data Source	**Model**	**Effect for males**	**Effect for females**
vital statistics, WHO	Extrapolation of senescent life expectancy without smoking for a group of 16 countries	+2.1 years LE(0)	+3.8 years LE(0)
vital statistics, WHO	Extrapolation of non-smoking mortality rates	+1.35 years LE(80)	+0.78 years LE(80)
Survey (NHIS 1978-2006)	Combine projected trends in distribution of smokers and relative risks of smokers to die, from survey data	+0.3 years LE(18)	
Survey (NHIS 1965-2001)	Covariate in Lee-Carter model	+22.5% better survival	+7.4% better survival
Survey (NHIS 1955-2007)	Covariate in linear regression lagged 25 years	+1.8 years higher LE(0)	none
vital statistics, WHO	Separate extrapolation of non-smoking and smoking-attributable mortality	+0.69 years gain in LE(0)	+0.24 years gain in LE(0)
Survey (NHIS 1965-2009), vital statistics (various sources 1950-2009)	Use smoking prevalence to predict lung cancer mortality to indirectly estimate smoking-attributable mortality	+1.54 years LE(40)	+0.85 years LE(40)

Recently, Janssen et al. proposed a general framework for the projection of mortality rates, combining all features of previous approaches that turned out to be advantageous over the years (Janssen, van Wissen et al. 2013). They confirmed that accounting for smoking results in more optimistic estimates of life expectancy in the long run – particularly in males – but at the same time sometimes also in less optimistic estimates in the short run – particularly in females. Moreover, their paper could be regarded as a recipe for how to deal with irregular mortality trends in

general, since the steps that it involves would also apply if other factors like smoking could be identified in the future.[2] For that reason the framework will be denoted as a "modern paradigm" in the next section of this paper (Figure 3).

The modern paradigm is a step-wise approach, where in the first step irregularities due to smoking were removed from mortality rates over a given period and for a group of countries. Although there is no consensus as to which method should be used to quantify the impact of smoking, the literature generally agrees that different approaches result in similar estimates (Bronnum-Hansen and Juel 2000, Rostron 2010, Oza, Thun et al. 2011). In their paper, Janssen et al. (2013) used a simplified version of the Peto-Lopez approach to account for the impact of smoking.

In the second step, a projection model is fitted to smoking-free mortality for a group of countries instead to the country of interest, this to prevent divergent trends in the long run. To allow for country-specific trends in the short run, this estimation is complemented by fitting a country-specific model to the country-specific residuals from the pooled model. This augmented version of the Lee-Carter model for a group of countries, enabling projection of coherent mortality trends, was suggested by Li and Lee (Li and Lee 2005).

Since each country could be situated in a different stage of the tobacco epidemic (see Figure 2), the third step involves the projection of smoking-attributable mortality separately for the country of interest. As the intensity of smoking is predominantly driven by the birth cohort and not by the calendar year, an age-

2 As explained in Chapter 2.1, smoking is a unique risk factor, and the past decades of research on determinants of mortality trends at population level have not revealed a factor of comparable quality. Particularly the established causal mechanism and the long delay between exposure and effect make smoking valuable for mortality projections.

period cohort approach was employed for this purpose (Janssen, van Wissen et al. 2013). A peculiarity in this step is that trends in smoking-associated mortality could only be projected reliably if the population of interest had already surpassed the peak of the impact of the smoking epidemic. In the absence of this peak, additional assumptions are necessary. However, it has been demonstrated that even very crude assumptions work better than ignoring smoking (Bongaarts 2014).

In the final step, smoking-free and smoking-related mortality projections were combined to arrive at projections of all-cause mortality rates. The different steps are summarized in Box 3 below.

Box 3. Steps involved in projecting mortality according to the modern paradigm of Janssen et al. 2013

1. Remove irregularities due to smoking for a group of countries.
2. Project regular trends in non-smoking mortality for a group of countries.
3. Project irregular smoking-related mortality trends separately for the country of interest.
4. Combine the non-smoking and smoking-related projection for the country of interest.

3. The case of the Netherlands

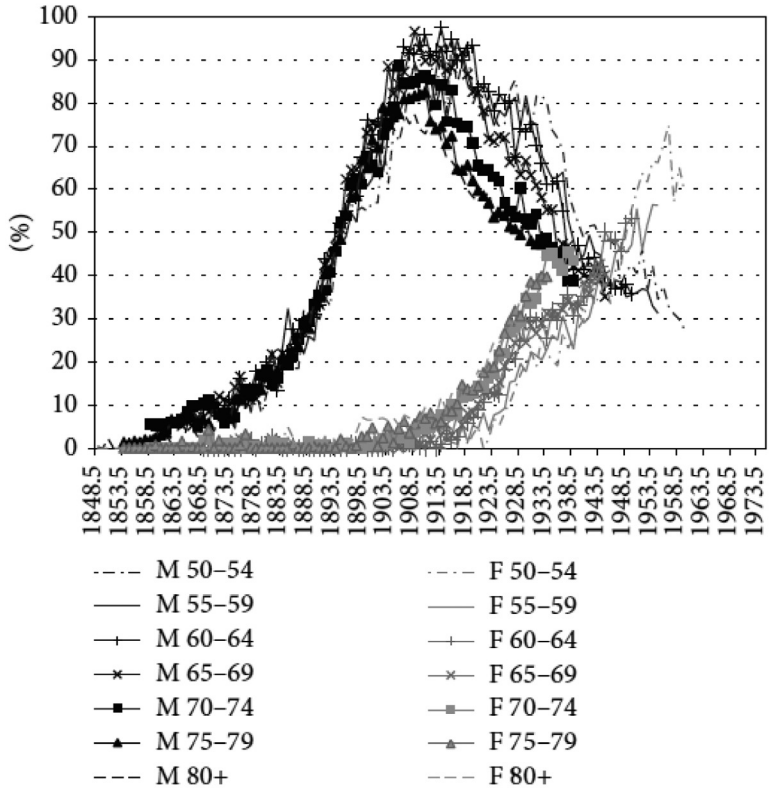
3.1 The smoking epidemic in the Netherlands and its effect on Dutch mortality trends

In the Netherlands, the smoking epidemic started among men born in the 1850s and much later among women born around 1900 (Figure 4). As predicted by the theoretical model of the smoking epidemic, the proportion of men exposed to smoking increased exponentially, reaching almost 100% for the birth cohort 1910 and subsequently declining rapidly to less than 30% for the younger cohorts. For females, the lifetime smoking exposure is still increasing, and it is less clear at which level the proportion will peak and when it will decline again (Janssen, van Wissen et al. 2013, Stoeldraijer, Bonneux et al. 2014).

To estimate the effect of the cigarette epidemic on Dutch mortality trends, we applied a recently proposed variant of the Peto-Lopez approach, termed the "Preston-Glei-Wilmoth" (PGW) approach (Preston, Glei et al. 2010). Same as the Peto-Lopez approach, the PGW approach uses observed lung-cancer mortality rates as a proxy for the intensity of smoking and applies multipliers to estimate the total damage of smoking on mortality.[3] The data we used for this purpose were lung-cancer deaths for the age groups (0, 1-4, 5-9, ... , 85-89) from the WHO Causes of Death Database, and all-cause mortality deaths and exposure for the age groups (0, 1-4, 5-9, ... , 95-99) from the Human Mortality Database (Human Mortality Database 2014). We linearly extrapo-

3 The crucial difference is that the multipliers in the PGW approach come from a regression model where lung-cancer mortality was regressed on mortality rates from other causes than lung cancer for twenty high-income countries, using data from 1950-2006. In the Peto-Lopez approach, the multipliers are based on the relative risks of smokers to non-smokers of lung-cancer mortality and several other causes of death in the Cancer Prevention Study II cohort that started in 1982 in the US.

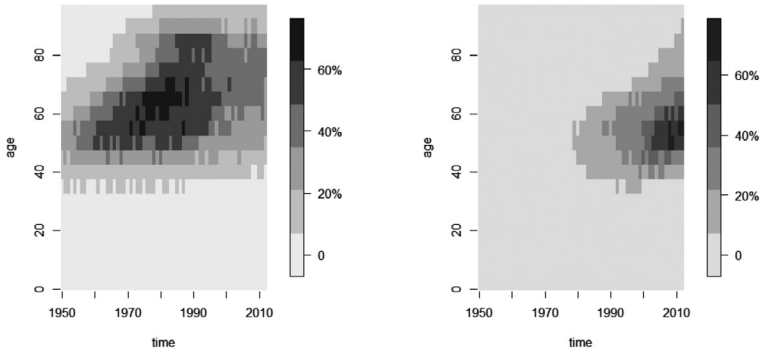
Figure 4. Lifetime smoking exposure by age and birth cohort for males (black) and females (grey). Source: (Janssen and van Poppel 2015)



lated the smoking-attributable fractions for age 90-94 and 95-99 based on the fraction at age 85-89 and assumed that the fraction is zero above age 99. The smoking-attributable fractions from the PGW approach were multiplied by the observed mortality rates resulting in smoking-free mortality rates.

The time trends of the impact of smoking on age-specific mortality rates in the Netherlands are in line with the predictions

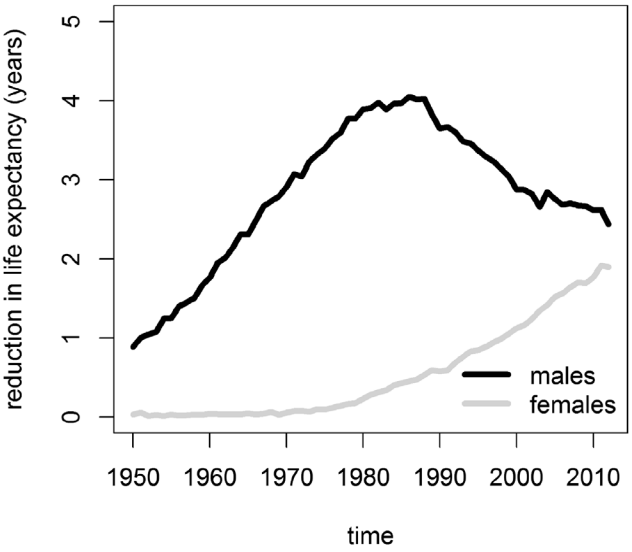
Figure 5. Percentage increase of age-specific mortality rates in Dutch males (left-hand side) and females (right-hand side) due to smoking, 1950-2012



of the theory of the smoking epidemic (Figure 5). Same as for the time trends in smoking exposure, also the time trends as to their impact on mortality vary between men and women. In Dutch males, mortality rates were elevated by smoking by more than 70% during the 1970s for the age range between 50 and 70 (left graph, Figure 5). The same impact for about the same age range occurred in women not until at least three decades later (right graph, figure 5). Thus the increase and decrease of the impact of smoking clearly operated in a cohort direction indicated by the diagonal developments in Figure 5. This figure clearly shows furthermore that the smoking epidemic is flattening out for males but is still on the rise for females.

To quantify the impact of smoking on period life expectancy, we applied life table techniques to the all-cause and smoking-free mortality rates (Preston, Heuveline et al. 2001). The resulting trends in the impact of smoking on life expectancy at birth again resemble the trends in smoking exposure shown in Figure 4. Our results showed a loss of one year of life expectancy in 1950 for

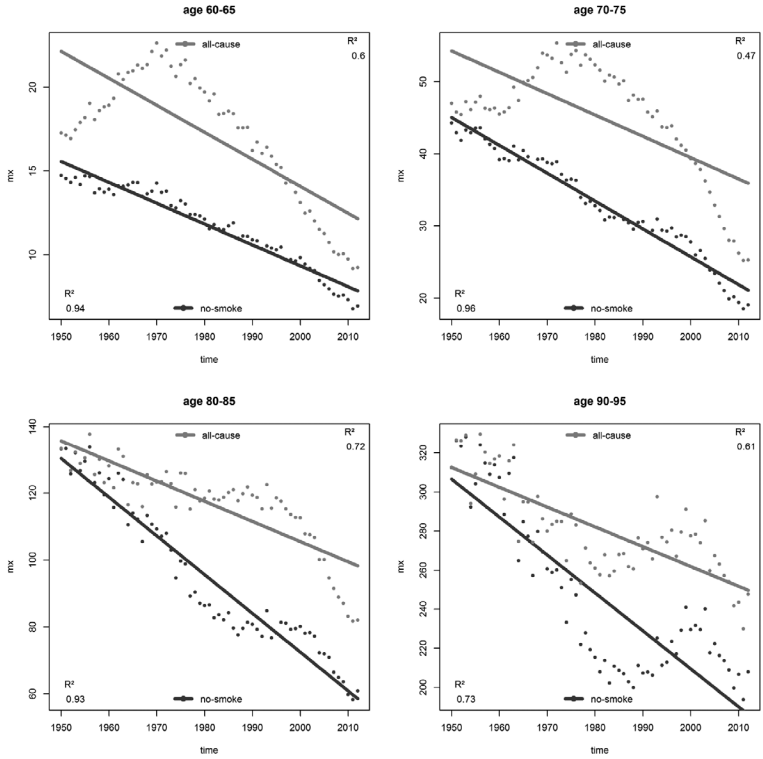
Figure 6. Impact of smoking on the reduction in life expectancy between 1950 and 2012 for Dutch males and females



men, increasing up until the 1980s to a loss of almost four years, and subsequently decreasing again to a loss of merely two years in 2009 (Figure 6). For women, life expectancy was not affected by smoking until the 1970s, but since then the cumulative damage of smoking increased rapidly to a loss of about 1.5 years of life expectancy in 2009, without any signs of peaking yet.

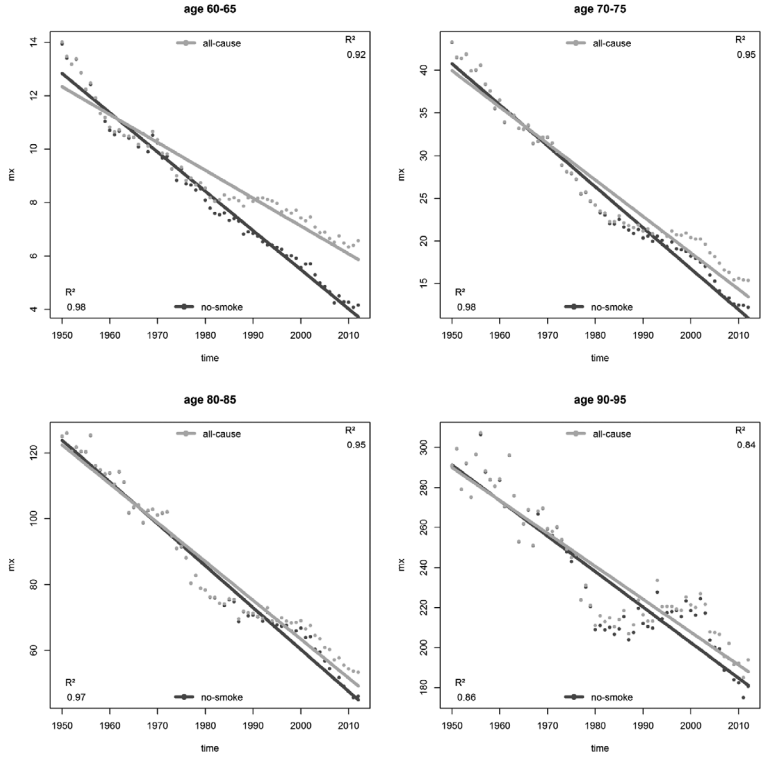
A closer look at the age-specific mortality trends for males (Figure 7a) and females (Figure 7b) provides a first hint that smoking indeed seems to be the major cause of the irregularities in mortality trends in the Netherlands. Contrary to the increase and subsequent decrease in the trend of all-cause mortality at age 60-65 and 70-75 in Dutch males, the smoking-free mortality trends developed more linearly except for this past decade, when the mortality decline accelerated. While a straight line explains

Figure 7a. Trend in male age-specific mortality rates (per 1000 persons) between 1950 and 2012 with and without the removal of smoking-associated mortality at age 60-65, 70-75, 80-85 and 90-95 in the Netherlands



merely 60% and 47% in the former case, in the latter case 94% and 96% of the variation in death rates at age 60-65 and 70-75 were explained (Figure 7a). At older ages this effect still applies, but here the removal of smoking could not fully remove the irregular mortality components, in particular the slower decrease in mortality during the 1990s and the faster decrease during

Figure 7b. Trend in female age-specific mortality rates (per 1000 persons) between 1950 and 2012 with and without the removal of smoking-associated mortality at age 60-65, 70-75, 80-85 and 90-95 in the Netherlands



the 2000s. For females, the trends were already more linear in all-cause mortality, plus the impact of the smoking epidemic occurred later in time and with a smaller magnitude than for males (Figure 7b). Again a steeper mortality decline is visible after 2001.

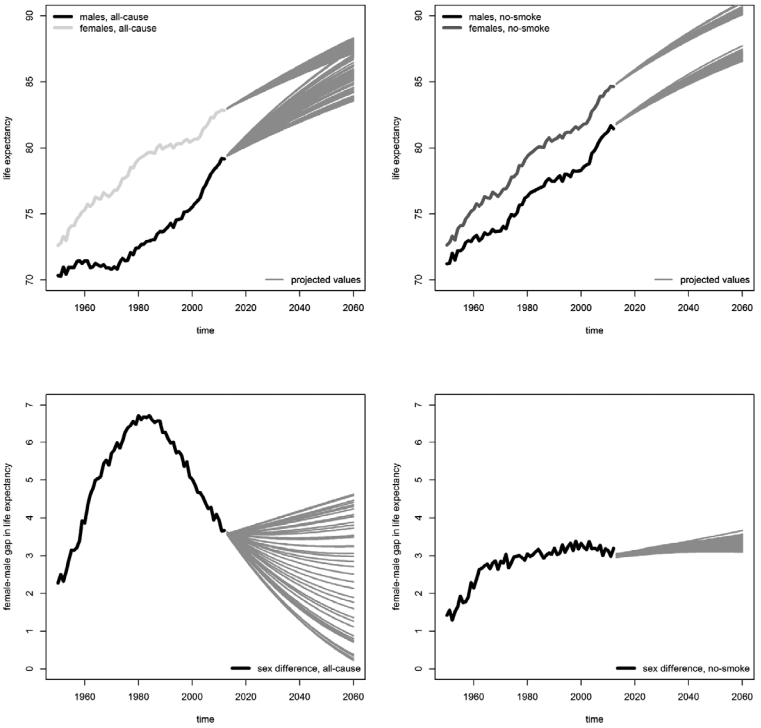
Table 2. Fit of a linear model to the trends in age-specific mortality rates between ages 35-39 and 95-99 and life expectancy at birth (PLE) in the Netherlands, 1950-2012

Indicator	age	Males			Females		
		all-cause	no-smoke	diff	all-cause	no-smoke	diff
age-specific mortality rates	35-39	89%	87%	-2%	86%	88%	2%
	40-44	86%	85%	-1%	88%	94%	6%
	45-49	80%	82%	2%	87%	96%	9%
	50-54	80%	89%	9%	87%	97%	10%
	55-59	71%	92%	21%	90%	98%	8%
	60-64	60%	94%	34%	92%	98%	6%
	65-69	49%	96%	47%	93%	98%	5%
	70-74	47%	96%	49%	95%	98%	3%
	75-79	57%	96%	39%	95%	97%	2%
	80-84	72%	93%	21%	95%	97%	2%
	85-89	76%	83%	7%	92%	93%	1%
	90-94	61%	73%	12%	84%	86%	2%
	95-99	42%	56%	14%	58%	60%	2%
PLE	0	83%	97%	14%	97%	98%	1%

Table 2 summarizes the effect of the removal of smoking on the trends in mortality rates and life expectancy. It shows the R-squared of the fit of a linear model to the trend in age-specific mortality rates and life expectancy between 1950 and 2012. Except for the very young age groups in males, in every case the trends in smoking-free mortality developed more linearly over time than trends in all-cause mortality. In particular between age 50 and 80 the smoking-free trends evolved quite linearly both in males and females. At older ages the removal of smoking was apparently less successful to explain irregularities.

Not only past trends in mortality were heavily impacted by smoking, also mortality projections were greatly influenced by

Figure 8. Trends in Dutch male (top, left) and female (top, right) life expectancy at birth and the female-male gap between 1950 and 2012 and projected trends until 2060, including the effect of smoking (bottom, left) and with smoking-associated mortality removed (bottom, right), demonstrating the effect of restricting the start of the fitting period stepwise by one year from 1950 to 1990 (grey lines)



Note: Mortality rates were truncated at age 100 in all models

this factor. That is because any Lee-Carter-based projection model merely extrapolates past trends, observed for a restricted period of time, into the future (Figure 8). We simulated the consequences

of choosing different fitting periods by fitting Lee–Carter models to data in the 1950–2012 range and then removing stepwise one year until merely 1990–2012 was included in the model fit, resulting in forty different projections. This exercise demonstrated that the projection of all-cause life expectancy is, especially in males, extremely sensitive towards the choice of the fitting period (Figure 8, upper left corner). The projected level of life expectancy in 2060 varies between 82 and 87 in males but only between 87 and 88 in females. This translates into a difference between male and female life expectancy in 2060, ranging between merely one year and almost six years, thus either resulting in an again increasing male–female gap in life expectancy or in an almost full closure of the gap until 2060 (Figure 8, lower left). After the impact of smoking was removed, the resulting projections became much more robust to the choice of the fitting period and more coherent among men and women (Figure 8, upper right). The estimated levels of life expectancy in 2060 vary only little at a value of about 86 years in males and about 89 years in females, irrespective of the choice of the fitting period. Interestingly, the gap between Dutch men and women, when adjusted for the impact of smoking, is projected to remain roughly constant between about 1970 and 2060 at a value of three years (Figure 8, lower right). This indicates that the widening and subsequent narrowing of the male–female gap in Dutch life expectancy is apparently almost completely driven by the impact of smoking.

3.2 Two competing Dutch projection models

The first official Dutch life expectancy projection that followed the modern paradigm was published by the *Rijksinstituut voor Volksgezondheid en Milieu* (RIVM) in 2010 (Luijben and Kommer 2010). Later this approach was also adopted by Statistics

Netherlands (CBS) in their 2012 and 2014 projections of life expectancy (Stoeldraijer, van Duin et al. 2013, van Duin and Stoeldraijer 2014). The removal of smoking-attributable mortality in the Netherlands did not reveal an underlying perfectly linearly evolving trend. Although adjusting for smoking resulted in more linear trends in female Dutch life expectancy, the trends in Dutch males became less linear, and in both cases there was a clear acceleration in the progress of life expectancy after about 2002 (see observed values for 1980–2009 in Figure 9 and Figures 7a and 7b) (Mackenbach, Slobbe et al. 2011, Stoeldraijer, van Duin et al. 2013, Janssen, Rousson et al. 2015). For this reason, step 2 of the modern paradigm (estimating non-smoking mortality for a group of countries) turned out to be especially important to project the irregular Dutch mortality trends without too much divergence to other Western countries for the long run. Due to the inclusion of experiences of other countries, the resulting projections of Dutch life expectancy were much more optimistic than previous official projections by CBS (see Figure 1). At the same time, the separate smoking-based projections took into account the temporary slower increase of female life expectancy in the near future due to the still growing impact of the smoking epidemic.

Applying a new approach, the AG published its AG2014 projection tables in 2014 (Acturieel Genootschap 2014). Contrary to earlier models, where improvement factors in Dutch mortality rates were extrapolated into the future (Peters, Nusselder et al. 2012), the new approach applied the Li-Lee technique to fit a Lee-Carter model, first simultaneously to a group of countries and second to the country-specific residuals of the first step. The Li-Lee technique involves the assumption that, in the long run, the rates of mortality improvement are similar among all countries. Another new feature is the much longer horizon of the projection, now

Table 3. Comparison of the approaches to project Dutch life expectancy of AG and CBS in 2014

Specifications	AG2014	CBS2014
Time span	1970–2013	1970–2013
Sample	15 countries	12 countries
	GDP above European average	Western Europe
Forecast horizon	2184	2060
Modelling of sex	yes (separately)	yes (separately)
Modelling of country	yes (common)	yes (common)
Modelling of smoking	No	yes (separately)

ranging until 2184 so that trends in cohort life expectancies can be estimated.

Despite the consistent findings in earlier literature on the relevance of including information on smoking, the AG did not account for this even though it did admit that "it is generally known that smoking has a negative effect on life expectancy" (Acturieel Genootschap 2014). Nevertheless, both CBS and AG also took mortality trends of other countries into account to model mortality in the Netherlands. Thus, by comparing the predictions of AG2014 with those of CBS2014, one could directly assess the consequences of including smoking and thereby answering the question whether it matters after all – at least for the Netherlands.

The set-up of the competing Dutch projection models is compared in Table 3. Aside from the differing decisions about modelling of smoking, the two projections also differ slightly with respect to the groups of countries included in their analyses. While the CBS simply focused on Western Europe, the AG used average GDP in Europe as a threshold to exclude countries that differ too much from the Netherlands in terms of economic devel-

opment, i.e. Southern European countries. Since both approaches took many other countries into account, the small differences in composition of the sample are unlikely affect the projections substantially.

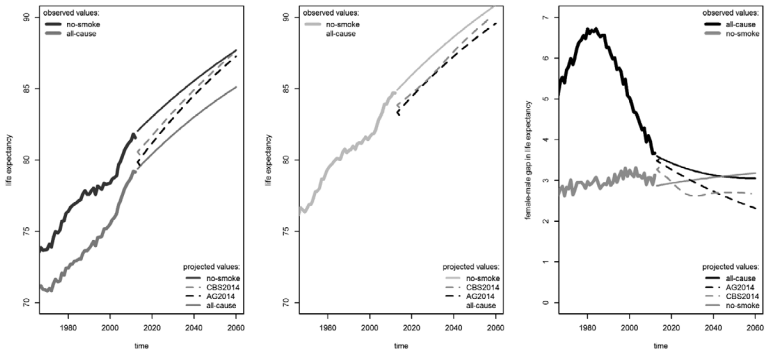
3.3 Assessing differences in model outcomes

To assess the model outcomes, we calculated period life expectancy by using the age-specific death probabilities published by AG2014, CBS2014, and the observed values from the Human Mortality Database 1970–2012 (Human Mortality Database 2014). We truncated all of the data at age 100 so that the more unstable patterns of mortality at higher ages do not affect the comparison of the models.[4] In addition, all outcomes were evaluated only up to 2060, to which year both projections provided estimates. First, we compared the AG2014 and CBS2014 model outcomes with respect to life expectancy at birth and the male-female gap in life expectancy at birth to a benchmark. In this benchmark, Lee-Carter models were fitted to the same age and time range, using Dutch data on all-cause mortality and smoking-free mortality based on the PGW approach (for details see Appendix A1–A3). Second, differentials of the AG2014 and CBS2014 models in period life expectancy at birth were contrasted by indicators that are more relevant for the pension and insurance sector, namely remaining period life expectancy at age 65, remaining cohort life expectancy at age 65, and the present value of future pension payments at age 65 (for details see Appendix A4).

Figure 9 presents a comparison of the model outcomes of the AG2014 and CBS2014 approaches with the benchmark models,

4 From age 90 onwards, the AG approach estimates the schedule of age-specific mortality rates based on the Kannisto method, which may result in larger differences from the CBS approach at higher ages.

Figure 9. Comparison of model outcomes of the projections AG2014 and CBS2014 and of a Lee-Carter model with (no-smoke) and without (all-cause) adjusting for smoking, showing life expectancy for males (left), life expectancy for females (center) and sex-differences in life expectancy (right)



Note: Mortality rates were truncated at age 100 in all models

where the impact of smoking was ignored (all-cause) and where smoking-associated mortality was removed beforehand (no-smoke). The projected values of life expectancy of the AG2014 and CBS2014 range between this upper and lower benchmark, exhibiting striking similarities. Compared to the lower benchmark, both approaches are in the long run much more optimistic over time, even converging to the upper benchmark for males at the end of the projection horizon. In addition, the CBS approach seems to be slightly more optimistic than that of the AG in general, but the differences are small compared to the much larger difference between the upper and lower benchmark.

The right hand side of Figure 9 shows the development of the male-female gap, indicating the strong impact of smoking on trends in sex-specific life expectancy in the past. While the gap

remained constant at a level of about three years in smoking-free mortality trends, the gap increased to almost seven years around 1980, subsequently declining fast to less than four years. The projections based on the high and low benchmark involve a value of the male-female gap in 2060 of about three years. By contrast, the CBS and AG models predict a steeper narrowing of the male-female gap in life expectancy below the benchmark values. While the gap according to the AG2014 model keeps narrowing up until 2060 to almost two years, the decrease in the gap according the CBS2014 model levels off around the year 2030 at a value of about 2.5 years.

To study the seemingly small differences in model outcomes of AG2014 and CBS2014 as expressed by period life expectancy at birth in more detail, we also used alternative indicators that focus on mortality beyond age 65, both in a period and cohort perspective (Table 4).

In terms of period life expectancy at birth, the differences between the two projections never exceeded one percent in 2014-2060, with slightly higher values for the CBS model (Table 4, panel A). In 2060 the values differed by merely 0.4 years for males and 0.6 years for females. These absolute differences were about the same for remaining life expectancy at the age of 65, where the CBS model predicts a 0.4 years higher life expectancy for males and a 0.2 years higher life expectancy for females (Table 4, panel B). The relative differences when using this indicator were slightly higher, ranging up to 3.4%, but this is mainly due to the fact that the values of remaining life expectancy at the age of 65 are much smaller than at birth. While CBS always predicts a higher life expectancy at birth than AG, the AG model is more optimistic for remaining life expectancy at age 65 in 2030 for females. However, in the long run CBS is more optimistic both for females and males.

Table 4. Projected period life expectancy at birth (Panel A), remaining period life expectancy at age 65 (Panel B), remaining cohort life expectancy at age 65 (Panel C) and the present value of future pension payments at age 65 (Panel D) for Dutch males and females according to the AG and CBS 2014 models for selected calendar years

A: period life expectancy at birth							
Sex	**Approach**	**2014**	**2020**	**2030**	**2040**	**2050**	**2060**
Males	AG2014	79.7	80.8	82.6	84.2	85.7	87.0
	CBS2014	80.4	81.4	83.1	84.6	86.1	87.4
	Difference	-0.9%	-0.7%	-0.6%	-0.5%	-0.4%	-0.4%
Females	AG2014	83.2	84.1	85.6	87.0	88.3	89.4
	CBS2014	83.7	84.4	85.7	87.3	88.8	90.0
	Difference	-0.6%	-0.3%	-0.1%	-0.3%	-0.6%	-0.7%

B: remaining life expectancy at age 65							
Sex	**Approach**	**2014**	**2020**	**2030**	**2040**	**2050**	**2060**
Males	AG2014	18.2	19.0	20.2	21.4	22.5	23.6
	CBS2014	18.8	19.5	20.7	21.9	23.0	24.0
	Difference	-3.4%	-2.6%	-2.2%	-2.0%	-1.8%	-1.8%
Females	AG2014	21.0	21.8	22.9	23.9	24.9	25.8
	CBS2014	21.5	21.9	22.6	23.8	25.0	26.0
	Difference	-1.9%	-0.5%	1.1%	0.4%	-0.5%	-1.0%

C: remaining cohort life expectancy at age 65							
Sex	**Approach**	**1970**	**1980**	**1990**	**2000**	**2010**	**2020**
Males	AG2014	14.7	15.3	16.7	18.9	20.4	21.8
	CBS2014	14.7	15.3	16.7	19.1	21.0	22.3
	Difference	0.0%	0.0%	0.0%	-1.4%	-2.8%	-2.6%
Females	AG2014	19.3	20.1	20.9	22.2	23.4	24.6
	CBS2014	19.3	20.1	21.0	22.5	23.4	24.2
	Difference	0.0%	0.0%	-0.4%	-1.3%	0.1%	1.3%

D: present value of future pension payments at age 65							
Sex	**Approach**	**1970**	**1980**	**1990**	**2000**	**2010**	**2020**
Males	AG2014	11.7	12.1	12.9	14.3	15.1	15.9
	CBS2014	11.7	12.1	12.9	14.3	15.5	16.2
	Difference	0.0%	0.0%	0.0%	-0.3%	-2.2%	-2.0%
Females	AG2014	14.5	15.0	15.4	16.2	16.8	17.4
	CBS2014	14.5	15.0	15.4	16.3	16.8	17.2
	Difference	0.0%	0.0%	-0.3%	-0.9%	0.2%	1.2%

Note: Mortality rates were truncated at age 100 in all models

By switching from the period to the cohort perspective in life expectancy, the calendar years for which projections are available move back in time (Table 4, panel C). For instance, the computation of remaining cohort life expectancy at age 65 in 1970 requires projected values up to 2004 and in 2020 up to 2054. In such a cohort perspective, the values for remaining life expectancy at age 65 are about three years higher in 2020 than in a period perspective. Aside from this, the absolute differences between AG2014 and CBS2014 are still rather small, ranging up to 0.5 years for males and 0.4 years for females in 2020. However, for females the CBS model is slightly less optimistic than the AG model in the long run. These patterns are virtually the same when using the present value of future pension payments at age 65 as indicator. Again, CBS is slightly more optimistic for males in 2020, while AG is slightly more optimistic for females in that same year. The absolute and relative differences are even smaller than for cohort life expectancy at age 65.

4. Conclusion

Accounting for the impact of smoking has become common in international projections of life expectancy during the past decade. A consistent result of these studies has been that mortality trends became more linear and more similar among countries, thus more predictable, after the effect of the impact of the smoking epidemic was removed. Furthermore, projected trends in life expectancy were more optimistic in the long run when taking smoking into account. Thus, the current literature clearly indicates that taking smoking into account can considerably reduce the longevity risk that arises from overly pessimistic or overly optimistic projections of life expectancy.

Simulating mortality projections based on different historical periods, we analyzed the potential merits of including information on smoking-associated mortality in the Netherlands, a country where mortality trends have developed in a much more irregular way than in most other Western countries. We found that also in such a deviating country, trends in smoking-free mortality rates were more linear over time and more similar among males and females than trends in all-cause mortality rates. A further merit of modelling smoking-free mortality was that the projection outcomes depended less on the choice and length of the historical period used to fit the model. Thus, more robust and more plausible extrapolations of past mortality trends are feasible for trends in Dutch smoking-free mortality.

A comparison of the most recent mortality projections by AG, which ignored the impact of smoking, and by CBS, which took smoking into account, indicated only small differences between the projected values of life expectancy at birth in 2014-2060. This finding, which contrasts with the prior simulation exercise,

where removing the impact of smoking had huge consequences, could be explained by the fact that both the CBS and AG models took also trends of many other Western countries into account. Furthermore, the estimates of both multi-country projection models ranged between the projected values of the two benchmark models, where we projected Dutch life expectancy based on Dutch mortality rates only with and without removing the impact of smoking. Generally, the CBS model was slightly more optimistic than the AG model, except for long-term trends in cohort life expectancy at the age of 65 and the present value of future pension payments at age 65, with AG being slightly more optimistic for females. This is because the CBS model anticipates a stronger impact of the smoking epidemic on females in the near future, lowering their progress in life expectancy temporarily.

Given the evidence from the literature review and our simulation exercise, we suggest that accounting for smoking should become a standard procedure in the projection of mortality rates, as that would facilitate the management of the longevity risk, particularly because the outcomes are more robust to different choices of the historical period. An approach for taking smoking into account is readily available, as suggested by Janssen et al. (2013), that is, combining the concept of quantifying the impact of smoking on mortality trends with the idea that mortality rates could be linearly extrapolated into the future if a stable underlying time trend could be uncovered. This concept could be applied both for the general population, but also for the specific composition of an insurer's portfolio. In the latter case, the projected sex- and age-specific mortality rates for the general population, where smoking is taken into account, could be used as reference to be applied to a specific portfolio population by using for instance a relational model (Charpentier 2014). If the

main interest is the trends of life expectancy in the very long run, as is often the case in actuarial applications, it could even be sufficient to only project smoking-free life expectancy without an additional model for smoking-associated mortality and then to add a fixed constant to account for a persistent fraction of smokers (Bongaarts 2006, Bongaarts 2014). This is because it could be argued that the impact of smoking is probably negligible in the long run, in particular for men where the most significant distorting effects of the smoking epidemic on mortality trends occurred in the past. If also the short-term trends in mortality projections are relevant, a separate projection of non-smoking and smoking-attributable mortality trends would seem to be preferable, as this would allow modelling of the nonlinear impact of smoking in the near term. That would be particularly relevant for women, where the most important effects of the smoking epidemic are yet to come to light.

Although taking smoking into account has many advantages, the disadvantages inevitably involved need to be evaluated before deciding on a projection model. First, to account for smoking requires that reliable data on age-specific lung-cancer mortality are available for a long period of time. Such is the case in the Netherlands and in many other high-income countries, but not in all and certainly not in less developed countries. A second aspect of the inclusion of smoking in a projection model is that assumptions on the further progression of the smoking epidemic are necessary. This is less of an issue in subgroups (e.g. men in the Netherlands) where the bell-shaped pattern of the impact of the smoking epidemic is almost completely expressed, so that the remaining part could easily be completed by simple means. However, in subgroups where the major part of the impact of the smoking epidemic lies in the future (e.g. women in Southern

Europe), the separate projection of smoking-associated mortality is more challenging.

Pooling of countries in mortality projections may provide a convenient alternative to explicitly modelling the impact of smoking on mortality trends, which we conclude from the relatively small differences between the outcomes of the CBS and AG models. Both models projected more optimistic mortality trends than our benchmark case, where only Dutch all-cause mortality rates were projected into the future. A possible explanation for this result is that the pooling of countries that are in different stages of the smoking epidemic helps to extract a more robust underlying trend that is unrelated to smoking. However, this hypothesis has not been evaluated so far and should be carefully assessed in further research. Until the pros and cons of pure multi-country projections are evaluated in more detail, forecasters would be well advised to follow the modern paradigm and thereby also take the distorting effects of the impact of smoking into account.

References

Acturieel Genootschap (2014). "Projection – Table AG 2014."

Bongaarts, J. (2006). "How long will we live?" Population and Development Review **32**(4): 605–628.

Bongaarts, J. (2014). "Trends in Causes of Death in Low-Mortality Countries: Implications for Mortality Projections." Population and Development Review **40**(2): 189–212.

Booth, H., J. Maindonald and L. Smith (2002). "Applying Lee–Carter under conditions of variable mortality decline." Population Studies **56**(3): 325–336.

Bronnum-Hansen, H. and K. Juel (2000). "Estimating mortality due to cigarette smoking: two methods, same result." Epidemiology **11**(4): 422–426.

Brouhns, N., M. Denuit and J. K. Vermunt (2002). "A Poisson log-bilinear regression approach to the construction of projected lifetables." Insurance: Mathematics and Economics **31**(3): 373–393.

Cairns, A. J., D. Blake, K. Dowd, G. D. Coughlan, D. Epstein, A. Ong and I. Balevich (2009). "A quantitative comparison of stochastic mortality models using data from England and Wales and the United States." North American Actuarial Journal **13**(1): 1–35.

Charpentier, A. (2014). Computational Actuarial Science with R, CRC Press.

Christensen, K., M. Davidsen, K. Juel, L. Mortensen, R. Rau and J. W. Vaupel (2010). "The Divergent Life-Expectancy Trends in Denmark and Sweden – and Some Potential Explanations." Crimmins, E.M.;/Preston, S.H./Cohen, B. [Eds.] (2010) International differences in mortality at older ages: dimensions and sources. Washington D.C.: The National Academies Press: 385–407.

Doll, R., R. Peto, J. Boreham and I. Sutherland (2004). "Mortality in relation to smoking: 50 years' observations on male British doctors." Bmj **328**(7455): 1519.

Doll, R., R. Peto, K. Wheatley, R. Gray and I. Sutherland (1994). "Mortality in relation to smoking: 40 years' observations on male British doctors." Bmj **309**(6959): 901–911.

Genootschap, A. (2010). "Prognose-tafel 2010–2060." Utrecht: Actuarieel Genootschap & Actuarieel Instituut.

Ham, D. v. (2005). "De Tafel van Afsterving van Johannes Hudde." De Actuaris **12**(6): 31–33.

Hári, N., A. De Waegenaere, B. Melenberg and T. E. Nijman (2008). "Longevity risk in portfolios of pension annuities." Insurance: Mathematics and Economics **42**(2): 505–519.

Human Mortality Database (2014) "University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany)."

Janssen, F. (2014). "De rookepidemie en de levensverwachting: langer leven en kleinere sterfteverschillen." Demos **30**(1): 1–3.

Janssen, F. (2014). "Voorspelling van de levensverwachting kan beter." Tijdschrift voor gerontologie en geriatrie **45**(4): 183–187.

Janssen, F., A. Kunst and J. Mackenbach (2007). "Variations in the pace of old-age mortality decline in seven European countries, 1950–1999: The role of smoking and other factors earlier in life." European Journal of Population/Revue européenne de Démographie **23**(2): 171–188.

Janssen, F. and A. E. Kunst (2007). "The choice among past trends as a basis for the prediction of future trends in old-age mortality." Population Studies **61**(3): 315–326.

Janssen, F., W. J. Nusselder, C. W. N. Looman, J. P. Mackenbach and A. E. Kunst (2003). "Stagnation in mortality decline among elders in the Netherlands." The Gerontologist **43**(5): 722–734.

Janssen, F., V. Rousson and F. Paccaud (2015). "The role of smoking in changes in the survival curve: an empirical study in 10 European countries." Annals of epidemiology **25**(4): 243–249.

Janssen, F. and F. van Poppel (2015). "The Adoption of Smoking and Its Effect on the Mortality Gender Gap in Netherlands: A Historical Perspective." BioMed Research International **2015**(Aricle ID 370274): 1–12.

Janssen, F., L. J. G. van Wissen and A. E. Kunst (2013). "Including the smoking epidemic in internationally coherent mortality projections." Demography **50**(4): 1341–1362.

Juel, K., P. Bjerregaard and M. Madsen (2000). "Mortality and life expectancy in Denmark and in other European countries What is happening to middle-aged Danes?" The European Journal of Public Health **10**(2): 93–100.

Keilman, N. (2008). "European demographic forecasts have not become more accurate over the past 25 years." Population and Development Review **34**(1): 137–153.

Keyfitz, N. (1971). "Models." Demography **8**(4): 571–580.

King, G. and S. Soneji (2011). "The future of death in America." Demographic Research **25**(1): 1–38.

Lee, R. D. and L. R. Carter (1992). "Modelling and Forecasting U.S. Mortality." Journal of the American Statistical Association **87**: 659–671.

Li, J. S., W. Chan and S. Cheung (2011). "Structural Changes in th Lee-Carter Mortality Indexes: Detection and Implications." North American Actuarial Journal **15**(1): 13–31.

Li, N. and R. D. Lee (2005). "Coherent mortality forecasts for a group of populations: An extension of the Lee-Carter method." Demography **42**(3): 575–594.

Li, S.-H. and W.-S. Chan (2007). "The Lee-Carter model for forecasting mortality, revisited." North American Actuarial Journal **11**(1): 68–89.

Lopez, A. D., N. E. Collishaw and T. Piha (1994). "A descriptive model of the cigarette epidemic in developed countries." Tobacco Control **3**(3): 242–247.

Luijben, A. H. P. and G. J. Kommer, Eds. (2010). Tijd en toekomst: deelrapport van de VTV 2010 Van gezond naar beter. RIVM-rapport 270061008. Houten, Bohn Stafleu Van Loghum.

Luy, M. and C. Wegner-Siegmundt (2014). "The impact of smoking on gender differences in life expectancy: more heterogeneous than often stated." The European Journal of Public Health: cku211.

Mackenbach, J. P., L. Slobbe, C. W. N. Looman, A. van der Heide, J. Polder and J. Garssen (2011). "Sharp upturn in life expectancy in the Netherlands: effect of more health care for the elderly? ." European Journal of Epidemiology **26**(12): 903-914.

Martikainen, P., P. Makela, R. Peltonen and M. Myrskyla (2014). "Income differences in life expectancy: the changing contribution of harmful consumption of alcohol and smoking." Epidemiology **25**(2): 182-190.

Mathers, C. D., T. Boerma and D. M. Fat (2009). "Global and regional causes of death." British medical bulletin: ldp028.

Meslé, F. and J. Vallin (2006). "Diverging Trends in Female Old Age Mortality: The United States and the Netherlands versus France and Japan." Population and Development Review **32**(1): 123-145.

Oza, S., M. J. Thun, S. J. Henley, A. D. Lopez and M. Ezzati (2011). "How many deaths are attributable to smoking in the United States? Comparison of methods for estimating smoking-attributable mortality when smoking prevalence changes." Preventive medicine **52**(6): 428-433.

Pampel, F. (2005). "Forecasting sex differences in mortality in high income nations: The contribution of smoking." Demographic research **13**(18): 455.

Peters, F., W. J. Nusselder and J. P. Mackenbach (2012). "The longvevity risk of the Dutch actuarial society." Netspar Design Paper: 1-56.

Peters, F., W. J. Nusselder, N. Reibling, C. Wegner-Siegmundt and J. P. Mackenbach (2015). "Quantifying the contribution of changes in healthcare expenditures and smoking to the reversal of the trend in life expectancy in the Netherlands " BMC Public Health.

Peto, R., J. Boreham, A. Lopez, M. Thun and C. Heath (1992). "Mortality from tobacco in developed countries: indirect estimation from national vital statistics." The Lancet **339**(8804): 1268-1278.

Pitacco, M. Denuit, S. Haberman and A. Olivieri (2009). Modelling Longevity Dynamics for Pensions and Annuity Business Oxford, Oxford University Press.

Preston, S. H., D. A. Glei and J. R. Wilmoth (2010). "A new method for estimating smoking-attributable mortality in high-income countries." International journal of epidemiology **39**(2): 430-438.

Preston, S. H., P. Heuveline and M. Guillot (2001). Demography: measuring and modeling population processes. Oxford, UK, Blackwell.

Preston, S. H., A. Stokes, N. K. Mehta and B. Cao (2014). "Projecting the effect of changes in smoking and obesity on future life expectancy in the United States." Demography **51**(1): 27-49.

Renshaw, A. E. and S. Haberman (2006). "A cohort-based extension to the Lee-Carter model for mortality reduction factors." Insurance: Mathematics and Economics **38**(3): 556-570.

Rentería, E., P. Jha, D. Forman and I. Soerjomataram (2015). "The impact of cigarette smoking on life expectancy between 1980 and 2010: a global perspective." Tobacco Control: tobaccocontrol-2015-052265.

Rogers, R. G., R. A. Hummer, P. M. Krueger and F. C. Pampel (2005). "Mortality attributable to cigarette smoking in the United States." Population and Development Review **31**(2): 259-292.

Rostron, B. (2010). "A modified new method for estimating smoking-attributable mortality in high-income countries." Demographic Research **23**: 399-420.

Rostron, B. L. and J. R. Wilmoth (2011). "Estimating the Effect of Smoking on Slowdowns in Mortality Declines in Developed Countries." Demography **48**(2): 461-479.

Staetsky, L. (2009). "Diverging trends in female old-age mortality: A reappraisal." Demographic Research **21**(30): 885-914.

Stewart, S. T., D. M. Cutler and A. B. Rosen (2009). "Forecasting the effects of obesity and smoking on US life expectancy." New England Journal of Medicine **361**(23): 2252-2260.

Stoeldraijer, L., L. Bonneux, C. Duin, L. Wissen and F. Janssen (2014). "The future of smoking-attributable mortality: the case of England & Wales, Denmark and the Netherlands." Addiction.

Stoeldraijer, L., C. Duin, L. Wissen and F. Janssen (2013). "Impact of different mortality forecasting methods and explicit assumptions on projected future life expectancy: The case of the Netherlands." Demographic Research **29**.

Stoeldraijer, L., C. van Duin and F. Janssen (2013). "Bevolkingsprognose 2012-2060: model en veronderstellingen betreffende de sterfte." Bevolkingstrends(juni): 1-27.

Thun, M., R. Peto, J. Boreham and A. D. Lopez (2012). "Stages of the cigarette epidemic on entering its second century." Tobacco control **21**(2): 96-101.

US Surgeon General (2014). "The Health Consequences of Smoking—50 Years of Progress: A Report of the Surgeon General, 2014." Washington, DC: US Department of Health and Human Services.

van Duin, C. and L. Stoeldraijer (2014). "Bevolkingsprognose 2014–2060: groei door migratie."

Wang, H. and S. H. Preston (2009). "Forecasting United States mortality using cohort smoking histories." Proc Natl Acad Sci U S A **106**(2): 393-398.

Willets, R. (2006). How Analysis of Mortality by Cause of Death is Currently Influencing UK Forecasts. Perspectives on Mortality Forecasting. T. Bengtsson and K. Christensen. Stockholm, Swedish Social Insurance Agency**:** 49-73.

World Health Organization (2008). "WHO report on the global tobacco epidemic, 2008: the MPOWER package."

World Health Organization (2013). "WHO Mortality Database ".

Technical Appendix

A1. Data

To derive mortality rates and construct life tables, we used sex and age-specific population counts and death counts from the Human Mortality Database in the age groups (0, 1-4, 5-9,...,95-99 years) (Human Mortality Database 2014). We furthermore obtained sex and age-specific lung-cancer death rates for the age groups (35-40, ... , 80-84 years) from the WHO mortality database on causes of death, as input for the indirect estimation of smoking-attributable mortality (World Health Organization 2013).

A2. Methods: Fitting the LC model

To extract a central time trend of mortality, we applied the LC model as expressed in equation (1) (Lee and Carter 1992). In this model, the average log mortality rate at each age $\alpha(x)$ is separated from the central time trend $\kappa(t)$ while allowing for slower and faster rates of decline at every age through the interaction term $\beta(x)$

$$\log m(x,t) = \alpha(x) + \beta(x)\kappa(x) + \varepsilon(x,t) \quad (1)$$

To fit the LC model introduced in (1), we followed Brouhns et al. (Brouhns, Denuit et al. 2002), who assumed that deaths were drawn from a Poisson distribution with person-years lived as offset and estimated the LC parameters via maximum likelihood (Brouhns, Denuit et al. 2002). This provided a more realistic assumption for the variance in death rates (Pitacco, Denuit et al. 2009). To achieve a unique solution of model (1) the following restrictions were made, in line with earlier studies (Cairns, Blake et al. 2009):

$$\sum_t \kappa(t) = 0 \tag{2}$$

and

$$\sum_x \beta(x) = 1 \tag{3}$$

The model was fitted in *R* using the lifemetrics package (available at: http://www.macs.hw.ac.uk/~andrewc/lifemetrics/). We fitted the LC model to all-cause mortality rates and to mortality rates where the impact of smoking was removed beforehand, as described below.

A3. Methods: Estimating the impact of smoking on mortality

We applied the indirect approach suggested by Preston, Glei, and Wilmoth (the PGW approach) to estimate the fraction of mortality attributable to smoking (Preston, Glei et al. 2010). Here, the basic idea is that the total cumulative damage of past smoking on all causes of death could be indirectly inferred from observed lung-cancer mortality rates. Defining smoking as the only source of variation in lung cancer rates [M_L], the intensity of smoking is computed as the difference between the observed M_L and the M_L among never-smokers at the same age and sex obtained from the Cancer Prevention Study II (a cohort study started in 1982 in the USA). To obtain the fraction attributable to smoking for causes other than lung cancer [M_0], the computed intensity of smoking is multiplied by a sex, age, and time-specific translation factor (Preston, Glei et al. 2010). These factors were obtained by regressing M_L on M_0 for a group of high-income countries between 1950 and 2006. Since the original approach provided translation factors only above the age of 50, we also used the additional factors computed by Martikainen et al. (2014) to esti-

mate smoking-attributable mortality between age 35-50 and between age 85-89 (Martikainen, Makela et al. 2014).

A4. Methods: Computing the present value of future pension payments

As described in Peters at al. (2012) we computed the present value of future pension payments at age 65 by first calculating cohort survival trajectories at age 65, based on the fitted and projected death probabilities *q(x,t)* provided by the AG 2014 and CBS 2014 projection, as shown in (4).

$$l_c(x,t) = 1 \cdot \Pi_{x=c}^{\omega} 1 - q(x, t + (x - c)) \tag{4}$$

Here, *lc* describes the cohort survival for those at age *c*=65 in year *t* up until the highest age ω=99.

$$a(t) = \sum_{c}^{\omega} \frac{l_c(x,t)}{(1+r)^{x-c}} \tag{5}$$

Finally, the present value of all future pension payments *a(t)* is computed by adding up the survivorship values l_c discounted by the interest rate *r* (here *r* = 0.03 was used). Thereby, one year of survival is translated into a pension of 1 euro.

OVERZICHT UITGAVEN IN DE DESIGN PAPER SERIE

1 Naar een nieuw pensioencontract (2011)
Lans Bovenberg en Casper van Ewijk
2 Langlevenrisico in collectieve pensioencontracten (2011)
Anja De Waegenaere, Alexander Paulis en Job Stigter
3 Bouwstenen voor nieuwe pensioencontracten en uitdagingen voor het toezicht daarop (2011)
Theo Nijman en Lans Bovenberg
4 European supervision of pension funds: purpose, scope and design (2011)
Niels Kortleve, Wilfried Mulder and Antoon Pelsser
5 Regulating pensions: Why the European Union matters (2011)
Ton van den Brink, Hans van Meerten and Sybe de Vries
6 The design of European supervision of pension funds (2012)
Dirk Broeders, Niels Kortleve, Antoon Pelsser and Jan-Willem Wijckmans
7 Hoe gevoelig is de uittredeleeftijd voor veranderingen in het pensioenstelsel? (2012)
Didier Fouarge, Andries de Grip en Raymond Montizaan
8 De inkomensverdeling en levensverwachting van ouderen (2012)
Marike Knoef, Rob Alessie en Adriaan Kalwij
9 Marktconsistente waardering van zachte pensioenrechten (2012)
Theo Nijman en Bas Werker
10 De RAM in het nieuwe pensioenakkoord (2012)
Frank de Jong en Peter Schotman
11 The longevity risk of the Dutch Actuarial Association's projection model (2012)
Frederik Peters, Wilma Nusselder and Johan Mackenbach
12 Het koppelen van pensioenleeftijd en pensioenaanspraken aan de levensverwachting (2012)
Anja De Waegenaere, Bertrand Melenberg en Tim Boonen
13 Impliciete en expliciete leeftijdsdifferentiatie in pensioencontracten (2013)
Roel Mehlkopf, Jan Bonenkamp, Casper van Ewijk, Harry ter Rele en Ed Westerhout
14 Hoofdlijnen Pensioenakkoord, juridisch begrepen (2013)
Mark Heemskerk, Bas de Jong en René Maatman
15 Different people, different choices: The influence of visual stimuli in communication on pension choice (2013)
Elisabeth Brüggen, Ingrid Rohde and Mijke van den Broeke
16 Herverdeling door pensioenregelingen (2013)
Jan Bonenkamp, Wilma Nusselder, Johan Mackenbach, Frederik Peters en Harry ter Rele
17 Guarantees and habit formation in pension schemes: A critical analysis of the floor-leverage rule (2013)
Frank de Jong and Yang Zhou

18 The holistic balance sheet as a building block in pension fund supervision (2013)
Erwin Fransen, Niels Kortleve, Hans Schumacher, Hans Staring and Jan-Willem Wijckmans

19 Collective pension schemes and individual choice (2013)
Jules van Binsbergen, Dirk Broeders, Myrthe de Jong and Ralph Koijen

20 Building a distribution builder: Design considerations for financial investment and pension decisions (2013)
Bas Donkers, Carlos Lourenço, Daniel Goldstein and Benedict Dellaert

21 Escalerende garantietoezeggingen: een alternatief voor het StAr RAM-contract (2013)
Servaas van Bilsen, Roger Laeven en Theo Nijman

22 A reporting standard for defined contribution pension plans (2013)
Kees de Vaan, Daniele Fano, Herialt Mens and Giovanna Nicodano

23 Op naar actieve pensioenconsumenten: Inhoudelijke kenmerken en randvoorwaarden van effectieve pensioencommunicatie (2013)
Niels Kortleve, Guido Verbaal en Charlotte Kuiper

24 Naar een nieuw deelnemergericht UPO (2013)
Charlotte Kuiper, Arthur van Soest en Cees Dert

25 Measuring retirement savings adequacy; developing a multi-pillar approach in the Netherlands (2013)
Marike Knoef, Jim Been, Rob Alessie, Koen Caminada, Kees Goudswaard, and Adriaan Kalwij

26 Illiquiditeit voor pensioenfondsen en verzekeraars: Rendement versus risico (2014)
Joost Driessen

27 De doorsneesystematiek in aanvullende pensioenregelingen: effecten, alternatieven en transitiepaden (2014)
Jan Bonenkamp, Ryanne Cox en Marcel Lever

28 EIOPA: bevoegdheden en rechtsbescherming (2014)
Ivor Witte

29 Een institutionele beleggersblik op de Nederlandse woningmarkt (2013)
Dirk Brounen en Ronald Mahieu

30 Verzekeraar en het reële pensioencontract (2014)
Jolanda van den Brink, Erik Lutjens en Ivor Witte

31 Pensioen, consumptiebehoeften en ouderenzorg (2014)
Marike Knoef, Arjen Hussem, Arjan Soede en Jochem de Bresser

32 Habit formation: implications for pension plans (2014)
Frank de Jong and Yang Zhou

33 Het Algemeen pensioenfonds en de taakafbakening (2014)
Ivor Witte

34 Intergenerational Risk Trading (2014)
Jiajia Cui and Eduard Ponds

35 Beëindiging van de doorsneesystematiek: juridisch navigeren naar alternatieven (2015)
Dick Boeijen, Mark Heemskerk en René Maatman

36 Purchasing an annuity: now or later? The role of interest rates (2015)
Thijs Markwat, Roderick Molenaar and Juan Carlos Rodriguez

37 Entrepreneurs without wealth? An overview of their portfolio using different data sources for the Netherlands (2015)
Mauro Mastrogiacomo, Yue Li and Rik Dillingh

38 The psychology and economics of reverse mortgage attitudes. Evidence from the Netherlands (2015)
Rik Dillingh, Henriëtte Prast, Mariacristina Rossi and Cesira Urzì Brancati

39 Keuzevrijheid in de uittreedleeftijd (2015)
Arthur van Soest

40 Afschaffing doorsneesystematiek: verkenning van varianten (2015)
Jan Bonenkamp en Marcel Lever

41 Nederlandse pensioenopbouw in internationaal perspectief (2015)
Marike Knoef, Kees Goudswaard, Jim Been en Koen Caminada

42 Intergenerationele risicodeling in collectieve en individuele pensioencontracten (2015)
Jan Bonenkamp, Peter Broer en Ed Westerhout

43 Inflation Experiences of Retirees (2015)
Adriaan Kalwij, Rob Alessie, Jonathan Gardner and Ashik Anwar Ali

44 Financial fairness and conditional indexation (2015)
Torsten Kleinow and Hans Schumacher

45 Lessons from the Swedish occupational pension system (2015)
Lans Bovenberg, Ryanne Cox and Stefan Lundbergh

46 Heldere en harde pensioenrechten onder een PPR (2016)
Mark Heemskerk, René Maatman en Bas Werker

47 Segmentation of pension plan participants: Identifying dimensions of heterogeneity (2016)
Wiebke Eberhardt, Elisabeth Brüggen, Thomas Post and Chantal Hoet

48 How do people spend their time before and after retirement? (2016)
Johannes Binswanger

49 Naar een nieuwe aanpak voor risicoprofielmeting voor deelnemers in pensioenregelingen (2016)
Benedict Dellaert, Bas Donkers, Marc Turlings, Tom Steenkamp en Ed Vermeulen

50 Individueel defined contribution in de uitkeringsfase (2016)
Tom Steenkamp

51 Wat vinden en verwachten Nederlanders van het pensioen? (2016)
Arthur van Soest

52 Do life expectancy projections need to account for the impact of smoking? (2016)
Frederik Peters, Johan Mackenbach en Wilma Nusselder

Netspar

Do life expectancy projections need to account for the impact of smoking?

Previously the gains in life expectancy have been consistently underestimated resulting in a considerable longevity risk jeopardizing the financial stability of pension funds, life insurers and public budgets. The goal of this paper is to assess whether taking into account the distorting impact of smoking on mortality trends helps to provide more reliable projections of life expectancy and thus reduces the longevity risk. For this purpose, Frederik Peters, Johan Mackenbach and Wilma Nusselder (all Erasmus MC) review the international literature on that topic and illustrate the impact of smoking on mortality trends and projections for the example of the Netherlands.

This is a publication of:
Netspar
P.O. Box 90153
5000 LE Tilburg
the Netherlands
Phone +31 13 466 2109
E-mail info@netspar.nl
www.netspar.nl

March 2016