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Future Mortality in Low-Mortality Countries

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Abstract

This paper provides an overview of past and expected future trends in life expectancy in populations of today's low mortality countries. Because these populations previously experienced strong decreases in infant mortality, the future mortality trends will be driven mainly by mortality among the old and oldest-old. The paper gathers empirical background data and theoretical considerations about past and likely future determinants of mortality including smoking, obesity, biomedical progress, environmental changes and socioeconomic conditions. Based on this knowledge an internet expert survey and a meta-experts meeting were carried out to formulate expert-based assumptions for future trends in life expectancy. The presented evidence and the experts' assessments indicate that that the positive influences on human mortality and life expectancy will likely outweigh the negative risk factors and lead to further increases of life expectancy. Moreover, the paper concludes that the differences between countries are likely to narrow further in the future.

Keywords

Mortality, life expectancy, determinants, future, trends, low mortality countries, projection

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1. Introduction

This paper provides an overview of past and expected future trends in life expectancy in populations with low levels of mortality. High and low mortality populations were separated on the basis of the level of child mortality in the year 2010 according to the revised estimates of the United Nations Inter-agency Group for Child Mortality Estimation (2011), with the threshold being 40 deaths per 1,000 children below age five. The low mortality population is comprised of 132 countries including Europe, North America, most of Oceania and Latin America, large parts of Asia (excluding the high mortality area in Central and Southern Asia), as well as Northern Africa (see Figure 1).

The populations of these countries are already engaged in an advanced phase of the demographic and epidemiologic transition. Because they previously experienced strong decreases in infant mortality, the future mortality trends are driven mainly by mortality in adult ages, primarily the old and oldest-old. Although the data sources on which the existing estimates of life expectancy for these populations are based vary considerably (due to differences in the death registration systems and the estimation techniques, see e.g. Luy (2010)), we have relatively good knowledge of past and current mortality trends and their causes.

Despite the similar general trends, today's low mortality countries are very heterogeneous in various aspects, including medical standards, access to health care, and behavioural risk factors like smoking prevalence. These diversities are strongly related to the populations' stages of economic development and contribute to a broad variance of life expectancy levels. Among men, life expectancy at birth for the years 2005-10 ranges between 60.2 in Kazakhstan and 79.5 in Iceland. Among women, the range is between 67.8 in the Solomon Islands and 86.1 in Japan.[1] To demonstrate this relationship between economic development and life expectancy we classified countries according to their current per capita income as an indicator of the economic development level of the populations.

[1] The numbers refer to the estimates of the 2010 revision of the UN World Populations Prospects (United Nations, 2011) to which all data in this chapter refers, if not stated otherwise.

Figure 1: Today's low and high mortality countries defined on the basis of child mortality (below age 5) below or equal to and above 40 deaths per 1,000 persons

We used the World Bank classification, which groups countries into high income ($12,276 or more annually), upper middle income ($3,976 - $12,275), lower middle income ($1,006 - $3,975), and low income ($1,005 or less).[2] Since current low mortality populations are mainly clustered in the high and upper middle income groups, we reclassified the countries into the two groups of high income and medium income populations. The first is identical to the World Bank classification, while the latter includes all remaining low mortality countries.[3]

Figure 2 shows for each low mortality country the life expectancy at birth for males (x-axes) and females (y-axes). The medium income populations are marked by grey diamonds and the high income countries by black filled circles. The figure reveals the strong correlation between life expectancy and the level of economic development for both sexes. High income countries are characterised by female life expectancy of more than 75 years, with Oman, Saudi Arabia, and Trinidad and Tobago being the only exceptions with slightly lower levels of female life expectancy. In contrast, medium income countries are characterised by male life expectancy below 75 years. Here, the only exceptions are Chile, Cuba, and Costa Rica. In these countries, life expectancy for men ranges between 75.5 and 76.5 years. The average life expectancy for both sexes combined in high and medium income populations differs by approximately six years, ranging from 72.1 to 78.0 years. In low mortality populations females enjoy higher life expectancies than males, with an average advantage of 5.3 years in high, and 6.0 years in medium income countries. The exception is Qatar where men outlive women by 0.8 years in terms of life expectancy at birth.

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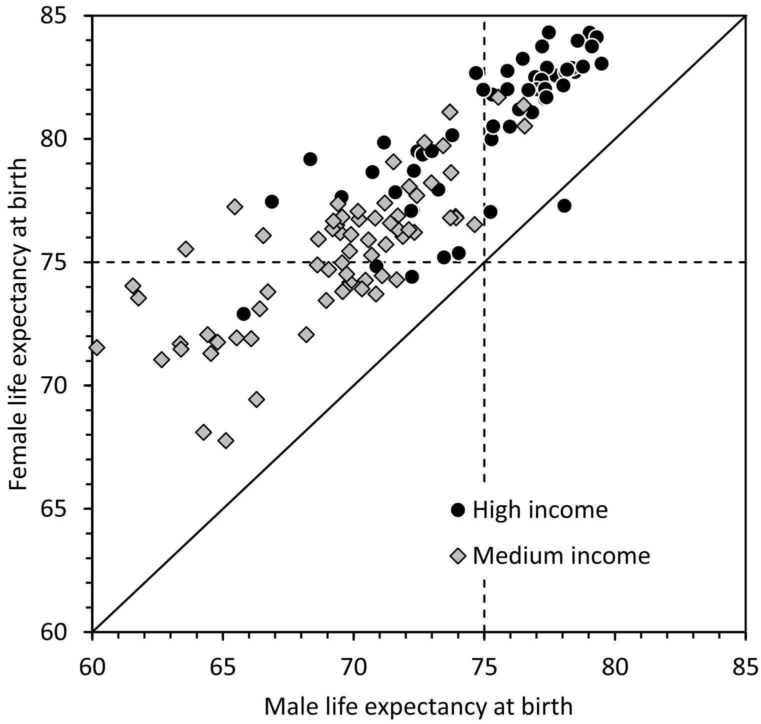
[2] More details about this classification can be found on the World Bank's website at http://data.worldbank.org/about/country-classifications.

[3] In fact, there are only three of today's low mortality countries that are classified by the World Bank as low income countries, namely the Democratic People's Republic of Korea, Kyrgyzstan and Solomon Islands.

We begin with an overview of the life expectancy trends in current low mortality countries from 1950 forward (Section 2). The figures refer only to the overall and sex-specific populations and do not provide insights into the mechanisms behind the trends. Such insights could be gained by investigating life expectancy trends at specific ages or for specific causes of death (see, e.g. Meslé & Vallin 2011). Section 3 provides the background for the project's expert survey and the subsequent meta-experts meeting that was held in San José, Costa Rica on February 21-22, 2012, to formulate the assumptions for projections of future trends in life expectancy. The section starts with a description of past trends in mortality in light of the so-called epidemiologic transition (3.1).

Figure 2: Today's low and high mortality countries defined on the basis of child mortality (below age 5) below or equal to and above 40 deaths per 1,000 persons



Note: categories of per capita income according to actual World Bank classification (see footnote 2), data on life expectancy from UN (2011); because no data on per capita income is available French Guinea, Guadeloupe, Martinique and Occupied Palestinian Territories are excluded from the graph

Then the most likely determinants of mortality in coming decades and their corresponding impacts on future life expectancy are presented (3.2). The end of Section 3 summarizes the mainstream expectations regarding future mortality trends, which can be divided into pessimistic (the "Olshansky School") and optimistic (the "Vaupel School") outlooks (3.3), and develops a conceptual framework for projecting future trends in life expectancy (3.4). The expert survey and the corresponding results are presented in Section 4. Section 5 summarizes the optimistic and pessimistic storylines for future trends in life expectancy as they were developed at the meta-experts meeting. The paper ends with a brief summary of the main conclusions.

2. Life Expectancy Trends from 1950 to 2010

2.1. Europe

Since 1950, the European life-expectancy pattern has undergone deep transformations (Luy, Wegner & Lutz 2011; Mackenbach 2013; Vallin & Meslé 2001). The northwestern part of Europe had much higher life expectancy levels in 1950 than the Mediterranean and Eastern regions, whose standards of living were generally inferior. By 1965, this difference was already much less marked, with a spectacular rise in the life expectancies of Southern and Eastern Europe. Indeed, in less than 20 years, the South and East had nearly succeeded in catching up with the countries of Northern and Western Europe.

In the early 1960s, this transformation seemed to be in compliance with Abdel Omran's pattern of epidemiologic transition (1971, see Section 3.1). European life expectancies were all converging toward a maximum, which Sweden had almost reached. However, from the mid-1960s, the situation changed completely. The countries of Eastern Europe, then governed by Communist regimes, were struck by a health crisis that considerably hampered their progress toward longer life expectancy. Indeed, in some cases life expectancy even declined, especially among males. At the same time, after a period of stagnation in the 1960s, life expectancy in Western Europe began to increase thanks to new advances in the treatment of cardiovascular diseases. By 1995, this divergent movement between East and West had transformed the European life expectancy map, and the new line of separation corresponded to that of the former Iron Curtain.

This new divergence was caused by two major events (Meslé & Vallin 2002). First, advances in health care were not limited to infectious diseases, as stated by Omran (1971). Progress in the treatment of cardiovascular disease and some forms of cancer, as well as advances in preventing “man-made” diseases such as alcoholism, smoking and accidents favoured the increase in life expectancy. Consequently, in the whole of Western Europe life expectancy continued to rise. At the same time, the communist countries, which had progressed very quickly in the field of infectious diseases, were unable to follow the new trends under way in the West. Thus, in 1995, after thirty years of near-stagnation among females and a decline among males, life expectancy in Russia was ten years below that of Sweden for females and almost 20 years below for males.

Since the last decade of the 20th century, trends in life expectancy in European countries have taken a new turn. Most central and eastern European countries have enjoyed the cardiovascular revolution and embarked on a new phase of convergence (Vallin & Meslé 2004). At the very beginning of the 1990s the Czech Republic was the first of these countries to re-establish progress toward longer life spans, followed by Poland, Slovakia, and Hungary, among others (Meslé 2004). In recent years, some progress has appeared in Russia, but it is too early to say if it will be sustainable. Southern European countries have continued to progress and are now the leaders of life expectancy in Europe.

European countries are now facing the challenging issue of the degenerative diseases that come with advanced age, especially neurodegenerative conditions like Alzheimer's disease. Future progress in life expectancy will depend on the ability of societies to efficiently manage the increasing medical burdens of people who live into very old age (see Section 3).

2.2. Northern America and Mexico

The United States and Canada have witnessed tremendous increases in life expectancy since the 1950s through slow, yet steady gains. Between 1950-55 and 2005-10, Americans experienced a 9.3 year gain in life expectancy (or 0.17 years per calendar year), whereas Canadians experienced a 11.6 year gain (or 0.21 years per calendar year). Compared to Americans, Canadians have experienced greater gains in life expectancy over the last almost six decades: they had slightly higher life expectancies at birth in 1950-55 (69.0 compared to 68.6 years), but substantially higher life expectancies by 2005-10 (80.5 compared to 78.0 years). The life expectancy gap between the Americans and Canadians has grown from 0.4 years in 1950-55 to 2.5 years in 2005-10. Furthermore, Americans life expectancy at birth has also lagged behind other high income nations (Woolf & Aron 2013).

Life expectancy at birth has increased for the overall populations and for both males and females in the US and Canada. Between 1950-55 and 2005-10, life expectancy at birth increased from 65.8 to 75.4 among US males, 71.7 to 80.5 among US females, 66.6 to 78.2 among Canadian males, and 71.5 to 82.8 among Canadian females. In every year, life expectancy at birth is higher for Canadian than American males. In the quinquennium 1950-55, life expectancy at birth is higher for American than Canadian females, but from 1955-60 through 2005-10, life expectancy at birth is greater for Canadian females.

These descriptive comparative trends are illustrative. We can speculate but cannot offer definitive evidence on the mechanisms that have produced these trends (see Section 3). Trends in life expectancy for the overall and sex-specific populations are most likely due to health behaviours, especially smoking; health conditions, especially obesity; and structural factors, including health care access and insurance (Rogers et al. 2010). Compared to Canada, the US has higher prevalence rates of smoking, obesity, and violence, along with limited access to health care, all of which most likely contributes to higher overall life expectancies in Canada. Further, the US has had a longer history of cigarette consumption, especially among males, which has contributed to lower male life expectancies and larger sex gaps in life expectancy compared to Canada (Pampel 2005).

In summary, three major findings stand out: (1) life expectancy at birth for the general population, as well as for males and females in the US and in Canada, has experienced remarkable gains since the 1950s; (2) today, compared to Americans, Canadians enjoy higher life expectancies at birth for the overall population and for males and females; (3) some of the differences between Canadian and American life expectancy are likely due to higher rates of smoking, obesity, and limited health insurance coverage in the US.

The remarkable increases in life expectancy in the US and Canada have been surpassed by Mexico's even more dramatic increases. Between 1950-55 and 2005-10, life expectancy at birth increased by a staggering 25.5 years in Mexico, from 50.7 to 76.2 years. Mexico has substantially narrowed but not completely eliminated the life expectancy gap with Canada and the US. Still, in 2005-10, the 1.8 year life expectancy gap between Mexico and the US is smaller than the 2.5 year gap between the US and Canada.

2.3. Latin America and the Caribbean

This section refers to the populations of Latin America and the Caribbean, excluding Mexico and the high mortality countries Bolivia, Haiti and Guyana (see Figure 1). From the early 1950s to the mid-1980s, two characteristics of life expectancy in the region were the existence of significant differences in both the size and pace of the yearly gains in life expectancy at birth. In 1950-55 two sets of countries are clearly distinguishable; those where mortality declined during the first half of the twentieth century, and those with high levels of mortality that had experienced very little change over this period. The former group includes Argentina and Uruguay, where mortality had been declining since the late nineteenth century (Palloni 1990; Palloni & Pinto-Aguirre 2011; Pérez-Brignoli 2010), and Brazil, Costa Rica, Colombia, Cuba and Panama, which showed evidence of declines prior to the introduction of modern medical technologies (Palloni 1990). Among those countries, life expectancy in 1950-55 ranged from 54.8 in Chile to 66.0 in Uruguay. The latter group of countries with high levels of mortality and small gains in life expectancy ranged from Honduras, with 41.6, to Ecuador, with 48.4 years.

Up to the 1960s, countries that reached the highest life expectancies were those in which the gains were related not so much to medical technology, but to improvements in standards of living, strengthened institutions and favourable conditions in international economic markets (Palloni 1990; Pérez-Brignoli 2010). Even though declines in mortality slowed for countries such as Argentina and Uruguay, they still maintained the highest life expectancy. For the rest of the countries, there is evidence that after the 1950s exogenous changes, particularly in medical technologies, and vertical programs (i.e. public health measures aimed at particular diseases) were behind the gains in life expectancy (Guzmán 2006; Palloni 1990).

Beginning in the 1970s, the relationship between life expectancy and socioeconomic conditions became stronger in Latin America and the Caribbean (Palloni 1990). This is probably due to the fact that countries such as Chile, Costa Rica and Cuba, with sustained gains in life expectancy, expanded social services and access to health care and infrastructure for their populations. The average gains that decreased beginning in the 1970s for all the countries, became more pronounced after the mid-1980s.

Until the early 1980s differences in life expectancy between countries in this geographical area remained large. The difference of approximately 24 years between the countries with highest and lowest life expectancies decreased only slightly in the early 1950s to 17 years in the early 1980s. However, as more countries reached life expectancy levels above 70 years, differences between countries declined. During the 1980s, the gains in life expectancy slowed down at the same time as a significant debt crisis occurred in all Latin American countries. Since that time, average gains have decreased steadily and considerably until today. Current levels of life expectancy for the quinquennium 2005-10 range in Latin America from a high of 78.9 years for Costa Rica to a low of 68.7 in Guyana.

A common characteristic throughout the different periods is that the pace of gains in life expectancy is not linked to original levels. While there is a group of countries that lagged behind the others throughout the 60 year period (Guatemala, Nicaragua, Honduras, El Salvador, and up to the year 2000, Peru), others lost their former leading position in the life expectancy ranking (Argentina, Uruguay and Paraguay), or moved from lower to top positions (Costa Rica and Cuba). Costa Rica and Cuba were the first countries in Latin America to achieve life expectancy levels above 70 years in the late 1970s, and today their life expectancy is even higher than in the US. El Salvador is an outlier, the only Latin American country that showed for some years a decrease in life expectancy, above all among men. This negative trend is due primarily to the armed conflicts that ravaged the country in the late 1970s and the 1980s.

Caribbean countries show a different pattern. In the early 1950s almost all reached a life expectancy above 50 years (with the Dominic Republic being the only exception) and differences were rather small. They had high gains during the early 1950s, and by 1960 their life expectancy was comparable to the forerunners of Latin America. During the subsequent fifty-year period their pattern of change is also remarkably similar. Today's life expectancy levels range from a high of 80.1 in Martinique to a low of 69.4 in Trinidad and Tobago.

2.4. East and Southeast Asia

From the mid-twentieth century forward, East and Southeast Asia have experienced the most spectacular mortality decline in the world. In 1950-55 life expectancies were 46.4 years for East Asia and 42.4 years for Southeast Asia—notably lower than the world average of 47.7 years. By 2005-10, life expectancy for the world population increased by slightly more than 20 years and reached 67.9 years. In contrast, life expectance rose about 27 years in both East Asia and Southeast Asia, and reached 74.0 years and 69.3 years, respectively. During this period, the most impressive mortality reductions took place in Vietnam and the Republic of Korea, where life expectancies increased by 33.9 years and 32.1 years respectively.

There were significant variations in mortality in East and Southeast Asia in the early 1950s. Life expectancies were already over 60 years in Japan and three small urban populations in Hong Kong, Macao and Singapore. At the same time, life expectancy was below 40 years in Indonesia. Although this gap has narrowed in recent years, the difference between high life expectancies (82.7 years for Japan, 81.6 years for Hong Kong, and 80.6

years for Singapore) and low life expectancies (67.9 years for Indonesia, 67.8 years for the Philippines, and 67.3 years for Mongolia) remains significant.

It is noteworthy that in the early 1950s, life expectancy in East and Southeast Asia was much lower than in the developed regions of the world. The gap between those Asian regions and much of the developed world was more than 20 years. That has changed significantly during the last six decades. In comparison with what has been achieved in developed countries, life expectancy for Southeast Asia is now about eight years lower, and the life expectancy for East Asia is less than three years behind. It is particularly noteworthy that Japan and Hong Kong have been leading the world in mortality decline in recent years. Life expectancies in South Korea and Taiwan have also increased rapidly (Zhao 2011; Zhao & Kinfu 2005). The currently highest life expectancy in the world can be found among Japanese women (see Section 1). If these trends continue, female life expectancies in some East Asian populations could reach 90 years by 2025, and perhaps even 100 years by 2060, as indicated by (Oeppen & Vaupel 2002; see Section 3.3.2).

2.5. Middle East and Northern Africa (MENA)

The vast majority of countries in this region are defined today as low-mortality countries. Only Sudan and Yemen are excluded due to their child mortality levels above the defined threshold at the beginning of this paper (see Figure 1). However, the MENA region is vast and encompasses a range of different mortality-relevant experiences, with values of life expectancy for the period 2005-10 ranging from 67.3 years in Iraq to 80.7 years in Israel.

Most countries in this region have experienced significant increases in life expectancy during the past 60 years, with the most impressive trajectories observed in the Gulf States, especially Bahrain and the United Arab Emirates (Omran & Roudi 1993; Roudi 2001). These two countries saw life expectancy increases from about 45 years in 1950-55 to 70 years in 1980-85, (an average increase of about 0.8 year per year). However, progress in life expectancy in the Gulf States has slowed since the late 1980s. In 2005-10, life expectancy values in these countries were about 75 years. Similarly, Syria and Jordan show relatively fast increases in the 1950s, 1960s and 1970s, followed by slower increases in the 1980s and thereafter. After a period of stagnation in the 1950s and 1960s, Turkey experienced increases in life expectancy from 49.0 years in 1965-70 to 73.0 years in 2005-10.

Progress has been more gradual in countries of Northern Africa. Starting from life expectancy values of about 43 years in 1950-55, these countries have experienced a slower but near linear increase in life expectancy, with little sign of slowdown in recent years. Life expectancy values in this region for the period 2005-10 range from 71.2 in Morocco to 74.0 in Libya. Egypt and Morocco experienced trends similar to those in Turkey.

The MENA region includes some outliers to the described trends. In Iran and Iraq, increases in life expectancy were abruptly interrupted in the early 1980s due to the war between the two countries, which generated many casualties. Recovery has been impressive in Iran, with a life expectancy of 72.1 years for the period 2005-10. Iraq, by contrast, has lost ground since the early 1990s, in part because of subsequent conflict in that country. With a value of 67.3 years in 2005-10, life expectancy in Iraq is actually lower than in 1990-95. Progress in Lebanon has also been hampered by conflict. In the 1950s and 1960s, Lebanon enjoyed one of the highest levels of life expectancy in the region. Progress has slowed significantly since the 1970s, and in 2005-10, with a life expectancy of 72.0 years, Lebanon is in the lower range among countries of the region.

Israel is another outlier in the region, with a life expectancy trajectory similar to those observed in Western Europe or North America (Na'amnih et al. 2010). Having started from a level of 68.9 years in 1950-55, life expectancy in Israel has increased in a near linear fashion, reaching a value of 80.7 in 2005-10. That is the highest life expectancy in the MENA region.

2.6. Former Soviet Republics of Central Asia and the Caucasus

Only four countries in this region are defined as low mortality countries: Armenia, Georgia, Kazakhstan, and Kyrgyzstan. Kazakhstan and Kyrgyzstan were experiencing life expectancy values of 55.0 years and 52.9 years, respectively, in 1950-55. Such values were among the lowest in the Soviet Union and were due to relatively high levels of infant mortality. Kazakhstan and Kyrgyzstan subsequently experienced notable increases in life expectancy, primarily driven by reductions in infant mortality. The two countries experienced virtually linear increases in life expectancy until the late 1980s, reaching values of 67.4 years and 66.0 years, respectively, for the period 1985-90. This progress ended with the break-up of the Soviet Union in 1991. The two countries experienced some deterioration in life expectancy during the 1990s, and levels for the period 2005-10 increase similarly to those of the period 1985-90 (Guillot 2007).

Values of life expectancy in Armenia and Georgia in 1950-55 (62.8 years and 60.6 years, respectively) were more favourable than in Central Asia and closer to the experience of Russia. However, in these two republics life expectancy started stagnating as early as the 1970s, with values oscillating around 70 years. As in Kazakhstan and Kyrgyzstan, Armenia and Georgia experienced declines in life expectancy in the 1990s (Duthé et al. 2010) but have experienced some mortality recovery during the first decade of the new century, with values of life expectancy around 73 for the period 2005-10.

3. Expectations for Future Changes in Life Expectancy

3.1. The Epidemiologic Transition and Recent Changes in Mortality

Section 2 provided an overview of the trends in life expectancy in today's low mortality populations since the middle of the 20th century. In most of these populations, the mortality decrease started some 50 years earlier, at the close of the 19th century. These changes in mortality gave rise to the theory of demographic transition and led to considerable interest from economists, medical doctors, and epidemiologists (e.g. Caselli 1989, 1995). In the field of epidemiology, trends by cause of death gave rise to the formulation of the theory of "epidemiological transition" by Omran (1971) who attempted to account for the extraordinary advances in health care made in industrialised countries since the 18th century.

Omran defined three epidemiologic "ages," with the first corresponding to the period of high mortality, in which infectious diseases were the primary cause of death. The second age is the transition period between the first and third age. The latter defines a new regime with constant low mortality in which degenerative and man-made diseases act as the primary cause of death (see Section 2.1). At the time Omran developed his theory of epidemiologic transition, most medical specialists as well as United Nations (UN) health experts saw life expectances generally converging toward a maximum age. Moreover, the most advanced countries were supposed to be already close to this limit. According to the projections of the UN (1975) at that time, the assumed point of convergence was a life expectancy of 5 years. Therefore, the epidemiologic transition proposed by Omran was an apt description of the mortality developments until the end of the 1960s, when the incidence of infectious diseases in the developed countries had been so far reduced that any further reduction could not lead to further significant gains in the average life expectancy.

Omran failed, however, to predict the so-called "cardiovascular revolution" that started in the 1970s and launched a new period of decreasing mortality (Omran 1983). Olshansky and Ault (1986) followed by Rogers and Hackenberg (1987), without criticizing the basic premises of the theory of epidemiologic transition, introduced the idea of a fourth stage during which the maximum point of convergence of life expectancies would seem to increase as a consequence of achievements in the treatment of cardiovascular diseases (Caselli, Mesle & Vallin 2002).[4] Olshansky et al. (1990) set this new maximum at 85 years, the same as that chosen by the UN (1989) for all populations in their projections at the end of the 1980s.

In recent years, the 85-year threshold has been strongly criticized by many authors who believe that such a limit cannot be determined (Carey & Judge 2001; Vaupel 2001). The validity of the threshold is also being challenged by the presence of populations that have already surpassed the 85-year maximum in female life expectancy at birth (see Section 1). With the dawn of the 21st century, the decline in mortality in some developed countries has given fresh impetus to achieving new maxima in life expectancy, particularly

[4] Only Olshansky and Ault (1986) called that additional stage the "fourth stage of the epidemiologic transition". The other authors defined this age as the "new" or "hybristic" stage.

for women. Estimating these potentials requires an assessment of the most likely determinants of future mortality, i.e. the most important risk factors, as well as the factors that might cause further reductions in mortality. We summarize some of these in the following subsections.

3.2 Most Likely Determinants of Future Mortality

Based on past experience in today's low mortality countries, smoking and obesity are major factors that can be individually influenced and have high potential to affect future mortality. Beside these health-behavioural factors, biomedical progress and the influence of environmental changes are likely to become main drivers in future mortality trends as described in this section. Another likely determinant is socioeconomic status, including individual educational attainment, occupation, income, and wealth. Within the prevalent societal, economic, and disease environment individuals can improve their socioeconomic situation and can consequently experience longer life time.

3.2.1. Smoking

An abundance of studies have identified smoking as a major health hazard and one of the most important factors that contribute to mortality differences between individuals and populations. Tobacco use has been linked to a variety of diseases and negative health outcomes, including adverse reproductive effects and mortality. Smoking increases the risk of death from at least 10 types of malignant neoplasm's (cancer), with lung cancer being the leading smoking-related fatal form of cancer (U.S. Department of Health and Human Services 2004). Smoking also causes cardiovascular and respiratory diseases, of which ischemic heart disease and chronic airway obstruction are the most important in terms of number of deaths (U.S. Department of Health and Human Services 2004). Smoking-related mortality is considered to peak some decades after the peak in smoking prevalence. Beyond being hazardous to smokers, second-hand smoke has also been shown to cause deaths in non-smokers, especially from heart diseases and lung cancer (U.S. Department of Health and Human Services 2004). In fact, smoking-related mortality has been shown to be responsible for the less favourable developments in life expectancy in Denmark, the Netherlands and the US (Christensen et al. 2010; Preston, Glei & Wilmoth 2010; Staetsky 2009).

Widespread smoking was first observed in the US. In the 1950s Americans had higher levels of cigarette consumption than any other population (Forey et al. 2002). In the following years smoking prevalence increased steadily in both the US and most other countries. Cigarette consumption in the US peaked in the mid-1960s and started to decline thereafter; in many other countries a similar decline was observed during the 1970s. Today, cigarette consumption is still receding, although some European countries and Japan have a higher smoking prevalence than the US (Crimmins, Preston & Cohen 2011).

It has been shown that the trend in smoking prevalence in a population follows the spread pattern of an epidemic and involves a diffusion process across socioeconomic strata

(Lopez, Collishaw & Piha 1994). The emergence of smoking has first been observed among groups of high socioeconomic status and then spreads to the rest of the population. Similarly, the decline in smoking prevalence has been first observed among groups of high socioeconomic status, who are typically the first to become concerned with the harmful effects of smoking (Pampel 2005). Today, smoking is much more common among groups of low socioeconomic status. These processes can be observed among both sexes, with higher prevalence rates in men and a time lag of 20-30 years between men and women.

A similar diffusion process has been observed in sex differences in smoking. Recent studies identified the major role of this process in the widening and narrowing of the sex gap in life expectancy (e.g. Pampel 2005; Pampel 2002; Preston & Wang 2006). The onset and peak of smoking prevalence in women has been considerably later than for men in almost all developed countries, which first contributed significantly to the widening and then to the narrowing in the sex gap in life expectancy in recent decades. Smoking is expected to contribute to a further narrowing in the gap between men and women (e.g. Preston & Wang 2006).

For the US, Wang and Preston (2009) predicted that the changes toward lower smoking prevalence will lead to a faster mortality decline than anticipated by most experts. These conclusions are supported by the projections of Bongaarts (2006) and Soneji & King (2011). In many low mortality countries, national health policies are currently conducting intensive anti-smoking campaigns that can be expected to lead to further decreases of smoking rates among women and men. It has been shown for several populations that these efforts led already to significant reductions in smoking prevalence and lung cancer mortality among men (Ádám et al. 2013).

3.2.2. Obesity

Obesity is another major factor that has been identified as a health hazard with possible consequences for the future development of life expectancy in the developed countries. According to the World Health Organization (WHO), a person is considered obese if he or she has a Body Mass Index (BMI) of 30 or more. The proportion of obese individuals has increased in the last 50 years in the US (Crimmins, Preston & Cohen 2011, p. 44). In 1960-62 about 11 percent of adult men and 16 percent of adult women were categorized as obese; by 2007-08 the proportion was 33 percent for adult men and 36 percent for adult women (Flegal et al. 2010; Flegal et al. 2002). Increases in obesity rates have been observed for many developed countries as well, although obesity levels and trends vary considerably by country (Alley, Lloyd & Shardell 2010). In the Anglo-Saxon countries the rise has been more rapid and the overall prevalence has been higher than in most other countries, while Japan and Italy experienced the lowest prevalence and slowest increase in obesity (Alley, Lloyd & Shardell 2010). In very recent years there is an indication that obesity rates in the US are levelling off, while at the same time they continue to increase for many other countries (Crimmins, Preston & Cohen 2011). Recent evidence for the US suggests that obesity reduces the life expectancy at age 50 by 1.54 years for women, and 1.85 years for men (Preston & Stokes 2011). The authors argue that the high prevalence of obesity in the US contributes substantially to its bad performance in terms of life expectancy as compared to many other developed countries (see Section 2).

Obesity is associated with a variety of diseases of the circulatory system (e.g. high blood pressure), diabetes, and certain cancers (colorectal, breast, endometrial, cancers of kidney, pancreas, liver and gallbladder). However, the consequences of increased obesity on a population's life expectancy have been a matter of debate (see also Section 3.3 below). Olshansky et al. (2005) suggested that the growing prevalence of obesity could lead to a potential decline in life expectancy in the future. Using a different forecasting method, Reither et al. (2011) confirmed that obesity may have an impact on death rates that is far worse than generally anticipated, especially for younger cohorts. In contrast, other recent studies indicate that the relationship between obesity and mortality is rather complex and that earlier studies have probably overestimated the effects. This is partly because the relationship between obesity and mortality varies by age and cause of death, and is confounded by smoking (Alley, Lloyd & Shardell 2010). Another reason recently brought forward is earlier data limitations. Almost all studies that showed a strong relationship between obesity and mortality used data collected before 1990 (Mehta & Chang 2011). Studies that used more recent data suggest a rather modest relation between mortality and obesity on the population level (e.g. Alley, Lloyd & Shardell 2010; Finkelstein et al. 2010). The relation is stronger in individuals with severe obesity (BMI >= 35) (Prospective Studies Collaboration 2009) and becomes stronger with age (Masters, Powers & Link 2013). Evidence for differences between men and women is mixed (Alley, Lloyd & Shardell 2010; Flegal et al. 2013).

Some studies even suggest that mortality associated with obesity has been declining over time (e.g. Flegal et al. 2010; Flegal et al. 2005; Mehta & Chang 2011). The association seems to have particularly changed for moderate obesity (BMI 30.0–34.9). Using three different data sources, Metha and Chang (2011) found no relationship between mortality and moderate obesity for more recent years. For severe obesity results have been mixed, suggesting no significant change in the relationship between mortality and obesity for individuals with a BMI of 35 and above (Mehta & Chang 2011). The impact of the complex and changing relationship between different levels of obesity and mortality on future life expectancy is not yet clear. Recent projections for the US indicate that the negative impact of the rise of obesity may be much lower than the expected gains in life expectancy due to the reductions in smoking prevalence (Soneji & King 2011).

3.2.3 Biomedical Progress

A major source of uncertainty for forecasts of life expectancy in the developed countries is the contribution of biomedical technology to the biology of aging and extending life spans. To our knowledge there have been no studies that investigate the possible impact of these technologies on extending human longevity. A recent review by Sierra et al. (2009) addresses the state of knowledge regarding the biological mechanisms that underlie the aging process. The study notes that several processes have been found to extend the life span of animals. At least one, caloric restriction, is now being investigated in humans, and others are being tested in animals with unknown prospects for human application.[5] The study also suggests that genetic manipulation of humans in order to extend lifespan is unlikely in the foreseeable future (Sierra et al. 2009).

Although it seems unlikely that complex biological mechanisms will be completely understood for many years to come, biomedical technology may contribute in the near future to the treatment of degenerative diseases and syndromes such as dementia. Dementia has been recognized as one of the most important medical problems in the elderly. Alzheimer's disease is the most prevalent and most studied subtype of dementia, accounting for 50 to 56 percent of all cases. Patients diagnosed with Alzheimer's disease typically die within 3 to 9 years after diagnosis (Querfurth & LaFerla 2010). The incidence of Alzheimer's disease is highly related to age and doubles every five years after age 65. After age 85, the odds of being diagnosed with Alzheimer's disease is higher than one in three (Querfurth & LaFerla 2010). The apolipoproteine E gene (APOE) has been identified as a major determinant for the risk of onset of this disease. There is currently no treatment for the disease and existing disease-modifying drugs yield only modest effects. The same is true for most drugs that are currently in the development pipeline, and a significant advance in secondary prevention will likely take one or two decades (see Van Marum 2008 for more details).

Although research in the field is increasing, understanding of the basic biological mechanisms of aging is still limited, and it is unclear if knowledge of these mechanisms can significantly contribute to increases in life expectancy in the near future. Similarly, it is impossible to assess whether a major breakthrough in the treatment or prevention of degenerative diseases will take place in the near future. Nevertheless, progress in understanding the underlying mechanisms of these diseases could in fact lead to increases in longevity even in the upcoming decade.

3.2.4. Environmental Changes

The impact of environmental conditions on the health and mortality of a population has long been a matter of study and concern. Climatic conditions affect the body and directly trigger either biomedical reactions such as infections, or affect the body through intervening social factors such as housing conditions, exposure to outdoor cold and heat, and other conditions. Air pollution is also discussed in this context as possible risk factor for mortality (see e.g. Wen & Gu 2012).

Some aspects of climate and environmental conditions on the mortality level of a population have been investigated in the context of seasonal changes in the chance of dying. These studies show that mortality varies systematically within the year; in most European countries and the US, higher mortality is observed during the winter season (Healy 2003; McKee 1989). The amplitude of these seasonal variations has decreased over time and it differs between countries (Rau 2004; Rau & Doblhammer 2003). Surprisingly,

[5] Note, however, that caloric dietary restriction (40% food intake reduction) has been shown to lengthen lifespans in some strains of mice, but it can shorten lifespans in other strains of mice (see Liao et al., 2010)

countries with the mildest winters, such as Portugal, Greece, Spain, Ireland, and the United Kingdom, experience the highest seasonal fluctuations in mortality, while seasonal excess mortality is lower in Northern and Central Europe (Healy 2003). These differences were largely attributed to differences in housing standards. An important implication was drawn from these observations: the key factor explaining the differences in seasonal excess mortality was the ability of the population to protect itself from environmental stress (Healy 2003).

A great deal of public, political, and scientific attention is devoted to the observed changes in the earth's environmental conditions. Climate change, resulting in a warming of the earth's surface, has been observed for some decades, and an overwhelming majority of the world's climate scientists agree that human activities contribute substantially to this ongoing development (Intergovernmental Panel on Climate Change (IPCC) 2007; Richardson, Steffen & Liverman 2011). The increases in the average temperature have been accompanied by extreme weather conditions—especially heat waves, storms, fires, and floods. However, the injuries and deaths caused by such events rarely have a direct impact on a population's life expectancy, especially not on the long-term trends as experienced with several naturally caused mortality crises during the last centuries (Browning, Bjornstrom & Cagney 2011).

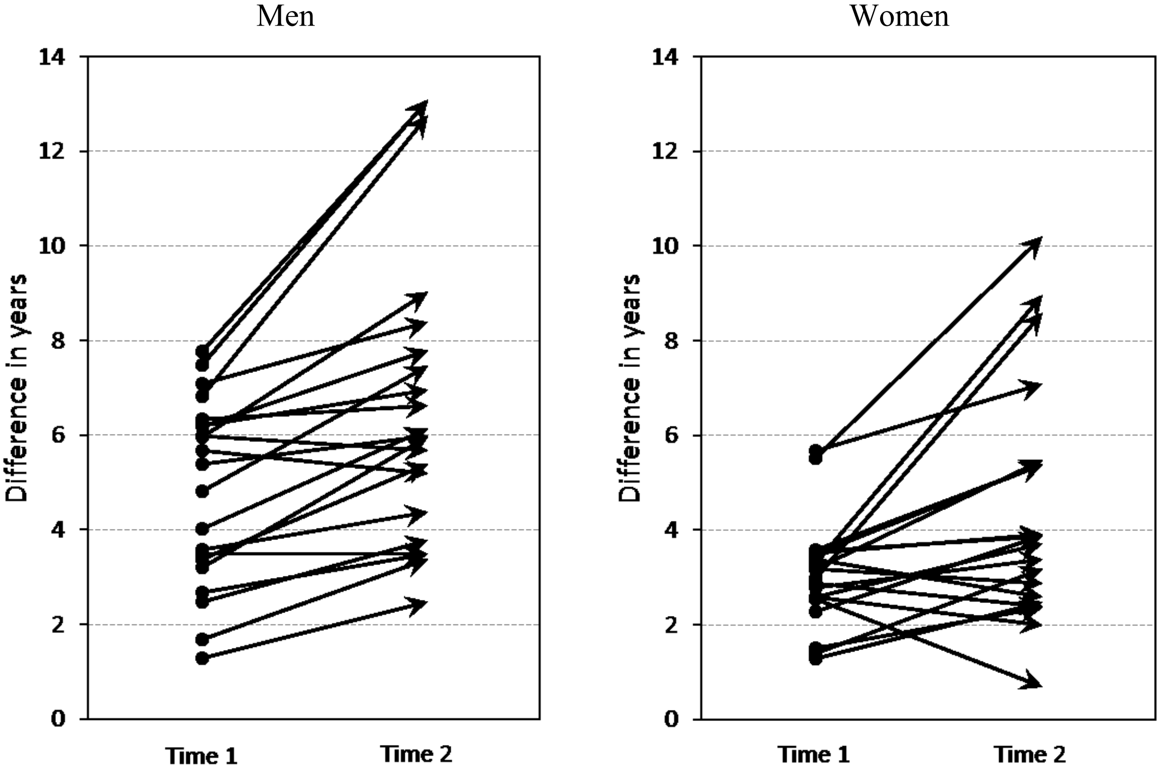
Indirect pathways of climate change can include water and food insecurity and the spread of infectious diseases (Gollin & Zimmermann 2012; McMichael & Lindgren 2011). As water and food insecurity is predicted to be more devastating in developing countries, climate change may increase population displacement and migration to the less affected countries. Assessment of the impact of climate changes on mortality in developed societies has just begun. Even recent pessimistic projections for the impact of climate change on US mortality yield only a modest increase in age-adjusted mortality of about 3 percent by the end of the 21st Century (Deschênes & Greenstone 2011). However, such projections do not take into account the likelihood that humans will be able to adapt to the new climatic situation, for instance by developing new lifestyles, and technologies, especially in light of the increases in the overall level of education (see subsequent Section 3.2.5).

3.2.5 Socioeconomic Status

Socioeconomic status has four main components: educational attainment, occupation, income, and wealth. These components are often combined to define social class. The relationships between mortality and socioeconomic determinants are well documented (see e.g. Valkonen 2006). The influence of variables such as occupational status and social class on cardiovascular mortality has been long established, and later studies added hypertension or hypercholesterolemia to the mortality-social class relationship.

In the last few decades several studies have indicated an inverse relationship between mortality and educational attainment. The differences vary in their extent between countries (Corsini 2010; Kunst 1997) and in general they are larger among men than among women (Ross, Masters & Hummer 2012). Figure 3 shows the trends in life expectancy between the education subgroups with highest and lowest mortality levels for selected populations, separated by sex. The data stem from different studies on education-specific life expectancy with the estimates referring to different countries, ages and calendar year periods between 1970 and 2006 (see notes below Figure 3).

Figure 3: Trends in life expectancy differences between population subgroups with highest and lowest education levels from different countries and at different ages and time periods



Notes: estimates refer to Austria 1981-91, 1991-01, 2001-06 (Klotz 2010), Belgium 1991-01 (Deboosere, Gadeyne & Van Oyen 2009), Czech Republic 1984-99 (Shkolnikov et al. 2006), Estonia 1989-2000 (Leinsalu, Vågerö & Kunst 2003), 1988-99 (Shkolnikov et al. 2006), Finland 1988-99 (Shkolnikov et al. 2006), Germany 1990-96 (Luy, Di Giulio & Caselli 2011), Italy 1982-87 (men only), 1987-92 (Luy, Di Giulio & Caselli 2011), Russia 1979-89 (Shkolnikov et al. 1998), 1988-99 (Shkolnikov et al. 2006), and the US 1970-80, 1980-90 (Crimmins & Saito 2001), 1982-90 (Manton, Stallard & Corder 1997), 1981-90, 1990-00 (Meara, Richards & Cutler 2008).

Among men (left panel in Figure 3) these maximum differences in life expectancy by education varied at the initial observation time of these studies (denoted “time 1” in Figure 3) between 1.3 and 7.8 years. In most populations, the differences increased over time ranging from 2.5 years to 13.1 years at the time of second observation (time 2). Reductions in education-specific mortality differences in these studies were reported only for Austrian men between 1991 and 2001 and between 2001 and 2006, with decreases in the life expectancy gap from 6.0 to 5.7 years and from 5.7 to 5.2 years respectively (Klotz 2010). Among women (right panel in Figure 3), the differences in life expectancy by education are smaller and more populations show decreases in education-specific mortality differentials. However, the overall range of the differences increased, as well. At time 1, the maximum differences in life expectancy by education varied between 1.3 and 5.7 years, while at time 2 the differences ranged from 0.7 to 10.2 years. Among both sexes, the highest differences are reported for Eastern European populations such as Russia and Estonia and the lowest for Western populations and higher age groups.

Despite the fact that the education gradient in mortality is a universal phenomenon, the role of education within the network of factors comprising the socio-economic status of persons is still unclear. Most studies consider educational attainment a mediating factor that helps individuals to acquire, develop, and use a set of resources, such as information about health behaviours, social psychological resources, access to and utilization of healthcare, and other types of socioeconomic attainment.

The 20th century saw revolutionary improvements in educational attainment. Younger cohorts have acquired higher and higher levels of education, shifting the entire educational distribution upward (see Lutz et al. 2007). These cohorts have been educated about the hazards of unhealthy life style and learned to deal with increasing complexities, while learning how to educate themselves using new forms of communication. These ongoing changes in the educational distribution are important when considering the impact of socioeconomic factors in the future. The mentioned inverse relationship between educational level and mortality is complex and the importance of different explanatory pathways has changed over time. Consequently, explaining the positive correlation between low education and mortality by linking it to improvement in socioeconomic conditions and the rise of education level may be insufficient.

The other main components of socioeconomic status—occupation, income, and wealth—are central to the stratification of society and represent the degree to which individual characteristics and resources can be converted into other, often material, resources. Individuals with more material resources are able to pay for medications and better health care, food of better quality and other health-promoting goods and services. Research also shows education differentials with respect to social support for stress, particularly stress linked to working conditions.

The main components of socioeconomic status are often primary indicators of a person's social status, a concept that is closely linked to social class. As to social class, the classical explanation is that the health risk factor of lower classes is linked to low income (which itself determines housing conditions and poor eating habits) and to higher occupational risk, such as accidents. Stressful living conditions may induce unhealthy behaviours such as alcoholism, smoking, and lack of physical exercise. This explanation, classic though it may be, is inadequate. If social class differentials can be related to differences in well-known risk factors, most of these differentials remain unexplained (Rose & Marmot 1981; Thiltgès, Duchêne & Wunsch 1995).

We note that the impact of socioeconomic status on mortality is not just a question of an individual's performance in this network of factors. The societal, political, and disease environment in which an individual lives is also important (e.g. Johansson 1991). This is likely an important mediator between socioeconomic status and individual health outcomes which could explain why socioeconomic status has different effects in different populations at different times.

3.3. The Debate between Optimists and Pessimists

The previous descriptions of the most likely drivers of future longevity illustrated that their impacts on mortality are complex and difficult to assess. For this reason, predicting the development of life expectancy is a matter of deep disagreement among demographers, epidemiologists and other population scientists. In recent years two schools of thought have developed that dominate the discussion about the most likely trends of future life expectancy (for the most recent dispute see Olshansky & Carnes 2013; Vaupel & Rau 2013). Both agree that mortality will continue to decrease, lifespan will increase, and life expectancy records will continue to be broken. Thus, the difference of opinion between the two schools about likely future trends in life expectancy "appears to be smaller than is widely presumed" (Bongaarts 2006, p. 608; see also Wilmoth 2001). They differ, however, in their opinions on the time-course and magnitude of these improvements.

3.3.1. Pessimistic View: the "Olshansky School"

The first school of thought is represented by Olshansky and colleagues who argue that future progress in life expectancy is likely to be much smaller than in the past. Their view is derived from several lines of reasoning. The first is that future increases in life expectancy are more difficult to achieve than in the past. As already mentioned in Section 1, the rapid increase in life expectancy during the first half of the 20th century was mainly driven by mortality reductions at young and early adult ages. Today's mortality levels at these ages are very low and any further mortality decline will only yield small increases in life expectancy in the future (Olshansky, Carnes & Désesquelles 2001). In 1990, Olshansky and colleagues calculated that eliminating all mortality before age 50 would lead to an increase in life expectancy of only 3.5 years (Olshansky, Carnes & Cassel 1990). Because of this, most of the recent increase in life expectancy has been achieved in older ages and likewise, any future increases must be fuelled by mortality reductions in the elderly population. Saving an elderly life, however, has a smaller impact on life expectancy than saving the life of a newborn, which is why life expectancy is becoming less sensitive to changes in death rates (Olshansky, Carnes & Cassel 1990). Thus, the increases in life expectancy may only continue at the present pace if death rates at older ages can be reduced much faster than in the past (Olshansky, Carnes & Désesquelles 2001).

A second, closely related line of reasoning argues that extrapolations of past trends in life expectancy are flawed because the mortality experience of today's cohorts is fundamentally different from that of earlier cohorts (Carnes & Olshansky 2007). These researchers argue that not only did the age pattern that caused the rise in life expectancy shift upward during the epidemiologic transition, but the cause of death pattern has dramatically changed as well. The early mortality regime was characterized by high mortality in younger ages, with deaths often caused by infectious diseases. Today's deaths occur at a late age and are caused by long-term processes that originate and progress within each individual (Carnes & Olshansky 2007). With these fundamental, and to a large extent unforeseeable, regime changes of the past in mind, it is likely that the future regime of mortality may depart from the known patterns as well (Carnes & Olshansky 2007; Miech et al. 2011).

The third line of reasoning refers to the emergence of new threats to further increases in life expectancy. One of those threats is obesity (Olshansky 2005), which has been increasing for several decades in many developed countries, most prominently in the US. As already outlined in Section 3.2.2, obesity has been associated with several negative health outcomes such as diabetes, and may lead to a shortened life. Despite the mixed empirical evidence, Olshansky and colleagues assume that obesity alone may lead to a levelling off or even a decline of life expectancy in the US. Infectious diseases are another major threat to further increases in life expectancy. They are still a leading cause of death in many low-income countries and they are re-emerging and increasing in the developed countries (Olshansky et al. 1997). Most of the increase has been fuelled by the AIDS epidemic, but other sources of infectious diseases, ranging from hospital-acquired infectious diseases to antibiotic resistant pathogens, have increased as well (Olshansky 2005). Moreover, according to Olshansky (2005), today's societies are much more vulnerable to global pandemics, such as influenza.

A fourth line of reasoning is based on the fundamental evolutionary theory that human bodies are not capable of infinite functioning and thus the duration of life is finite (Carnes, Olshansky & Hayflick 2013). The most prominent scholar who advocates the limited life span perspective is James Fries. In his most influential paper he argued that the length of life is ultimately fixed and that the average maximum life span will be approximately 85 years (Fries 1980).

On the basis of these considerations, Olshansky and colleagues conclude that life expectancy for both sexes combined will—in accordance with Fries' approach—unlikely exceed age 85 (see also Section 3.1), although this limit is considered a "soft one" (Couzin-Frankel 2011). They argue that unless the aging process itself can be modified, life expectancy gains will become increasingly difficult in the future and will likely "be measured in days or months rather than years" (Olshansky, Carnes & Désesquelles 2001, p. 1492).

3.3.2. Optimistic View: The "Vaupel School"

A second school of thought is represented by James W. Vaupel and colleagues, who have long argued against the limited lifespan paradigm, mainly directed against the "Fries limit" of 85 years. Collecting and using high-quality empirical data, Vaupel and colleagues present evidence indicating that the limited life span paradigm as proposed by Fries is wrong (Kannisto 1988, 1994, 1996; Kannisto et al. 1994). The optimists' arguments on the future of life expectancy are heavily based on evidence derived from available empirical data on past trends in mortality.

A first set of evidence shows that mortality rates at older ages have decreased for several decades for all developed countries that have reliable data (e.g. Kannisto 1994; Kannisto et al. 1994). Recent data illustrate that these trends have continued in many countries, although the pace of decrease varies (Rau et al. 2008). Mortality reduction for the extreme ages has also been shown for countries such as France and Japan (Robine & Saito 2003), indicating that survival rates even at the highest ages can be modified. This is further supported by mortality data on the German elderly before and after reunification of East and West Germany. Before 1990, mortality of East- and West-Germans increasingly diverged. After unification, East German mortality dropped close to West German levels within a very short time, most strikingly even for men and women who were 80 years and older at the time of unification (Vaupel, Carey & Christensen 2003). These empirical observations strengthen the view that human mortality is highly plastic (see also Burger, Baudisch & Vaupel 2012; Gage 1994) and that future improvement in living conditions and medical progress can have a large effect on the life spans of individuals at all ages.

A second set of evidence is female period life expectancy in the country where women live the longest, first published by Oeppen and Vaupel (2002) and recently modified by Vallin and Mesle (2009). The so-called “record life expectancy” has increased for more than 170 years, most of its time at an almost linear pace with an increase of approximately 2.5 years per decade. Shkolnikov et al. (2011) showed that record cohort life expectancy also increased more or less linearly until today, with an even stronger pace of 4.3 years per decade. Vaupel and colleagues reason that if a limit of life expectancy was being approached—either a limit that could not be overcome with medical technology or an absolute limit on the human body’s lifespan—the pace of increase in the record holding country would begin to slow down. As of today there is no sign of a deceleration in the increase of female record life expectancy (Christensen et al. 2009). This perspective has been supported just recently by alternative investigations of trends in life expectancy by Cohen and Oppenheim (2012) and Rossi et al. (2013). A similar work by White (2002) revealed that the linear life expectancy increase not only holds for the world’s record life expectancy, but also for the average life expectancy of high income countries as demonstrated for the years 1955-96.

A third set of evidence is based on findings in non-human species. Vaupel and colleagues refuted Fries’ prediction that death rates should rise rapidly at advanced ages. Studies in large populations of Medflies showed that their age trajectory of mortality reached a maximum and then declined (Carey et al. 1992). Mortality decelerations were also found for other insects and species such as nematode worms (e.g. Curtsinger et al. 1992). Later on, laboratory research confirmed that changes in environmental factors such as diet, as well as genetic factors can have a large impact on the age trajectory of mortality for some species (e.g. Mair et al. 2003).

Based on these different types of empirical observations, Vaupel and colleagues conclude that there is no convincing evidence that life expectancy is approaching a limit or that the increase in life expectancy is decelerating (Vaupel 2010). They argue that as long as life expectancy continues to increase with no sign of deceleration, it is reasonable to assume that future progress in life expectancy will continue to be similar to the progress of the past. Extrapolating the observed life expectancy trends to the future with a similar pace as record life expectancy yields impressive results. Median cohort survival time, which is the age until which half of the cohort will survive, will be above 100 years of age for recently born cohorts in many developed countries (Christensen et al. 2009). In these projections, Japan will continue to be the leading country in terms of life expectancy, with more than half of the babies born in 2007 becoming at least 107 years of age (Christensen et al. 2009).

3.4. A ‘Conceptual Framework’ for Assessing the Potential of Future Life Expectancy

The previous sections made it clear that today almost no progress in life expectancy can be made by further reductions of mortality at young ages. However, summarizing all empirical evidence and theoretical considerations, additional gains in life expectancy are still possible due to further reductions of mortality at older ages. Achieving these gains requires an understanding of the best strategies and preventions against the main risk factors. This could lead above all to further decreases in mortality from cardiovascular diseases, particularly from ischemic heart diseases, and cancer.

Another key function for increasing longevity lies in people's increased awareness of their own health status. This increases the chances for an early diagnosis of severe diseases, enhances the efficacy of new treatments and—with the introduction of healthier lifestyles—lessens a number of other risks. However, it is difficult to establish whether the greater attention paid to the health status of more recent cohorts is a direct result of health education policies (e.g., early cancer prevention measures for women, anti-smoking campaigns to combat lung cancer) that have only been implemented in some countries, or the outcome of a change in the social and economic structure that affects most populations of today’s low mortality countries. The latter seems plausible given that the proportion of more highly educated people has risen during this century and hence provided more and more individuals with access to better health information and the development of preventive lifestyles.

All these arguments indicate that enormous potentials for further increases of longevity exist, and they might be the milestones of the path our postindustrial society will follow toward a truly new phase in health transition. Without overlooking the effects of economic change on a society’s mortality level, the possibility for this new phase to become a reality depends on the interplay between a new health culture and further discoveries in treatment, therapy, and bio-genetic and biomedical techniques. The former would act on the individual and social control over risk factors and the possibility of making an early diagnosis; the latter would provide more prompt and effective structures and treatment. Consequently, the recent increased pace of the decline in mortality in more developed countries appears to justify hope for further significant gains in life expectancy.

Population scientists, including demographers and epidemiologists, have long been aware that the diversity in mortality levels and patterns across individuals and populations is the net result of a host of interactions between societal, environmental, biological, and behavioural variables, the mechanisms of which remain elusive (Lopez, Caselli & Valkonen 1995). A death above age 30 generally results from a number of associated and competing pathologies and is rarely the result of a single morbid condition or injury. Demographic and descriptive epidemiological studies have typically assessed health patterns and trends in terms of the immediate medical cause of death. A broader and more relevant concept is that of "determinants of mortality" that may affect several medical causes of death, e.g. smoking as a cause of lung cancer.

Considering the causality, some determinants have a negligible impact on adult mortality in industrialized countries. Rather their impact is much more likely to be felt through interactions that are often synergistic with individual health behaviour (e.g. smoking) and can substantially alter the risk of death from certain causes. Besides acting directly and indirectly, determinants of mortality also operate dynamically throughout an individual life course. Each individual's life course starts with a basic situation at birth, to which various careers are added (e.g. Graham 2002; Kuh et al. 2003; Kuh & Shlomo 2004). Each of these careers is defined by different states and events, and can influence the individual risk of dying either immediately or through an accumulation of factors. Studies of mortality then have to incorporate temporal variation exposures, with conceptual frameworks for adults having to take into account the life history of individuals (Caselli 1991; Caselli et al. 1991; Caselli, Duchène & Wunsch 1987; Caselli & Lopez 1996). In particular, studies have demonstrated that the life conditions experienced in infancy and childhood have an impact on mortality at old ages (Bengtsson & Lindström 2000; Doblhammer 2004; Montez & Hayward 2011).

In today's developed countries, individual lifestyle (smoking, alcohol and drug abuse, and obesity) is a dominant factor in the survival of adults. An important contribution can also be attributed to socioeconomic status, as outlined in Section 3.2.5 (see also Marmot 1995), or educational level, possibly deriving from relative wealth (e.g. availability and use of health services). Genetic factors and selection effects may also play an important role in determining the longevity of the elderly, in part through interactions with adverse health behaviour. Understanding all of the determinants of mortality and their interactions and changes over time is a complex undertaking. The problem is made even more difficult by the consideration that the evolving economic, social, environmental, and cultural situation in the developed world could with time produce new risks factors (such as obesity or drug overdoses), create new pathologies (e.g. the emergence of AIDS), or lead to the spread of others (such as Alzheimer's and other neurodegenerative diseases). However, if the passage from the mortality patterns of the ancient regime to those emerging in a modern industrial society permitted average life expectancy to double, it is reasonable to expect that this new emergent phase is characteristic of a modern knowledge-based, post-industrial society and will lead to further increases in life expectancy. A more difficult question is to assess if the pace of life expectancy increases will continue.

4. Expert Survey on Future Trends of Life Expectancy in Low Mortality Countries

In 2011, a global internet survey on likely future trends in fertility, mortality, migration, and the main factors behind them (i.e., their relevance and impact) was conducted among the members of major population associations and selected other professional organizations. The survey, a collaboration between IIASA's World Population Program and Oxford University, is the basis for new population forecasts by age, sex, and level of education for most of the world's countries, as presented in Lutz, Butz, and KC (forthcoming). For the survey, experts selected a country for which, as part of their assessment, they provided numerical estimates of the likely range of the gain in life expectancy between 2020 and 2030, and between 2040 and 2050 ("best guess" estimates plus 80 percent uncertainty intervals). The experts could add additional countries or regions for their assessments. Altogether, the low-mortality module was completed for 30 countries by 75 experts. For summarizing the results in this section we grouped the countries into five regions.

Table 1: Number of experts and assessed countries in the IIASA-Oxford Demographic Expert Survey

North America		Western Europe		Asia	
Canada	3	Austria	3	China	1
United States of America	20	Germany	2	Indonesia	3
		Italy	4	Iran (Islamic Republic of)	3
		Netherlands	1	Japan	1
		Norway	1	Occupied Palestinian Territory	1
		Spain	1	Philippines	1
		Sweden	2	Thailand	3
		Israel	*1*	Vietnam	1
Latin America		**Eastern Europe**		**Total**	
Argentina	3	Bulgaria	1	Countries	30
Brazil	5	Czech Republic	3	Experts	75
Costa Rica	3	TFYR Macedonia	1		
Cuba	1	Romania	1		
Mexico	2	Russian Federation	1		
		Serbia	1		
		Ukraine	1		

Table 1 presents for each region the included countries and the corresponding number of experts who assessed the mortality trends for these countries. The highest number of assessments was provided for the US (20 experts), while most other countries were assessed by three or fewer experts. There is one exception to the regional composition of Section 2, as we include Israel in Western Europe because its mortality level is more comparable to the Western European countries than to the selected Asian countries (see Section 2.5). The expert assessments were analysed along two key dimensions: (1)

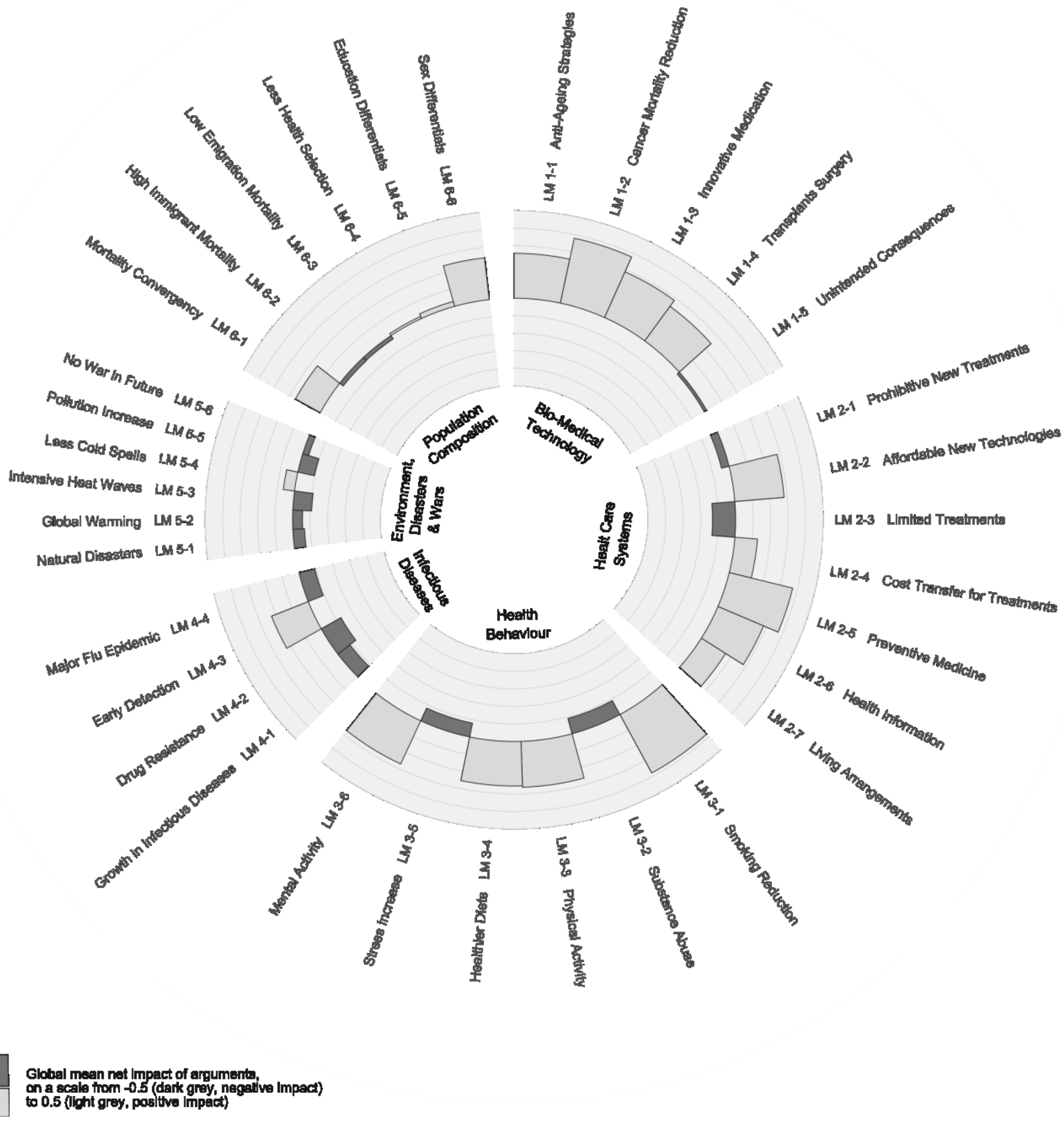
estimates for future trends in life expectancy and (2) rankings of the relevance and impact of individual arguments pertaining to the expected main factors behind future trends.

The following results refer to the experts' final projections of life expectancy at birth, illustrated alongside with the empirical trends since 1950-55 and comparisons to the projections of the 2010 revision of the UN World Populations Prospects until 2050-55 (United Nations 2011). Hence, the experts' estimates refer to the decades 2020-30 and 2040-50 respectively. The gains in life expectancy for the 2005-20 and the 2030-40 time periods are derived from interpolating the decadal estimates related to the initial values of the period in 2005. The grey areas around the expert trend indicate the range of the 80 percent uncertainty intervals assessed by the experts. The regional and global estimates were further weighted by the population sizes of the countries based on the actual UN data and the corresponding medium variant predictions until 2050-55 (United Nations 2011). For comparing the regional mortality trends estimated by the experts with those by the UN, we selected only those countries for which the experts have assessed the future gain in life expectancy.

After providing numerical estimates for the decadal gains in life expectancy, the experts were asked to assess the validity and relevance of alternative arguments about the forces that could shape future mortality trends in the country or region they chose. In total, the survey contains 34 arguments that were grouped into six clusters: (1) changes in bio-medical technology, (2) effectiveness of health care systems, (3) behavioural changes related to health, (4) possible new infectious diseases and resurgence of old diseases, (5) environmental change, disasters and wars, and (6) changes in population composition and differential trends in population subgroups (all single arguments can be found in the appendix of this paper). For each argument the experts could assess its likelihood, its conditional impact, and its net impact. The validity was measured along the following response scale: very likely wrong; more likely wrong than right; ambiguous; more likely right than wrong; and very likely right. The conditional impact gives the respondents' assessments regarding the consequences of the argument for future life expectancy, if it becomes true. The scale comprises five categories for the arguments' effect on future life expectancy: strongly decreasing; moderately decreasing; none; moderately increasing; and strongly increasing. Validity and conditional impact were then used to determine an argument's net impact on future life expectancy. In the survey, these net impacts were predefined as a combination (multiplication) of an argument's validity and its conditional impact, but the experts were free to change the calculated mean net impacts if they wished to do so. At the end of the questionnaire the experts could assign each cluster of arguments its relative importance for future trends in life expectancy.

Figure 4 presents the net impact of each argument in a Circos plot. Each segment of the plot presents one cluster, with the size of the segment depending on the importance of the cluster as assessed by the experts. The most significant clusters include arguments about behavioural changes related to health (25% importance), effectiveness of health care system (20% importance) and changes in biomedical technology (19% importance). Beyond the relevance of those clusters, the displayed segments also contain the arguments with the highest net impact for all considered low-mortality countries. A positive impact on future mortality is mainly expected from reduction in smoking prevalence (LD3-1), breakthrough in the understanding of carcinogenic processes (LD1-2), and progress in preventive medicine (LD2-5). In contrast, the highest negative impact is expected to come from limited access to medical treatments due to the growing elderly population (LD2-3), abuse of alcohol and drugs (LD3-2), and expected increase in morbidity caused by increased stress level (LD3-5).

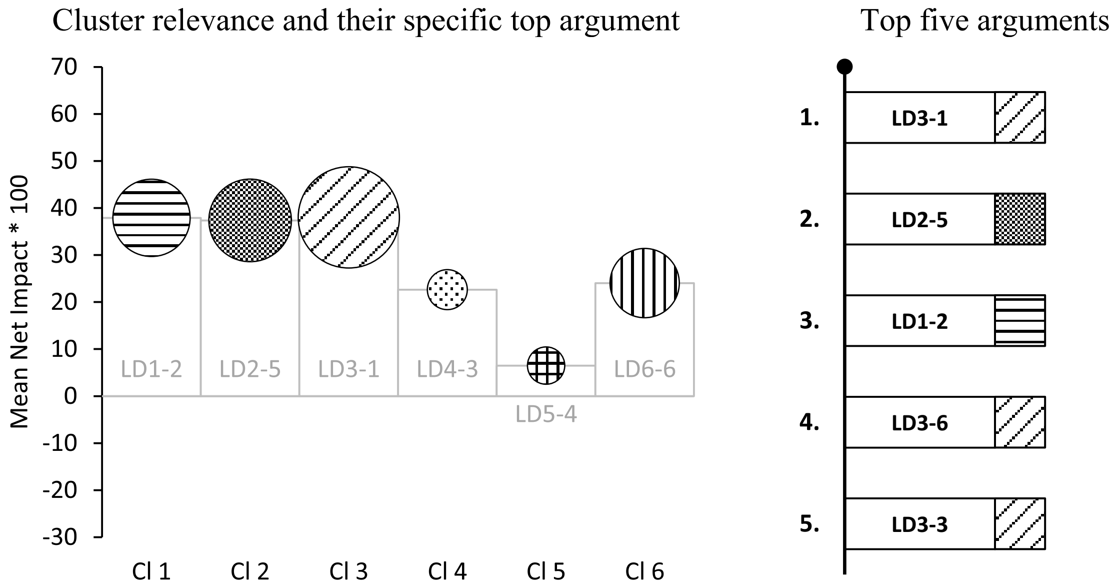
Figure 4: Number of experts and assessed countries in the IIASA-Oxford Demographic Expert Survey



Data: IIASA-Oxford Demographic Expert Survey; own calculations

Another way of analysing the expected impact of arguments is presented by ranking net impact in relation to the relevance of the underlying clusters. Since the net impact of an argument can be either positive or negative, we used the absolute value in the characterisation of the overall ranking. In the left panel of Figure 5 each cluster is represented by one circle, with the size of the circle symbolising the importance of the cluster. Moreover, the location of the circle along the y-axis shows the argument with the highest net impact on future life expectancy within the specific cluster. Circles located in the positive area indicate a positive impact of future survival conditions, and vice versa.

Figure 5: Cluster relevance and the ranking of highest impact arguments for all low mortality countries

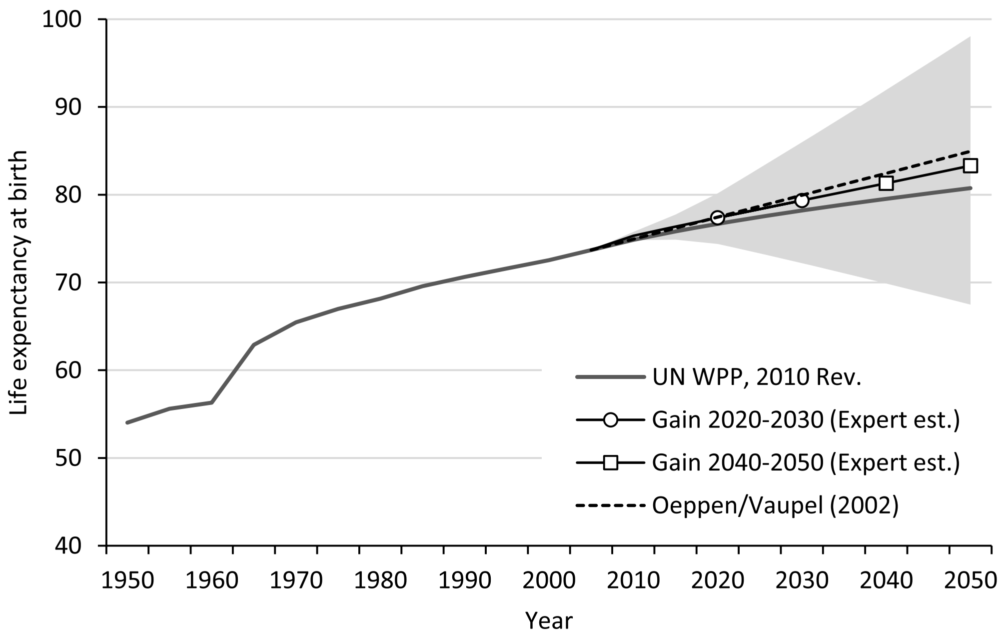


Data: IIASA-Oxford Demographic Expert Survey; own calculations

Figure 5 shows that the arguments with the highest net impact are included in the most relevant clusters. This pattern is reflected in the left panel of the graph. The group of behavioural arguments (third circle) is assessed as the most important cluster for future life expectancy, with the most important argument being the decrease in the prevalence of smoking (LD3-1). The second rank is occupied by changes in biomedical technology (first circle). Within this cluster, expected breakthroughs in understanding of carcinogenic processes (LD1-2) have the highest impact on future life expectancy. The effectiveness of the health care system (second circle) places third in the ranking. The greatest influence on future survival, based on the arguments that make up this cluster, is expected progress in preventive medicine (LD2-5). Figure 5 also presents the rankings of the other clusters and their most relevant argument. The cluster concerning changes in population composition and differential trends in population subgroups (sixth circle) holds fourth place. Within this group, reduction of the sex differential in mortality (LD6-6) has the highest impact. But the value of the net impact is visibly lower than the arguments of the three main clusters. The last ranked clusters include arguments about the possibility of new infectious diseases and the resurgence of old diseases (fourth circle), as well as the influence of environmental changes, disasters and wars (fifth circle). The main arguments within these clusters are increased capability of early detection and control to avoid the spread and impact of new infectious diseases (LD4-3), and the minor positive effect of less extreme winters on survival of the elderly (LD5-4).

The combination of the cluster balance and the net impact of single arguments allows a further total ranking of all arguments. The right panel of Figure 5 presents the five arguments with the highest assessed impact on future life expectancy weighted by the cluster relevance. This ranking is mainly dominated by behavioural factors. The argument ranked first, decreasing smoking prevalence (LD3-1), is supplemented by increasing mental and social activities to prolong lifetime among the elderly (LD3-6, fourth rank) and expected increased awareness of the importance of physical activity to counteract obesity (LD3-3, fifth rank). The second-ranked argument, however, is dedicated to progress in preventive medicine (LD2-5), while breakthrough in carcinogenic processes (LD1-2) occupies the third rank. Altogether, these top arguments are all assessed as having a positive effect on future life expectancy.

Figure 6: Previous and expected future global trend in life expectancy at birth

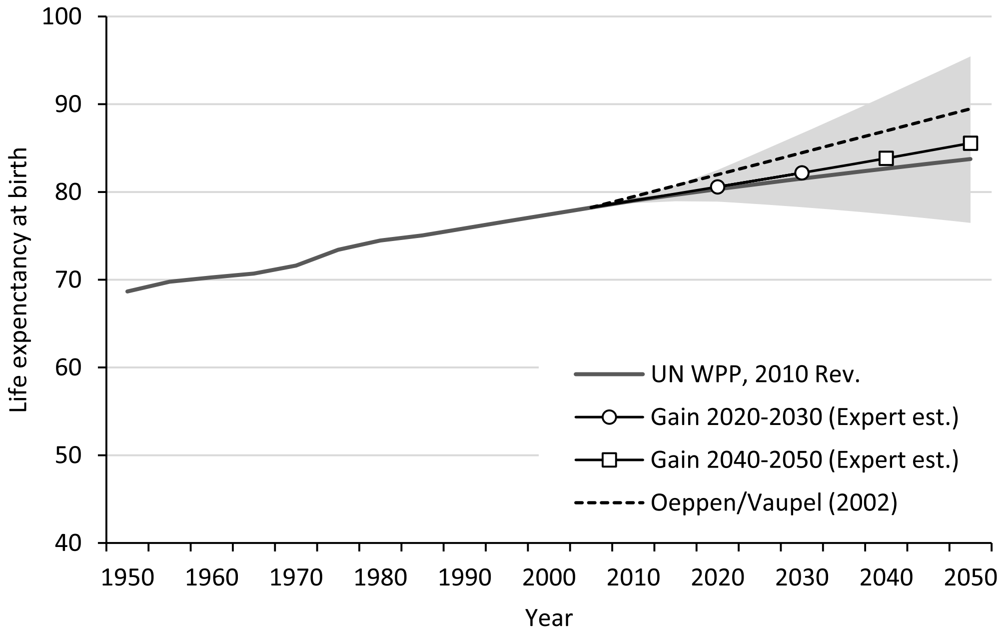


Data: IIASA-Oxford Demographic Expert Survey, UN World Population Prospects, 2010 Revision (UN 2011); own calculations

The resulting global trend in future life expectancy is presented in Figure 6. In the past, life expectancy increased from 54.0 years in 1950-55 to 73.4 years in 2005-10. The UN (2011) estimates in their medium variant a further increase to 80.8 years in 2050-55.

However, the experts assessed a constant gain in life expectancy of two years for the decades 2020-30 and 2040-50. Consequently, the predicted life expectancy is 83.3 years and thus 2.6 years higher than the UN projection. The uncertainty range assessed by the experts presents a wide range of 67.5 to 89.1 years by the end of the projection period. Note, however, that this uncertainty reflects the fact that several experts did not modify the wide limits of the uncertainty range set in the online survey. Figure 6 also shows the optimistic linear trend of life expectancy as proposed by Oeppen and Vaupel (2002). These authors have derived a yearly increase in life expectancy of about 0.25 years per year for countries with the highest life expectancy (see Section 3.3.2). This assumption implies that the life expectancy for the last projection period 2050-55 increases to almost 85 years, 1.6 years higher than the experts' assessment. These results reflect a global perspective on future life expectancy wherein the expected impacts of several arguments are computed as the averages of the expert assessments for different countries and regions. These global estimates indicate that the experts' best guess expectations lie below the optimistic linear pattern suggested by Oeppen and Vaupel (2002), a relationship that is valid for most of the regions.

Figure 7: Previous and expected future trend in life expectancy at birth for Northern America

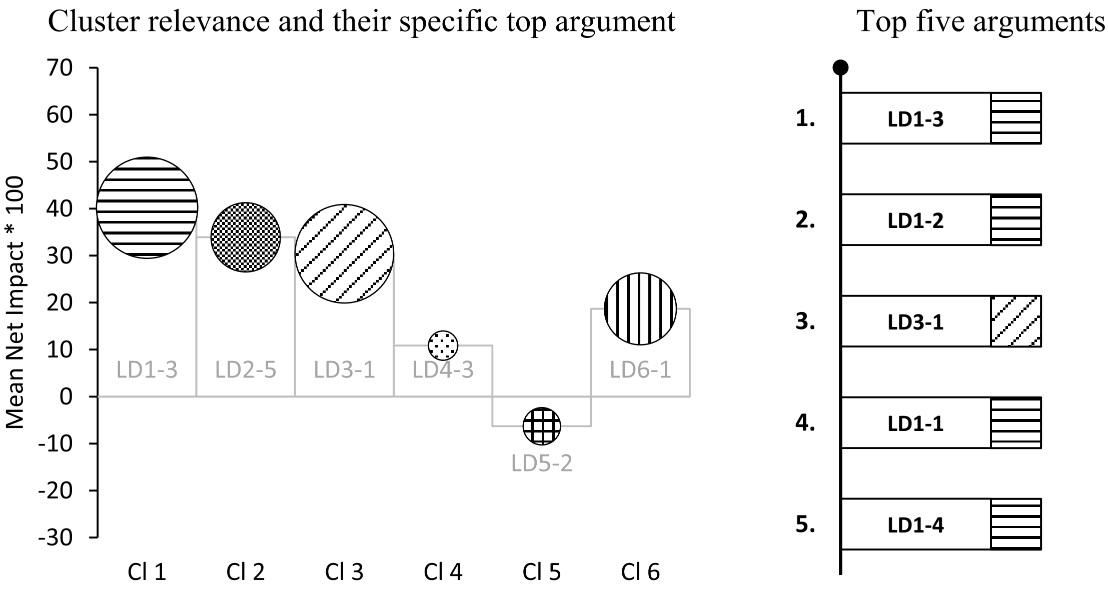


Data: IIASA-Oxford Demographic Expert Survey, UN World Population Prospects, 2010 Revision (UN 2011); own calculations

An extreme example of this difference between the “Oeppen/Vaupel-line” and the experts’ assessments is North America. Figure 7 shows that the trend predicted by the experts for 2050-55 is 85.6 years, 1.8 years higher than the UN estimate of 83.8 years. But the optimistic trend (Oeppen/Vaupel-line) for North America suggests a much stronger increase to 89.5 years, almost four years higher than the estimate put forward by the experts. For the European and Asian regions, on the other hand, the difference between the expert assessments and the optimistic line is significantly lower compared to North America.

Another interesting point is the ranking of the underlying arguments for future survival in North America (Figure 8). Biomedical improvement (first circle) was assessed as being the most important cluster. Within this group, as well as for all other clusters, the argument about innovative medicine and the expected containable effect on life threatening diseases is assumed to have the highest positive impact on life expectancy. The group of arguments relating to changes in health-related behaviour (third circle) holds second rank. The decline in smoking prevalence has the highest expected impact on life expectancy within this cluster. Changes in population composition and differential trends in population subgroups (sixth circle) are ranked third.

Figure 8: Cluster relevance and the ranking of highest impact arguments for Northern America



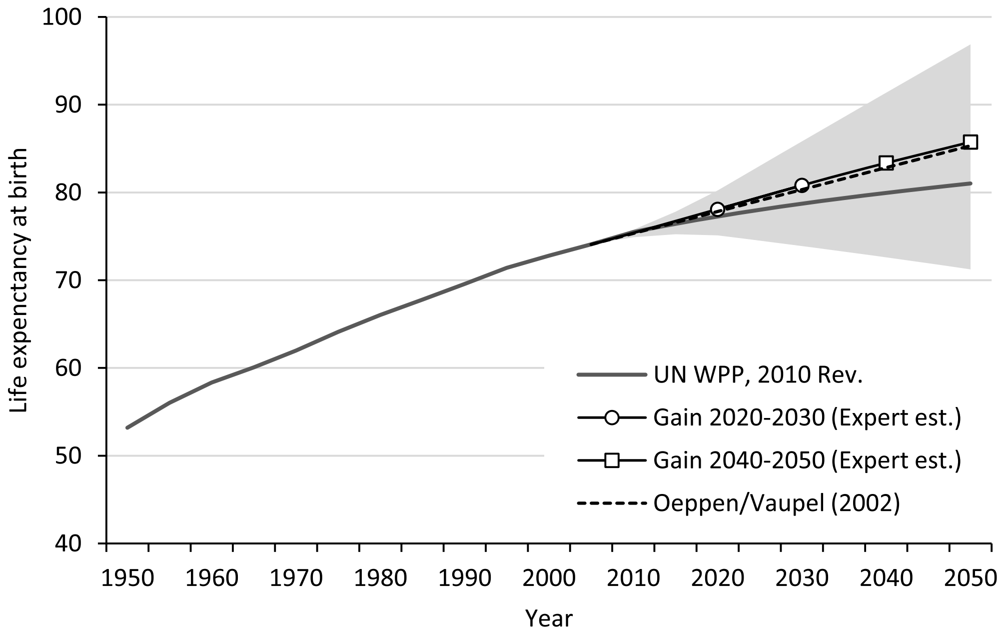
Data: IIASA-Oxford Demographic Expert Survey; own calculations

The greatest influence on future survival is expected from convergence of mortality among ethnic minorities to mortality of the indigenous population (LD6-1). Although the assessed impact of further progress in preventive medicine on life expectancy (LD2-5) is higher than that of population composition and, surprisingly, of reduction in smoking, the entire cluster concerning effectiveness of the health care system ranks only fourth. The last-ranked clusters include arguments about influence of environmental changes, resurgence of old infectious diseases, and the possibility of new infectious diseases.

Although the cluster ranking almost follows the global one, the ranking of the top arguments (right panel of Figure 8) is dominated by the cluster about biomedical technology. Thus, progress in innovative medication (LD1-3, first rank), expected breakthrough in cancer treatment (LD1-2, second rank), development of effective anti-ageing strategies (LD1-1, fourth rank), and improvements in surgery including transplants and implants (LD1-4, fifth rank) are expected to be the major drivers of future increases in life expectancy in North America. Only the third rank is not dedicated to the progress of biomedical technology, but to health behavioural changes. As in the global perspective, on-going decrease of smoking prevalence (LD3-1) is assessed to reduce future mortality.

Only in the Latin American region did the experts assume a linear trend in life expectancy, reflecting almost exactly the optimistic “Oeppen/Vaupel-line” (see Figure 9). While the UN predicts an increase in life expectancy from 74.0 years in 2005-10 to 81.0 years in 2050-55, the experts expect an increase to 86.0 years in the last projection period. An interesting consequence of this linear increase is that Latin America is expected to become the region with the second highest life expectancy in 2050-55. Only Western Europe is assumed to have a higher life expectancy of 90.1 years. The life expectancy in all other regions is expected to be lower, with 85.6 years in North America, 82.1 years in Asia, and 79 years in Eastern Europe.

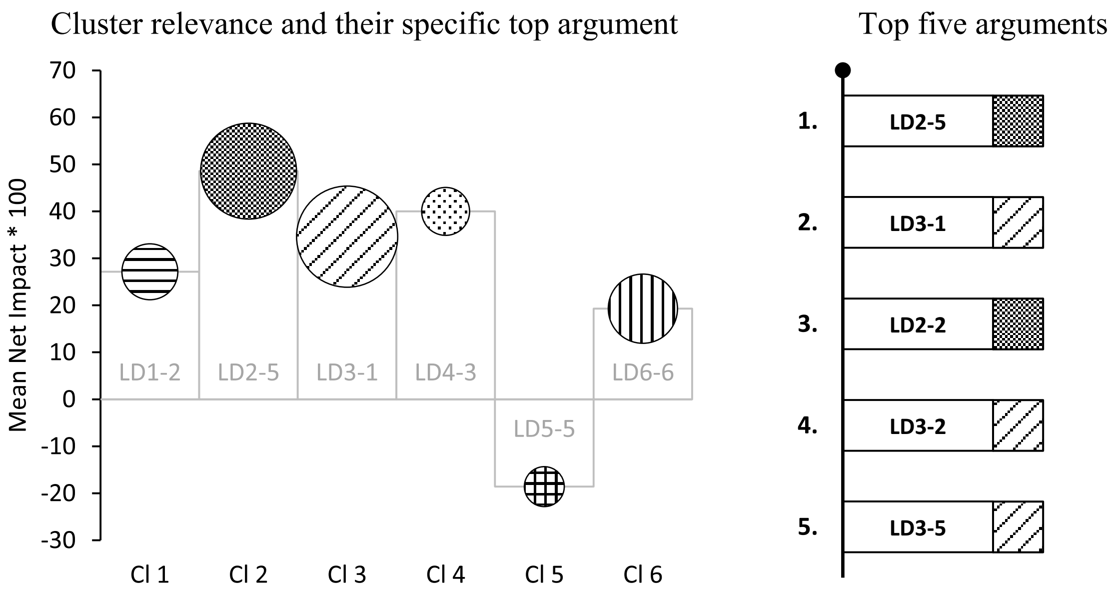
Figure 9: Previous and expected future trend in life expectancy at birth for Latin America



Data: IIASA-Oxford Demographic Expert Survey, UN World Population Prospects, 2010 Revision (UN 2011); own calculations

Alongside the exceptional trend in life expectancy, the experts also assessed different cluster relevancies for Latin America. The most important cluster is again related to changes in health-related behaviour (third circle), as illustrated by the biggest circle in the left panel of Figure 10. Reduction of smoking prevalence (LD3-1) is expected to play a major role. The second ranked cluster includes all arguments about the effectiveness of health care systems (second circle). The main argument within this cluster is further progress in preventive medicine (LD2-5), which has a net impact 15 points higher than decline in smoking prevalence. The third rank is occupied by the cluster about changes in population composition and differential trends in population subgroups (sixth circle). It is only in Latin America and Asia that the experts ranked this cluster within the top-three, with the most important arguments being the reduction of sex differentials in mortality (LD6-6). In all other regions, the three main clusters refer to health-behavioural changes, progress in biomedical technologies, and effectiveness of the health care system. A further interesting characteristic for Latin America is the relatively high net impact compared to other regions of the expected improvement of earlier detection and control of the occurrence of new infectious diseases (LD4-3), although the related cluster is only ranked fourth.

Figure 10: Cluster relevance and the ranking of highest impact arguments for Latin America

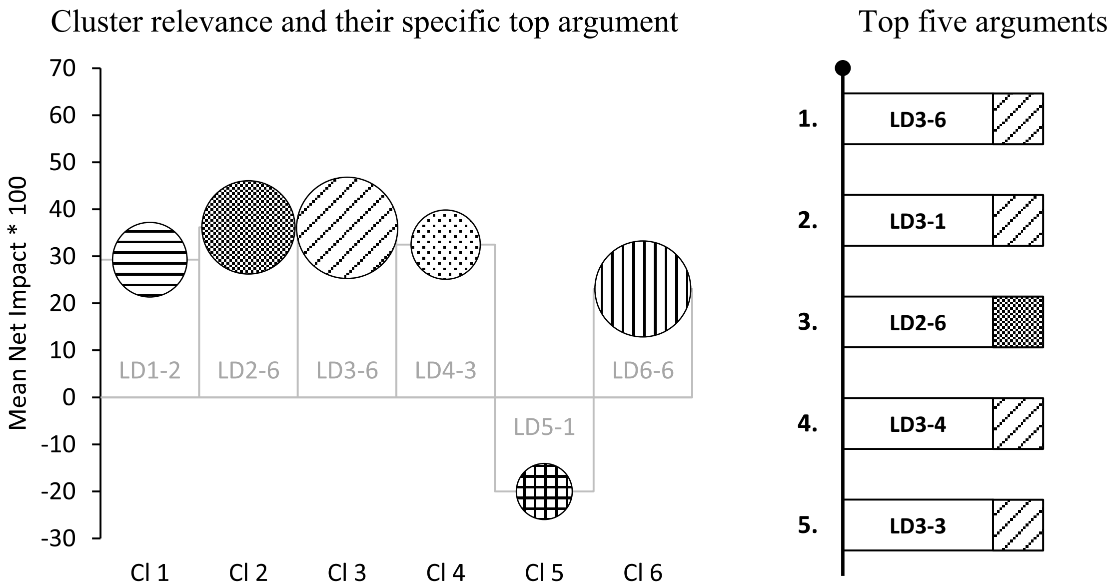


Data: IIASA-Oxford Demographic Expert Survey; own calculations

The top five ranking of arguments (right panel of Figure 10) is composed of the expected ongoing effectiveness of health care systems and health-behavioural factors. The first rank is occupied by future progress in preventive medicine (LD2-5). Moreover, the presence of effective and easily affordable new technologies (LD2-2, third rank) is expected to improve future survival conditions. All other arguments in the top five belong to the cluster about changes in health behaviour. The decrease in smoking prevalence (LD3-1, second rank) is expected to reduce future mortality. The other arguments relating to alcohol and drug abuse (LD3-2, fourth rank) and increasing stress levels (LD3-5, fifth rank) are assessed as being factors that will increase future mortality.

The dominance of behavioural factors in the ranking of the top five arguments is also valid for Europe and Asia. In particular, decrease in smoking prevalence is assumed to be the key factor for the future trend in European life expectancy. Both Eastern and Western Europe share the same pattern of cluster relevance, the one seen in the global perspective. However, this does not hold for Asia, where the importance of clusters and the top ranked arguments are interestingly different from the other regions. Analysis of the cluster relevance, illustrated in the left panel of Figure 11, shows the almost identical importance of each group of arguments. Although behavioural factors play a major role in the experts' expectations for future life expectancy, the other clusters, especially the ones relating to the occurrence of new infectious diseases, environmental changes, disasters, and wars have a higher relevance than the assessments for the other regions. This pattern could be caused by the heterogeneous composition of countries within this region, which includes both Japan, with the highest worldwide life expectancy, and the Occupied Palestinian Territory, where life expectancy is around 10 years lower.

Figure 11: Cluster relevance and the ranking of highest impact arguments for Asia



Data: IIASA-Oxford Demographic Expert Survey; own calculations

As in most regions, the highest ranked arguments in Asia are dominated by health behavioural factors (right panel of Figure 11). Indeed, the most relevant argument is not decrease in smoking prevalence as in the global perspective, but positive impact of increasing mental and social activities among the elderly (LD3-6). Reduction of smoking prevalence (LD3-1) is ranked second. The third rank is held by expected better and faster medical and health information dissemination (LD2-6), which aims to improve the effectiveness of future health care systems. The fourth and fifth ranks again refer to health behaviour. Increased awareness of the importance of nutrition (LD3-4) and increase of physical activities (LD3-3) are assessed as having a positive effect on future life expectancy. The last two factors also play a major role in the future trend of life expectancy in Western and Eastern Europe.

The main conclusions of the expert assessments for low mortality countries is characterised by a stronger increase in future life expectancy compared to the UN estimations. In the case of Latin America, the predicted trend is identical to the optimistic linear increase in life expectancy by 0.25 years per year according to the "Oeppen/Vaupel-line". However, the range of uncertainty always includes both the UN estimations and the linear trend proposed by Oeppen and Vaupel (2002). These assessments also show that the future trend in life expectancy is expected to be influenced mainly by health behavioural factors such as reduction of smoking prevalence, effectiveness of health care systems (with the ongoing progress of preventive medicine as the major argument), and growth of biomedical technologies, with the main aim of understanding and treating carcinogenic processes.

5. Meta-Experts' Assessment of Future Life Expectancy Trends

The information in the previous sections provided the basis for the meta-experts meeting that took place in San José, Costa Rica on February 21-22, 2012.[6] The primary purpose of the meeting was to develop storylines for the "best guess" as well as the "optimistic" and "pessimistic" scenarios for future life expectancy trends in low mortality populations. This section summarizes the outcomes of these storylines for Europe, North and Latin America, and Asia.

5.1. Storylines for Europe

Most experts believe that life expectancy in Europe will continue to increase. To achieve substantial gains in life years until 2050, several conditions have to be fulfilled. Most importantly, behavioural changes, especially reductions in smoking, need to continue. To continue over time, behavioural changes would have to be supported by a continued educational expansion. In Eastern Europe people would also have to decrease their alcohol consumption, and countries in the region would have to improve their health care systems. For Europe as a whole, medical progress will have to contribute substantially to increasing

[6] Participants of the meta-experts meeting: Gilbert Brenes, Central American Population Center, University of Costa Rica; Graziella Caselli, University of Rome La Sapienza, Italy; Sven Drefahl, Stockholm University, Sweden; Michel Guillot, University of Pennsylvania, US; Wolfgang Lutz, Wittgenstein Centre, Austria; Marc Luy, Wittgenstein Centre, Austria; France Meslé, INED, Paris, France; Arodys Robles, Central American Population Center, University of Costa Rica;, Richard G. Rogers, University of Colorado at Boulder, US; Sergei Scherbov, Wittgenstein Centre, Austria; and Edward Tu, Hong Kong University of Science and Technology.

life expectancy, especially through progress against diseases such as cancers and neurodegenerative diseases such as dementia.

European life expectancy may also increase more slowly or even start to stagnate. Such a scenario is possible in Eastern Europe if the current life style issues remain unchanged for a long period. In the rest of Europe the most hazardous life style characteristic is smoking. If the smoking epidemic in women continues or the reduction of smoking prevalence in men stops, life expectancy increase would be dampened. Economic stagnation or an economic crisis could have a similar effect, especially if there is an increase in the number of people without significant resources. Another problem could occur if the European health systems, which stand out for their universal availability, do not have the means to function as desired. Other factors that could contribute to a slower increase in life expectancy are speculative and include the development of drug resistance in existing diseases, the appearance of new diseases, and the creation of new technologies and materials that might prove dangerous.

5.2. Storylines for Northern and Latin America

Similar to Europe, most experts believe that life expectancy in the Americas will continue to increase. In such positive scenarios life expectancy at birth could reach 90 years by 2050, which corresponds to a decadal increase of about 2.5 years. It is expected that the factors contributing to this positive scenario are similar for the countries of North America and Latin America. The most important factors expected to increase life expectancy in North America are continued improvements in health behaviours, including further decreases in smoking, drinking, and drug abuse, as well as increases in physical activity to counteract trends in obesity. These changes are closely linked with continued progress in educational attainment. For Latin America, health behaviours are expected to be the second most important factor; only improvements in preventive medicine, including the early detection of chronic diseases like hypertension and obesity, are considered more influential. The experts agree that biomedical research also must contribute significantly to allow life expectancy to increase rapidly.

Conversely, negative health behaviours, violence (especially homicides and suicides) and reductions in government support, including reductions in Social Security, Medicare, and Medicaid, could slow gains in life expectancy considerably, especially in North America. This negative trend could be even stronger if the health care system loses its effectiveness when larger proportions of the population begin to reach old age. Vulnerability of the elderly may increase because many may not be able to rely on family support, due to increased divorces, fewer children, and other changes in family structure. The effect of environmental changes is much less predictable; however, natural disasters could occur more frequently and affect life expectancy, especially in Latin America. Infectious diseases might also play an increasingly important role in some parts of Latin America.

5.3. Storylines for Asia

If it is true that current human life expectancy is far from a biological limit, better health behaviours fuelled by the rapid increase in education may also play an important role in Asia's future life expectancy. However, if life expectancy is to continue to rise at a quick pace, smoking prevalence must decrease and the number of smoking women must remain small. Further improvements in democratization and public health as well as new medical interventions will also play an important role in rapidly increasing life expectancy.

However, if women adopt the smoking behaviour of Asian men and thus smoking incidence remains stable, developments will be less positive. Negative health behaviours that imitate the lifestyle in Russia may also lead to only slow progress in Central Asia. Similarly, political turmoil and uncertainty are factors that may lead to only modest increases or even stagnation in life expectancy, particularly in East Asian and Muslim countries.

5.4. Expected Convergence and Optimistic Future Trends

At the end of the meeting, meta-experts expressed their expectations for future trends in life expectancy, indicating whether they support the optimistic or pessimistic views as described in Section 3.3. The majority identified themselves as optimists, expecting further increases of life expectancy during the coming decades with the changes being at least close to the increase described by Oeppen and Vaupel (2002). Moreover, the meta-experts expect that the differences between countries will further decline in the future, and they proposed to use a convergence model for the projections of future life expectancy with regional convergence processes.

6. Conclusions

The evidence presented in this paper indicates that that the positive influences on human mortality and life expectancy will likely outweigh the negative risk factors, thus supporting the optimists' perspective on future trends in life expectancy. The possibility that new risk factors and/or new diseases will occur in the future cannot be excluded, as outlined by the views of the pessimists and discussed in Section 3. However, the experience of how people in the past have dealt with such impacts provides reason to believe that future societies will profit from increasing education levels and thus be able to adapt to coming threats and challenges. The expectations gathered by both the expert survey (Section 4) and the meta-experts meeting (Section 5) pointed in this same optimistic direction, toward increases in future life expectancy in today's low mortality countries that are close to or somewhat below the 2.5 years per decade increase as indicated by the so-called "Oeppen/Vaupel line" (see Section 3.3.2). Moreover, the meta-experts agreed that the differences in life expectancy between countries are likely to narrow further in the future, suggesting a regional convergence process for projections of future life expectancy.

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Appendix

List of arguments for assessing future mortality trend in low-mortality countries

Module 1: **Progress in Bio-medical Technology**	
LM1-1	Increased understanding of bio-medical ageing processes will allow us to develop effective anti-ageing strategies
LM1-2	Breakthroughs in the understanding of carcinogenic processes will lead to substantial changes in mortality from cancers
LM1-3	Innovative medication will make hitherto life threatening diseases containable
LM1-4	Improvements in surgery including transplants and implants will improve longevity
LM1-5	Unintended adverse consequences of new bio-medical technologies will outweigh their benefits

Module 2: **Health Care System**	
LM2-1	The cost of new treatments will be prohibitive to large segments of the population
LM2-2	There will be some very effective and easily affordable new technologies
LM2-3	Because of the growing elderly population there will be limited access and increased waiting times for treatment
LM2-4	Society will be able and willing to afford expensive new treatments
LM2-5	Progress in preventive medicine (e.g., screening, genetic testing) will decrease death rates
LM2-6	Better and faster medical and health information dissemination will improve longevity
LM2-7	Changing living arrangements will improve the health of the population, above all the elderly

Module 3: **Health-related Behaviour**	
LM3-1	Smoking prevalence will decline
LM3-2	Substance abuse (alcohol and drugs) will lead to more premature mortality and accidents
LM3-3	Increased awareness of the importance of physical activity will lead people to exercise more
LM3-4	Increased awareness of the importance of nutrition will lead people to adopt healthier diets
LM3-5	Increased stress levels will contribute to increased morbidity
LM3-6	Increasing mental and social activities at old age will increase longevity

Module 4: **Infectious Diseases**	
LM4-1	There will be a growth in infectious diseases leading to increases in overall mortality
LM4-2	Increasing drug resistance to known infectious diseases will increase mortality
LM4-3	Increased capability of early detection and control will help to contain the spread and impact of new infectious diseases
LM4-4	A major flu epidemic (avian or other) is likely to occur over the next 25 years

Module 5: **Environment, Disasters and Wars**	
LM5-1	Increased frequency and intensity of natural disasters (such as flooding and strong storms) will increase mortality
LM5-2	Global warming will lead to the spread of Malaria
LM5-3	More intensive heat waves during summer will increase mortality among the elderly
LM5-4	Less extreme cold spells during winter will decrease mortality among the elderly
LM5-5	Increased pollution including nuclear contamination will increase mortality
LM5-6	This country is unlikely to experience wars in the future

Module 6: **Population Composition**	
LM6-1	For ethnic minority groups already resident in this country and their descendants, mortality rates will converge to those for the indigenous population, thereby reducing mortality
LM6-2	The majority of new immigrants will come from countries where mortality rates are higher than in this country, thereby raising mortality
LM6-3	Emigration of low mortality populations from this country will raise mortality rates
LM6-4	Due to the considerably decreased levels of mortality in the young and youngest age groups, less health selection occurs and thus more frail people will reach middle and high adult ages, thereby increasing mortality at those ages
LM6-5	Mortality differentials between higher and lower education groups will increase
LM6-6	Mortality differences between men and women will decline

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