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TRENDS IN CAUSES OF DEATH IN LOW MORTALITY COUNTRIES: IMPLICATIONS FOR MORTALITY PROJECTIONS

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Abstract

This study examines the potential role information about trends in causes of death could have in improving projections of mortality in low mortality countries. The first half of the paper summarizes overall trends in mortality by cause since the middle of the 20th century. Special attention is given to the crucial impact of the smoking epidemic on mortality and on causes of death patterns. The last part of the paper discusses the implications for projections and reaches two conclusions. First, mortality projections can be improved by taking into account the distorting effects of smoking. Mortality attributable to smoking has risen in the past but has now leveled off or declined thus boosting improvements in life expectancy. Second, making cause-specific projections is not likely to be helpful. Trends in specific medical causes of death have experienced discontinuities in the past and future trends are therefore difficult to predict.

One of the greatest achievements of modern societies is the massive reduction in mortality that has occurred over the past two centuries. For thousands of years before the 19th century life expectancy at birth remained around 30 years with large fluctuations due to epidemics, famines and wars. The mortality transition that followed raised life expectancy first in northwestern Europe and North America and, after variable delays, in other world regions. Today, life expectancy in the most advanced countries exceeds 80 years and even in the least developed countries the average life expectancy has reached 61 years [1] (United Nations 2013).

The term "epidemiological transition" refers to the change in the distribution of causes of death that accompanies the mortality transition. According to Omran (1971) this transition consists of three phases: 1) The pre-transitional "age of pestilence and famine" during which infectious and parasitic diseases are dominant, 2) the transitional "age of receding epidemics" during which infectious and parasitic diseases are brought under control initially by improvements in public health, sanitation, nutrition and higher standards of living and subsequently through mass immunization, septic procedures and antibiotics , and 3) the post-transitional "age of degenerative disease and man-made diseases" during which non-communicable diseases such as cardiovascular disease and cancer become the main causes of death. In the most advanced countries in Europe and North America the second phase started in the early 19th century and ended around 1960 when infectious disease had become only a very minor cause of death. In the poorest countries of the contemporary developing world this transition is still underway and could last several more decades. Omran (1971) claimed that during the third phase mortality "eventually approaches stability at a relatively low level (p.517)".

In the early 1970s Omran's framework provided a reasonable summary of long-range epidemiological trends. Declines in communicable diseases had been well documented around the world. Moreover, demographers widely believed that life expectancy at birth had an upper limit around seventy five years, in part because declines in mortality had nearly stalled during the 1960s in many high income countries (Olshansky and Ault 1982; Mesle and Vallin 2006). The UN in fact incorporated an upper limit of 75 years[2] in its long-range population projections for all countries (UN 1977).

However, during the 1970s and 1980s life expectancy improvements in the developed world accelerated again and it became clear that the epidemiological transition would not soon end in stability. This led researchers to revise Omran's ideas by expanding the number of transition stages. The initial proposals for a fourth stage from Olshansky and Ault 1982 ("The age of delayed degenerative diseases.") and from Rogers and Hackenberg 1987 (" hybristic stage") were not successful and have been largely ignored in the subsequent literature. More recently Horiuchi (1999); Vallin and Mesle (2001) and Mesle and Vallin (2006) proposed an alternative fourth stage called the "cardiovascular revolution". This addition was based on accumulating evidence that rising life expectancy after the 1960s was primarily due to rapid declines in cardiovascular disease. This extension of the original epidemiological transition framework seems to be well supported and could become widely accepted.

Horiuchi (1999) proposed a more radical revision in which five transitions instead of one take place over the course of human history [3]. The five transitions between successive epidemiological regimes are as follows: from external injuries in hunter gatherer societies to infectious disease in agricultural societies to cardiovascular disease in industrial societies to cancer in high technology societies and finally to senescence in the future. Each of these five transitions occurs when one class of leading causes of death declines or largely disappears and is replaced by another disease which already existed but had not yet been brought under control. According to Horiuchi advanced countries with low mortality now have completed a large part of the cardiovascular phase and are beginning the fourth transition to the cancer phase. In this more comprehensive framework Omran's transition is simply the second in a set of five.

As various potential revisions of Omran's framework are being debated there is wide agreement in the literature about trends in overall mortality in contemporary societies. In particular, life expectancy is rising rapidly in most countries (United Nations 2013) and there is no sign of an upper limit to life (Bongaarts 2006, National Research Council 2000; Oeppen and Vaupel 2002; Shkolnikov 2011, Wilmoth 1997). It is also understood that countries need not move through their mortality and epidemiological transitions in a linear fashion, because temporary reversals are not uncommon (e.g. the HIV/AIDS epidemic in Africa and the health crisis accompanying the breakup of the Soviet Union).

An important reason for studying the changing distribution of causes of death is their potential to inform the production of mortality projections. Future trends in life expectancy have become a matter of great interest to researchers and policy makers because rapid population aging is threatening the future solvency of health and pension systems and the economic viability of aging societies. A variety of projection methods have been developed, but, surprisingly, most of these methods for forecasting future mortality trends take no account of trends in causes of deaths.

The purpose of the present study is to contribute to the debate about the potential role information about causes of death can have in improving projections of mortality. The first half of the paper summarizes overall trends in mortality by cause since the middle of the 20th century. Special attention will be given to the crucial impact of the smoking epidemic on mortality and on causes of death patterns. The last part of the paper discusses the implications of these past trends for future evolution of the mortality transition.

I. PAST TRENDS

This study focuses on trends in death rates and the distribution of causes of death in 15 countries with high life expectancy and relatively high quality statistics on the causes of death: Australia, Austria, Canada, Denmark, Finland, France, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, UK, and the US[4]. This group of countries is at the leading edge of the epidemiological transition and they share similar trends in mortality and life expectancy. A better understanding of the evolution of causes of death at the end of the mortality transition may be gained by an assessment of this set of “peer” countries.

Standardized death rates

The age-standardized death rate (“death rate”) is used as the principal indicator of levels and trends in mortality. This is common practice in the cause-of-death literature because it allows the simple decomposition of the total death rate into the additive contributions of individual causes of death. Death rates are age-standardized to remove the confounding effect of differences in population age structures in comparisons of levels of mortality across countries, over time and among causes.

Figure 1 plots trends in death rates for each of the 15 peer countries from 1955 to 2010 (the population of OECD in 2010 is used as the reference population[5]). These countries have experienced large and steady declines over the past half century and the trajectories are broadly similar. This finding is not surprising because the countries have comparable standards of living, medical care and public health conditions and advances in medical treatment, drug therapy, and life styles diffuse rapidly across countries (Riley 2001). In addition, these countries have not experienced major economic or political crises between 1955 and 2010. The thick black line indicates the unweighted average death rate which declined from 1592 per 100000 in 1955 to 765 in 2010, a 52% drop (in all figures the term “average” refers to the unweighted average of the 15 peer countries).

As expected, there is a strong inverse correlation between the standardized death rate and life expectancy. Figure 1 also plots the average life expectancy at birth from 1955 to 2010. This average rose from 69.2 years in 1955 to 81.1 years in 2010, an increase of 11.9 years at an annual pace of 0.22 years. Average life expectancy and the standardized death rate each show a steady near-linear trend. Interestingly, mortality levels for the individual countries converge between 1955 and 2010 with the standard deviation declining from 176 to 71 deaths/100000 for the death rate and from 2.6 to 1.2 years for life expectancy.

Causes of death

Figure 2 plots the cause-of-death components of the average death rate, separately for males and females. To simplify this and later figures only the 15 country average is plotted. This allows the discussion to focus on commonalities among country trends rather than on the specific features of individual countries. Furthermore, the large number of causes of death is collapsed into three groups: cardiovascular disease, cancer and all other causes. Estimates of the number of deaths according to year, country, age, sex and selected causes were extracted from the World Health Organization Mortality Database (WHO 2013) [6]. It should be emphasized that the quality of these data is sometimes problematic especially at older ages due to inaccuracies in the coding and diagnosis of causes of death and to repeated revisions of the International Classification of Diseases and Injuries (Anderson 2013, Glei et al. 2010). However, inconsistencies and errors are likely to be small because estimates are averaged for a set of 15 peer countries and causes of deaths are combined into large groups (Vallin and Mesle 2001).

The top line in Figure 2a plots the average death rate per 100000 females (unweighted and age-standardized) from 1955 to 2010. It declined throughout the period although the pace of decline was slightly faster before than after 1980. By 2010 the female death rate had reached 46% of its

1955 level. This overall female death rate equals the sum of its three cause-of-death components which are also plotted in Figure 2a. Cardiovascular disease was the most important cause of death over the past half century; it declined sharply ending 69% lower in 2010 than in 1955. Cancer is the second most important cause of death. In contrast to cardiovascular disease its death rate is nearly stable although a very modest decline is evident after the mid-1990s. The “other” component consists of more than a dozen causes of death: diseases of the endocrine, nervous, circulatory, respiratory, digestive, musculoskeletal and genitourinary systems, diseases of skin/tissue and blood, pregnancy and childbirth, perinatal conditions, congenital anomalies, infectious and parasitic diseases, mental disorders and external causes. Each of these other causes typically has a much smaller death rate than cardiovascular disease or cancer, but together they make up a substantial part of overall mortality. The death rate from other causes combined shows a nonlinear pattern, with a rapid decline until around 1980 followed by a plateau.

The comparable death rates by cause for males are plotted in Figure 2b. The trends are broadly similar to those for females, but there are notable differences: 1) male mortality exceeds that for females for all causes, 2) the overall death rate decline was slower before 1980 than afterwards, 3) the cardiovascular death rate was nearly constant until the mid-1970s before declining sharply in later decades and 4) cancer mortality rose modestly until the mid-1980s before declining slightly by 2010.

The distribution of causes of death has clearly changed substantially over the past half century. As shown in Table 1 between 1955 and 2010 the proportion of the average death rate attributable to cardiovascular disease declined from 52 to 34% for females and from 48 to 33% for males. In contrast, the role of cancer nearly doubled (from 15 to 27% for females and from 15 to 30% for males). Other diseases combined showed little change in their relative contributions (of course individual other diseases may show trends but these will not be examined here).

The main finding from this examination of cause-of-death patterns in this group of 15 peer countries is that the massive decline in cardiovascular disease has been the dominant driver of overall decline in the death rate (accounting for 66 and 64 percent of the total decline among females and males respectively). This trend is made possible by rapid innovations in medical treatments and prevention and deserves to be called the cardiovascular transition. Cancer death rates have made very little contribution to the decline in the overall death rate throughout the past half century and the same is true for other diseases combined after 1980.

The impact of smoking

The adverse impact of smoking on health and mortality is well established (CDC 2010; Ezzati et al. 2002; Doll et al. 2004; Jha, and Peto.2014 ; NRC 2011; Peto and Lopez 1992; Peto et al. 2012; Preston et al. 2010a). Smoking is not only responsible for the large majority of lung cancer deaths world-wide, but also raises mortality from other cancers, cardiovascular disease and most other diseases. Differences between countries in the timing and size of the smoking epidemic, the lagged effect of smoking on death rates, and the mortality declines following cessation, all contribute to explaining mortality trends and differences among countries since the middle of the 20th century.

Estimating the death rate attributable to smoking is not straightforward and requires fairly complex procedures as well as reliable vital statistics. One of the oldest such method was developed by Peto and Lopez (1992). Instead of relying on limited data on smoking behavior their method uses observed lung cancer mortality as an indirect indicator of exposure to smoking (see appendix for details). This approach has the advantage of using readily available vital statistics on causes of death which allows it to provide estimates of smoking attributable deaths rates by cause, sex and age (for ages 35 and above) for many populations. Peto et al. (2012) provide summary estimates for 47 countries from 1950 to 2005. An alternative indirect method for estimating mortality attributable to smoking for ages 50+ was developed by Preston et al. 2010b. Interestingly, the two different methods produce very similar estimates. For present purposes the Peto-Lopez method will be used in part because it is the most widely applied and it provides results for larger range of ages (i.e. 35+ instead of 50+)[7]. For further discussion of the method see Murphy and Di Cesare, (2012) , Pampel 2005, Pérez-Ríos and Montes (2008), Preston et al. (2010b),and Rostron and Wilmoth. (2011).

Figure 3 presents the average smoking attributable death rate from 1955-2010 by sex. The male trend shows a clear inverted U-pattern, which increases over time from 1955 to around 1980, peaks at 325 per 100000 and then declines. This pattern reflects the rise and fall of smoking about two to three decades earlier. Smoking rose steadily in the first half of the 20th century and peaked in the 1960s when the adverse health impact became widely known (National Research Council. 2011).

The smoking impact among females has also risen over time, but it is much smaller than among males and shows no up and down pattern. A plateau appears to have been reached for females around 2010. This trend is more or less as expected from the lower and later uptake of smoking among females compared to males. Smoking prevalence is now also declining among females in many high income countries (Forey et al 2002, 2011; OECD 2012; Pampel 2010) and it is therefore plausible to assume that the female smoking attributable death rate will peak and then decline in the future.

Figure 4 plots the average overall death rates for males and females with and without smoking. The thick solid lines represent the observed death rates which, as discussed earlier, show a fairly steady decline over time. However, the gap between male and female rates has not been constant and rises and falls over time. This pattern is largely due to the non-linear trend in smoking mortality among males compared to females. After the smoking attributable mortality is removed the trends in the overall death rates (dashed lines) are close to parallel for males and females and the male–female gap is nearly constant. This finding is consistent with conclusions reached earlier by Pampel (2002) and Preston (2010b).

The smoking attributable death rates from cardiovascular disease and cancer are presented in Figures 5 and 7 respectively. Among males the smoking impact on both diseases first rises, peaks and then declines as was the case for all causes in Figure 3. However, there is a significant difference in the timing of the peak impacts of cardiovascular disease and cancer. The peak smoking mortality from cancer (in 1985) occurs nine years later than the peak in the smoking mortality from cardiovascular disease (in 1976). There is also a difference in the peak years among females. Their peak in smoking attributable cardiovascular mortality was reached in the mid-1990s and the peak in cancer from smoking (if it happens) will be in 2010 or later. These differences in the timing of peaks among both males and females are largely explained by the fact that the delay between the time of smoking exposure and the onset of cardiovascular disease is on average shorter than the time between smoking exposure and the onset of cancer (Oza et al 2011).

Figure 6 plots cardiovascular death rates with and without smoking by sex and Figure 8 presents the same information for cancer. A key finding in Figure 8 is that the rise and fall in the observed cancer death rate among males is largely attributable to variations over time in the smoking impact. The male cancer rate without smoking is nearly flat from 1955 to mid-1990s. For females the nearly flat pattern in the observed cancer death rate turns into a modest decline without smoking. The implications of these trends will be discussed further below.

The impact of smoking on all other diseases combined is smaller than on cancer or cardiovascular disease between 1955 and 1995 (Figure 9), but after 1995 it exceeds the rapidly declining impact on cardiovascular disease. This component combines death rates from more than a dozen separate diseases, each with its own trajectory. The overall trend in the death rate from other diseases without smoking is essentially flat after 1980 for both males and females (see Figure 10). This average conceals modest increases in some diseases (e.g. mental disorders and diseases of the nervous system, and diabetes) and continuing declines in others.

Variation among countries

The preceding analysis examined average trends in causes of death in 15 peer countries with low mortality. This aggregation allowed a more succinct assessment of common trends. Of course, levels and trends vary among countries. These differences could be examined by replicating figures 2-10 for each country, but that would produce an unwieldy amount of information. Instead, the country specific information for 2010 will be summarized in the form of rankings for different types of mortality by cause (a rank of 1 represents lowest mortality, a rank 15 the highest).

Table 2 presents two panels of rankings, the upper one is for females and the lower one for males. The first three columns of numbers summarize results for all causes, with the first column ranking the observed death rate, the second ranking the death rate without smoking and the third ranking the death rate attributable to smoking.

The results for females in the first column of Table 2 indicate that Japan and France score best in the comparison of observed death rates while Denmark and the US score poorest. This ranking is influenced by the level of smoking and, according to the third column, smoking attributable mortality among females is lowest in Japan and Spain and highest in Denmark and the US.

Mortality without smoking (column 2) is lowest in Japan and Canada and highest in Austria and Finland.

The ranking of male mortality from all causes is broadly similar to that of females but there are notable differences. The observed death rate rank of males in Japan is second behind Australia and Denmark and Finland scores last. Smoking attributable mortality is lowest in Australia and Sweden and highest in Denmark and the Netherlands.

The remaining columns in Table 2 present similar ranking for cardiovascular disease (columns 4-6) and for cancer (columns 7-9). The findings speak for themselves, but a few results are noteworthy:

- Japanese females rank first or second in all comparisons presented in Table 2. The same is true for cardiovascular disease among males but the cancer rates for males –with and without smoking- are only average.
- The US has the lowest death rate from cancer without smoking, for both males and females, despite its relatively poor score on overall mortality. This finding is partly attributable to wider screening and more aggressive treatment of cancer in particular of prostate and breast cancer in the US (Preston and Ho 2010).
- France scores much better in cardiovascular disease than cancer particularly among males. Finland shows the reverse

A full discussion of these findings and their explanations is beyond the scope of this study.

II. IMPLICATIONS FOR THE FUTURE

The future mortality trajectory of a country has important implications for health and social policy, in particular in aging populations where pension and health care costs are rising steeply. Mortality projections are, therefore, among the most useful products of demographic analysis. Developed countries often have government agencies that make such projections (e.g. the Actuaries of the Social Security Administration in the US), and the United Nations Population Division makes projections for 238 countries and regions. All these projections anticipate substantial increases in future life expectancy. For example, according to the UN, life expectancy of the 15 peer countries included in the present analysis will rise from 81.1 to 86.3 years between 2010 and 2050 (UN 2013).

A substantial literature discusses the development and application of mortality projection methods. As a result, a wide diversity of methods is available (Janssen and Kunst 2007, Janssen et al 2013; Wilmoth 2005). In general these existing projection methods rely wholly, or in part, on extrapolation of past trends in mortality rates, longevity measures, or parameters in mortality models (Janssen et al 2013; Keyfitz 1991; Murphy 1990; Lee 1998; Tabeau, Jeths, and Heathcote 2001). Forecasts for individual countries can differ substantially for several reasons: methods vary in nature and level of complexity, the extrapolation can take different forms (e.g. linear and non-linear), may be period or cohort based, and the duration of past trends from which projections are made ranges widely.

A notable feature of nearly all existing methods is that they ignore trends in causes of death (a few exceptions will be noted below). The following discussion examines whether methods for projecting mortality can be improved by taking account of trends in smoking or in the medical causes of deaths.

The impact of smoking

As demonstrated above, smoking has had a very substantial impact on past mortality. Among females the average mortality attributable to smoking has risen throughout the past half century while among males it rose during the 1950s 1960s and 1970s, peaked around 1980 and then declined (see Figure 3). Clearly, past mortality trends would have been different in the absence of smoking. For females the average annual rate of decline in the death rate for the period 1955-2010 was 1.41 % per year with smoking (i.e. observed) and would have been 1.65% without smoking (see Table 3). The corresponding rates for males are 1.24 and 1.44 % per year. In other words, the rising mortality from smoking slowed down the pace of decline in the observed death rate between 1955 and 2010 by 0.24 % per year for females and by 0.20% per year for males (see last column of Table 3). Janssen and Kunst (2007) report similar findings for the period 1950-1999 for a somewhat different group of countries. (Note that the effect of smoking on the rate of increase in the death rate varies with the beginning and end points selected for the period. For example, the smoking impact on the rate of increase among males is much higher for the period 1955-1980 than for 1955-2010, because the smoking impact peaked around 1980 and declined substantially by 2010 as shown in Figure 3).

The implications of this finding for projections are illustrated in figure 11 which relies on hypothetical data. The thick solid line presents the "observed" death rate from 1950 to 2050. The thick dashed line plots the trajectory for the death rate without smoking which is assumed to be linear. The difference between these lines equals the smoking impact which is assumed to rise between 1950 and 2000 and to decline between 2000 and 2050. The key result of these assumptions is that the observed death rate declines at a slower rate before than after 2000. That is, the rising impact of smoking slows down the decline in the observed death rate before 2000 and the reverse occurs after 2000 when the declining smoking impact accelerates observed declines. Although hypothetical, these trajectories broadly resemble the average male and female populations in the 15 peer countries over the past half century. The projected post-2000 accelerating declines in death rates in Figure 11 could well become reality for a number of countries as the impact of smoking wanes.

Given these hypothetical conditions, let us imagine that a projection is made in 2000 based only on information available up to that year. It would not be unreasonable to project the observed trend from 1950-2000 into the future. In that case the projection would follow the path of the thin line labeled "Basic projection 2000-2050" in Figure 11. It is clear that this projection overestimates future mortality because it ignores the distorting effect of smoking. But this would not be obvious to an analyst in 2000 who chooses to ignore the smoking effect.

Mortality projections are distorted whenever the impact of smoking rises in the past but subsequently levels off or declines. This seems to be the case for many high income countries, although the peak years vary among countries and have occurred earlier for males than for females. Ignoring the smoking epidemic in these countries yields an upward bias in death rate projections and a downward bias in life expectancy projections. Unfortunately many existing mortality projection methods rely on extrapolation of past observed mortality trends and ignore the smoking impact; they therefore tend to underestimate future declines in mortality.

Only a few studies explicitly adjust mortality projections to account for the impact of smoking e.g. Bongaarts 2006, Janssen and Kunst 2007, Janssen et al. 2013, Girosi and King 2008 , TPAM 2011, Pampel 2005, and Wang and Preston 2009. Each of these studies relied on different projection methodologies and their findings are therefore not easily compared or summarized. The size of the adjustment depends on the duration of the historical period on which the projection is based and on the timing of the peak in smoking mortality as well as on the assumed future trend in smoking mortality. However, taking smoking into account generally produces a lower projection of mortality (and higher life expectancy) in the long run than standard projections that do not take smoking into account. Making explicit adjustments for the distorting effects of smoking is likely to improve the accuracy of projections but further research and testing is needed.

Given the wide variety of existing projection methods it is not possible here to describe how these different methods could be adjusted. In general, however, such adjustments consist of four distinct steps: 1) Divide the mortality indicator of interest into a smoking and non-smoking components (e.g. by using the Peto-Lopez method), 2) Project the non-smoking component with whatever method is considered most appropriate, 3) Project the smoking component taking into account the non-linear pattern expected over the course of the smoking epidemic, and 4) Combine the smoking and non-smoking projections to obtain the adjusted overall projection. An illustration of this approach for the US is found in TPAM 2011.

An adjustment of mortality projections for the distortions from the smoking epidemic is not unlike the adjustment often made for the distortions in mortality trends caused by the AIDS epidemic in heavily affected African countries. In these countries AIDS mortality began rising around 1990 when the epidemic took off and the peak occurred around 2005 when treatment became widely available (UNAIDS 2012). A naïve projection of the trend from 1990-2005 would typically lead to rapid future rises in AIDS mortality[9]. In reality the trend in AIDS mortality reversed after 2005 and by 2050 the level of mortality is expected not to be far from the level that would have been observed if the epidemic had never occurred. The UN projections make an explicit adjustment to take into account the up and down trend in AIDS mortality (United Nations 2013).

In general, mortality projections can be improved by special adjustments if a behavioral or medical cause of death has recently experienced or in the future can be expected to experience a discontinuity in trend over time. Such a discontinuity causes distortions in projections because it implies that past trends are not good predictors of future trends. An appropriate adjustment can remove this distortion.

The impact of the changing causes of death

As noted, most conventional methods for projecting mortality rely on the extrapolation of death rates or indicators derived from death rates (e.g. life expectancy). However, when cause-of-death trends are available and reliable it is possible to project the death rate from each cause separately and add them up to produce an alternative projection of the overall death rate (Board of Trustees 2011; Mathers and Loncar. 2006; Giroshi and King 2008).

However, cause-of-death projections perform poorly in tests with historical data. The key problem is that past trends in mortality by cause of death have seen abrupt changes in the pace of improvement of certain causes. To illustrate, take the observed trends in causes of disease from 1955 to around 1980 from Figures 3 to 10 and extrapolate them linearly to 2010 assuming only information available in 1980. Such a projection for cardiovascular disease for females would yield a result that is not too far from the observed 2010 level, because cardiovascular disease declined at roughly the same pace before and after 1980. But projections made in the 1970s for cardiovascular disease among males would overestimate the 2010 observed level because the projection would miss the sharp downturn after 1980. The same is true for male cancer mortality which rose before the 1980s and declined afterwards. A similar problem would arise in the projection of other diseases. The aggregate death rate for this group declined before 1980 and would be projected to decline further between 1980 and 2010. In reality the death of this group of disease was nearly stable after 1980, and such a projection would therefore yield a large underestimate for 2010. In sum, extrapolations of past trends of causes of death have been an unreliable basis for projection.

One of the best known mortality projections for the US is made by the Actuaries of the Social Security Administration (Board of Trustees 2013). This projection relies on the extrapolation of death rates by cause of death. Assessments by Technical Panels of the Social Security Advisory Board (SSAB) have been critical of this approach (TPAM 2003, 2007, 2011). For example, the 2003 Technical panel concluded "A model based on separate projections by cause of death over a long time horizon is both implausible and inconsistent with historical experience." [p.38]. This is one of the key reasons why these Technical Panels have recommended alternative and more conventional projection methods for the US Social Security Administration.

DISCUSSION AND CONCLUSION

Between 1955 and 2010 the average standardized death rate dropped by more than half in the 15 low mortality countries included in this study. An analysis of the causes of death showed that the main driver of this trend was a decline in cardiovascular disease which accounted for two-third of the overall decline. Average death rates from cancer and other diseases also declined but by much smaller amounts.

Smoking has left a major imprint on past mortality levels and trends. Among males the average death rate attributable to smoking rose to a peak around 1980 when smoking was responsible for one in five male deaths. The average female death rate attributable to smoking has risen steadily over recent decades and accounted for one in six deaths in 2010 when it appeared to be at or close to a peak.

The preceding analysis of future implications of these trends suggests two conclusions. First, mortality projections can be improved by taking into account the distorting effect of smoking attributable mortality. This epidemic has slowed mortality improvements in the past and once smoking-attributable mortality peaks observed mortality improvements accelerate (other thing being equal). An adjustment to standard projections requires some assumption about the future trend of smoking mortality but even an approximate adjustment is likely to be better than ignoring smoking all together.

Second, making cause-specific projections is not likely to be helpful. The main reason is that trends in causes of death have experienced discontinuities in the past (e.g. the onset of the cardiovascular decline in the 1970s was unexpected and so was the end of the decline in other causes of death around 1980). The future will likely have more such surprises in store.

These two conclusions may appear to be inconsistent. If one cause of mortality (smoking) should be taken into account then why not other medical causes? The answer to this question lies in the predictability of a discontinuity in mortality trends related to a cause --whether behavioral or medical. Smoking mortality belongs to a class of causes in which the future trend can be predicted to be different from the past trend with a high degree of certainty, because fairly reliable information on past smoking behavior and on smoking related mortality is available. The same is true for HIV/AIDS in the most heavily affected countries, and for the mortality of wars, famines and many other epidemics. In contrast, there is no good reason to expect a major trend change for any specific medical cause of death. Even though a trend change is likely in one or more causes of death as medical science progresses, it is not possible to predict which diseases will benefit most.

The conclusion that cause-of-death specific projections should be avoided because they are unreliable does not mean that trends in causes of death are not important. To the contrary, further success in reducing mortality from different causes is necessary to drive the continuing mortality transition. The distribution of causes of death can evolve along different trajectories and it could do so quickly or slowly, thus leading to a potential wide diversity of outcomes in future decades.

Life expectancy trends could surprise on the upside in countries where a large smoking epidemic has peaked and where 1) the rapid ongoing decline in cardiovascular disease continues, 2) the recent modest declines in cancer mortality accelerate, 3) the plateau in the group of other diseases turns out to have been temporary, and 4) the manipulation of the genes responsible for aging allow the delay of senescence in the not too distant future. Under this scenario the distribution of deaths will evolve quickly and mortality will decline rapidly.

On the other hand, future efforts to conquer leading diseases and to change smoking habits may become more difficult and expensive than in the past. While the death rate from cardiovascular disease will almost certainly decline further, progress against cancer has been slow despite large investments (OECD 2012) and major breakthroughs against cancer and senescence could be decades into the future. In addition, the unexpected and unwelcome plateauing of other diseases may not be temporary and certain disease could even see a rise (e.g. neurological diseases and diabetes).

The evidence from the past half century is more consistent with the optimistic view for the future evolution of the mortality transition, but even under the pessimistic scenario the highest achieved life expectancy will likely rise substantially in future decades. This continuing progress in the countries at the leading edge of the mortality transition will of course also benefit people in the rest of the world where mortality is still higher than in the most advanced countries.

Appendix: Summary of the Peto-Lopez method for estimating the mortality impact of smoking.

A number of methods are available to estimate the mortality attributable to smoking (Perez-Rios and Montes 2008). The method proposed by Peto et al. (1992) –usually referred to as the Peto-Lopez method-- is one of the most widely used and one of the least demanding of data. A key simplifying assumption is that the impact of all past smoking on overall mortality and on specific causes of death in a given year can be estimated from lung cancer rates in that year. The method therefore does not require data on smoking behavior.

The method requires that the following data are available:

D_{kast}= Observed death rate for cause *k*, age *a*, sex *s* and year *t* . Nine groups of causes of death are distinguished: 1=Lung cancer, 2=Upper aero-digestive cancer, 3=Other Cancer, 4=Chronic obstructive pulmonary disease, 5=Other respiratory, 6=Vascular, 7=Cirrhosis, 8=Other Medical, 9=External. Calculations are made for five age groups: 35-59, 60-64, 65-69, 70-74, 75-79.

DS_{1as}= Observed lung cancer death rate of smokers estimated from the American Cancer Society Cancer Prevention Study II (CPS-II). This large prospective cohort study was conducted in the US in the mid-1980s and included more than one million adults (Thun et al. 2007).

DNS_{1as}= Observed lung cancer death rate of non-smokers in CPS-II

RR_{kas}= The risk ratio of the death rate of smokers vs. non-smokers by cause and sex in CPS-II

Note that D_{kast} is the only country specific variable required. The variables DS_{1as}, DNS_{1as} and RR_{kas} are assumed fixed for all populations and times at the levels estimated from CPS-II.

From these input data the Peto-Lopez method calculates the death rate attributable to smoking for a given population in several steps:

1) The "proportion of smokers" is estimated as

$$P_{ast} = (D_{1ast} - DNS_{1as})/(DS_{1as} - DNS_{1as})$$

P_{ast} is expected to be between 0 and 1 depending on the past prevalence of smoking.

2) The excess mortality rate attributable to smoking by cause, age and sex

$E_{1as} = RR_{1as} - 1$ for lung cancer

$E_{kas} = 0.5*(RR_{kas} - 1)$ for other diseases except cirrhosis (k=7) and external causes (k=9)

$E_{7as} = E_{9as} = 0$

The reason for reducing excess risk for other diseases by 50% is that that not all excess mortality of smokers compared to nonsmokers is due to smoking.

3) The smoking attributable fraction of the death rate equals

$A_{kast} = P_{ast} * E_{kas} / (P_{ast} * E_{kas} + 1)$

Smoking attributable fractions are set to zero for ages<35 and are set to the estimate for 75-79 for ages 80+. Negative values are set to zero.

4) The death rate attributable due to smoking by cause, age, sex and time equals

$DA_{kast} = D_{kast} * A_{kast}$

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Table 1 Distribution of causes of death 1955 and 2010 (percent)

FEMALES	1955	2010	MALES	1955	2010
All	100	100	All	100	100
Cardiovascular	52	34	Cardiovascular	48	33
Cancer	15	27	Cancer	15	30
other	33	39	other	37	37

Table 2 Ranking of 15 countries by death rate in 2010 (1 is lowest rate, 15 is highest)

FEMALES

	ALL CAUSES OF DEATH			CARDIOVASCULAR DISEASE			CANCER		
	Observed	Without smoking	Smoking effect	Observed	Without smoking	Smoking effect	Observed	Without smoking	Smoking effect
Australia	5	3	8	5	4	7	7	6	8
Austria	9	14	7	15	15	8	8	11	7
Canada	7	2	13	3	1	12	11	5	14
Denmark	15	13	15	10	6	15	15	15	15
Finland	8	15	5	13	13	6	4	7	4
France	2	4	3	2	3	3	6	8	5
Italy	4	7	4	11	12	4	5	9	3
Japan	1	1	2	1	2	2	2	2	2
Netherlands	12	8	11	6	5	10	14	14	11
Norway	11	10	10	9	10	11	12	12	10
Spain	3	6	1	4	7	1	1	4	1
Sweden	10	12	9	14	14	9	10	10	9
Switzerland	6	5	6	7	11	5	3	3	6
UK	13	11	12	8	8	13	13	13	12
US	14	9	14	12	9	14	9	1	13

Table 2 Cont.

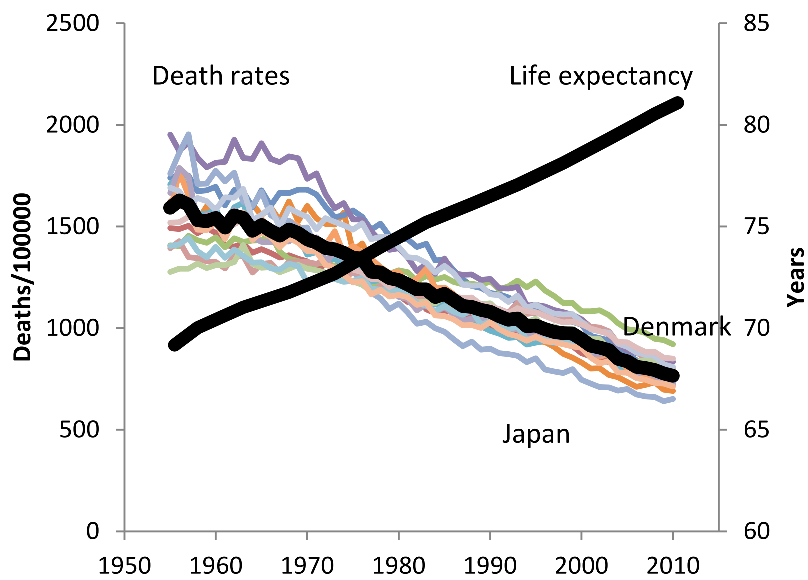
MALES

	ALL CAUSES OF DEATH			CARDIOVASCULAR DISEASE			CANCER		
	Observed	Without smoking	Smoking effect	Observed	Without smoking	Smoking effect	Observed	Without smoking	Smoking effect
Australia	1	2	2	4	5	1	6	9	2
Austria	12	12	6	14	14	10	7	11	6
Canada	3	1	8	3	3	5	5	2	10
Denmark	15	14	15	11	10	15	15	15	14
Finland	14	15	5	15	15	12	1	3	3
France	8	8	10	2	2	7	13	14	13
Italy	5	3	11	8	8	11	11	5	11
Japan	2	5	4	1	1	2	8	10	7
Netherlands	10	6	14	6	6	13	14	12	15
Norway	11	10	7	10	11	6	10	13	5
Spain	6	4	13	5	4	9	12	6	12
Sweden	7	13	1	13	13	3	2	7	1
Switzerland	4	7	3	7	7	4	4	4	4
UK	9	9	9	9	9	8	9	8	8
US	13	11	12	12	12	14	3	1	9

Table 3: Average annual rate of decline in age standardized death rate 1955-2010

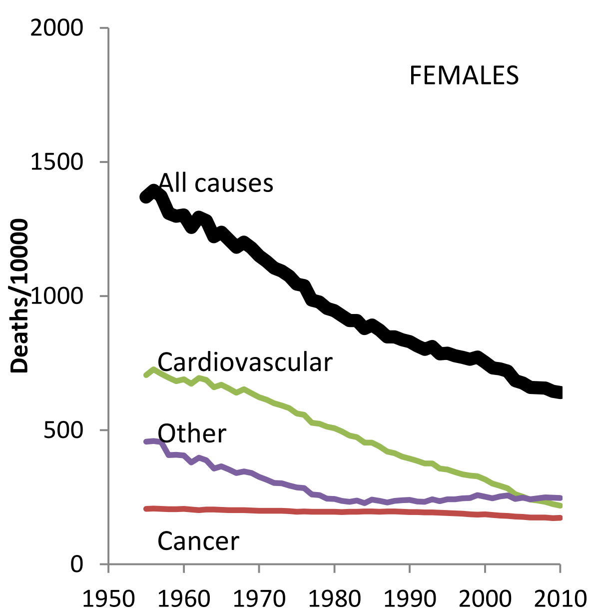
	% decline per year 1955-2010		
	Observed	Without smoking	Smoking impact
Females	1.41	1.65	-0.24
Males	1.24	1.44	-0.20

Figure 1 Death rate (age standardized) and life expectancy at birth, 15 countries



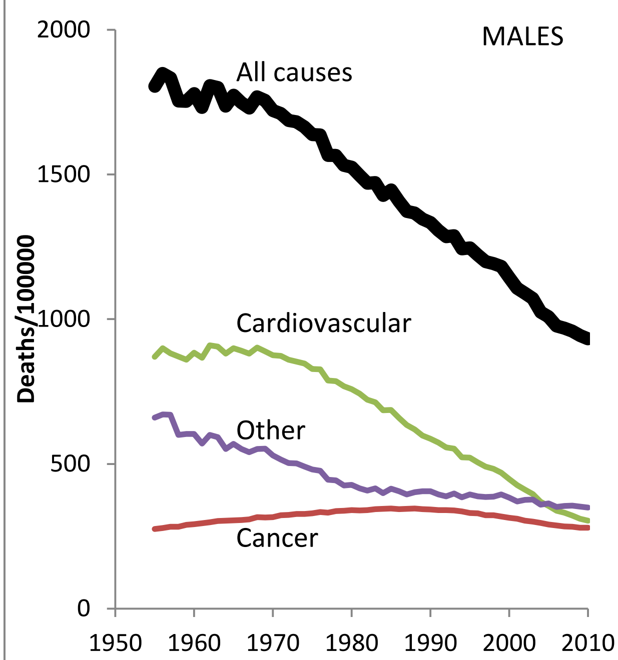
Source: Author estimates based on WHO 2013 and UN 2013

Figure 2a Death rate by cause average 15 countries



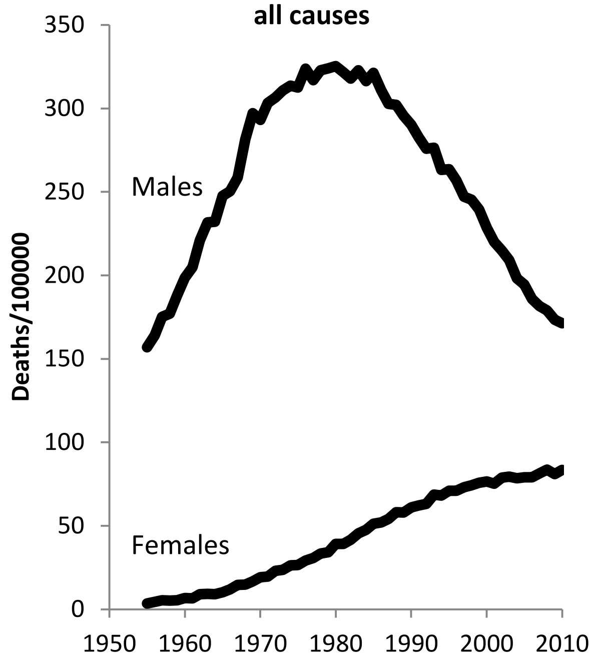
Source: Author estimates based on WHO 2013

Figure 2b Death rate by cause average 15 countries



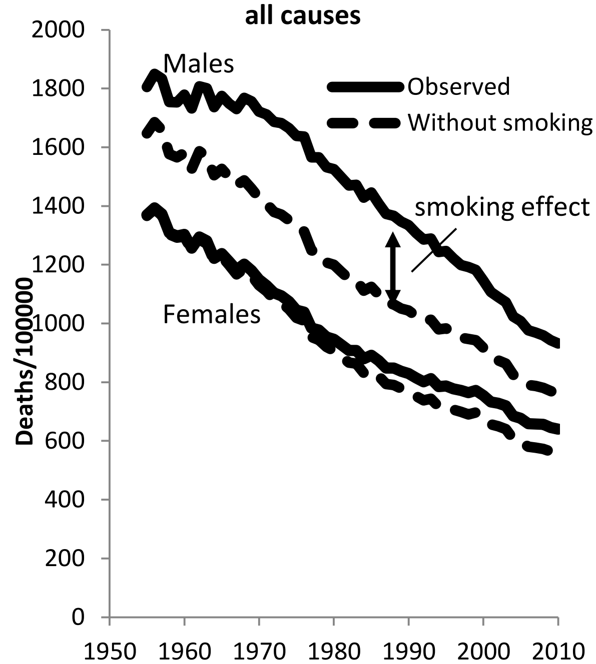
Source: Author estimates based on WHO 2013

Figure 3 Death rate attributable to smoking all causes



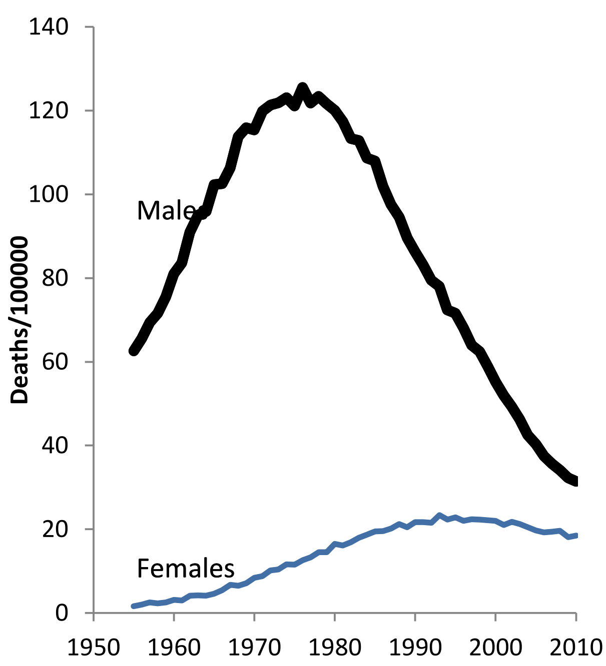
Source: Author estimates based on WHO 2013

Figure 4 Death rates, observed and without smoking all causes



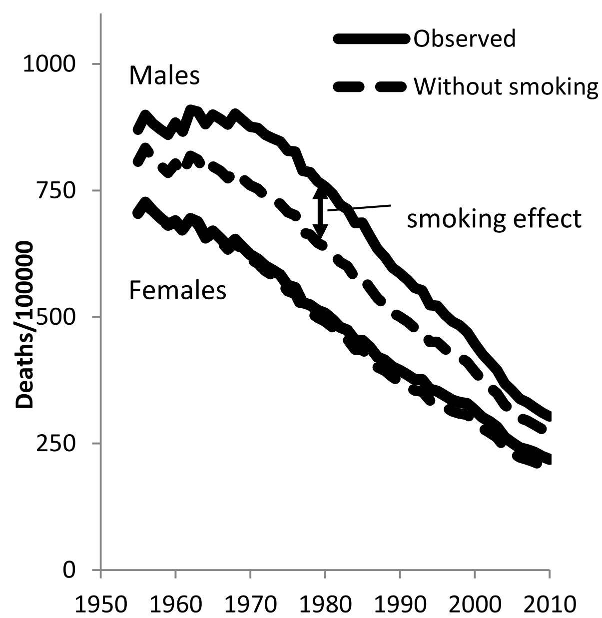
Source: Author's calculations based on WHO 2013

Figure 5 Death rate attributable to smoking cardiovascular disease



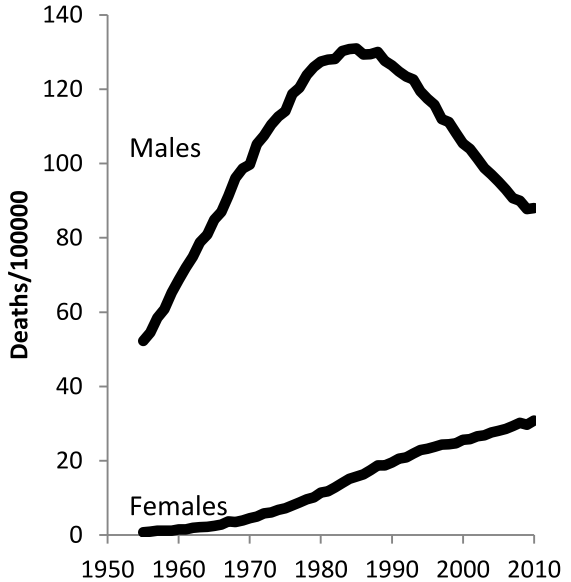
Source: Author's calculations based on WHO 2013

Figure 6 Death rates, observed and without smoking cardiovascular



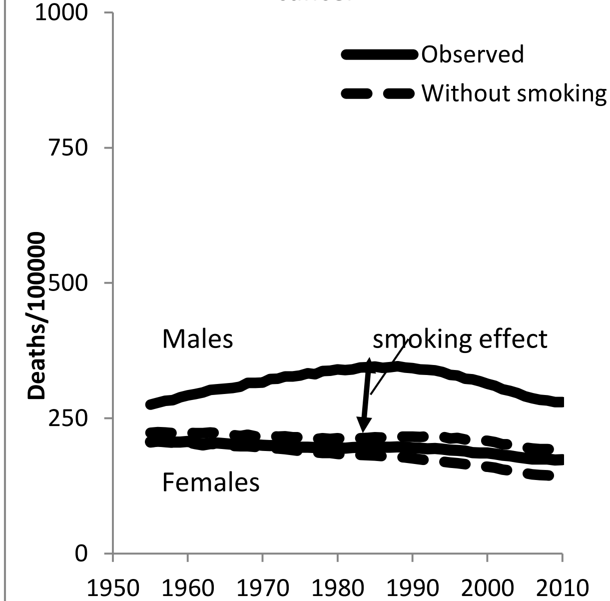
Source: Author's calculationsbased on WHO 2013

Figure 7 Death rate attributable to smoking cancer



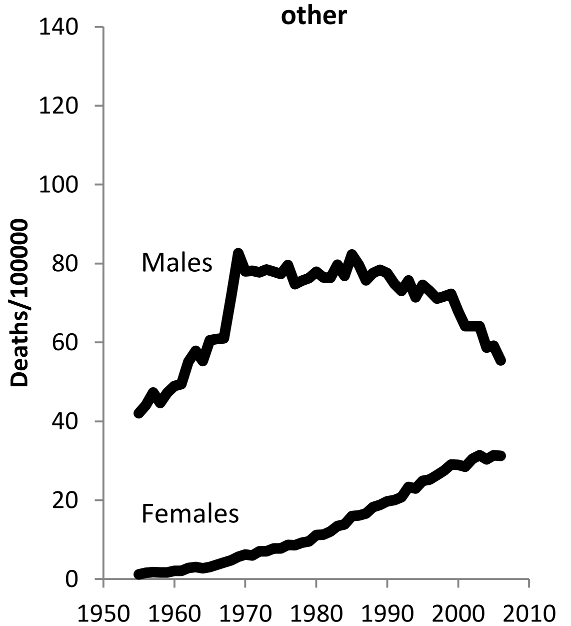
Source: Author's calculations based on WHO 2013

Figure 8 Death rates, observed and without smoking cancer



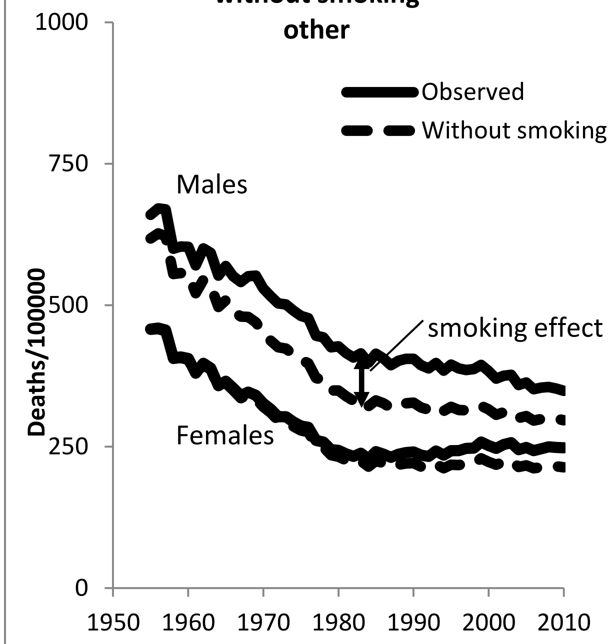
Source: Author's calculations based on WHO 2013

Figure 9 Death rate attributable to smoking other



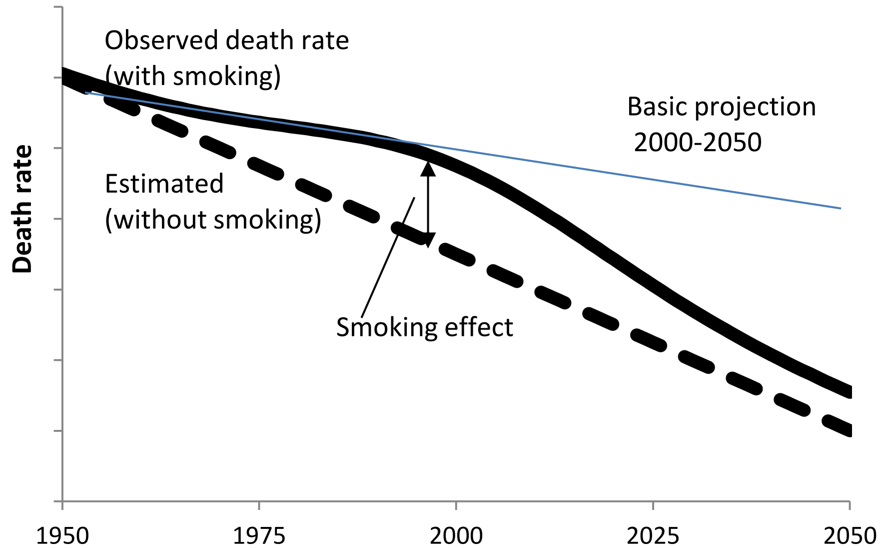
Source: Author's calculations based on WHO 2013

Figure 10 Death rates, observed and without smoking other



Source: Author's calculations based on WHO 2013

Figure 11. Hypothetical trends in death rate with and without smoking



End notes

[1]In June 2013 the least developed world consisted of 49 countries: : 34 in Africa, 9 in Asia, 5 in Oceania and one in Latin America and the Carribean (UN 2013)

[2] 72.6 for males and 77.5 years for females

[3] A still more radical proposal was made by Vallin 1993 who suggest that the term epidemiological transition be dropped in favor of the term "health transition". Vallin and Mesle 2004 and Mesle and Vallin 2013 further propose to describe historical health transitions as a series of divergence/convergence stages.

[4] This is a subset of the 17 high income countries analyzed by NRC 2013. Germany was excluded because it does not have cause of death data before 1990 and Portugal was dropped because it has a large proportion of death for which the cause of death is not identified

[5] http://stats.oecd.org/. The overall death rate from a specific cause of death is determined by the age pattern of death rates associated with the cause and by the age distribution of the population. To allow comparisons among countries a standard population age distribution (OECD in 2010) is applied to the observed age pattern of mortality for each cause of death. The resulting age-standardized cause-specific death rates allow proper comparisons among populations and over time. The choice of the standard population age distribution has some effect on the levels of standardized rates, but has a minimal impact on comparisons over time or among populations. The standardized rates are of course somewhat different from the unstandardized rates for each country and cause, but trends and differences in unstandardized rates cannot easily be analyzed because of the distorting effects of changes in the population age structure.

[6] Estimates are available until 2010 except for Canada and France for which the data series end in 2009. For these two countries estimates for 2010 were obtained by assuming that that the pace of change in the death rate by cause between 2009 and 2010 is the same as the average pace between 2004 and 2009. Ill-defined deaths have redistributed to all other cause-of-death categories

[7] See Pampel 2005, Pérez-Ríos and Montes 2008, NRC 2011 and Roston and Wilmoth 2011 for a discussion of various methods for estimating smoking attributable mortality.