# AXA PAPERS

Risk education
and research

## No.1
## LONGEVITY


redefining / standards

# LONGEVITY

The advancements in longevity in developed countries have been dramatic over the last few decades, though these improvements do not impact all countries uniformly. Experts do not agree on what the future holds in terms of longevity. Some demographers estimate that the trend will continue at its current pace or perhaps more steadily than it has, while others argue that life expectancy will increase at a slower rate, stabilize, or even decline in some developed countries due to socio-environmental variables. The drivers of longevity remain complex, and the consequences of emerging threats (obesity, electromagnetic waves, genetic engineering, pollution, etc.) on life expectancy are controversial and hotly debated.

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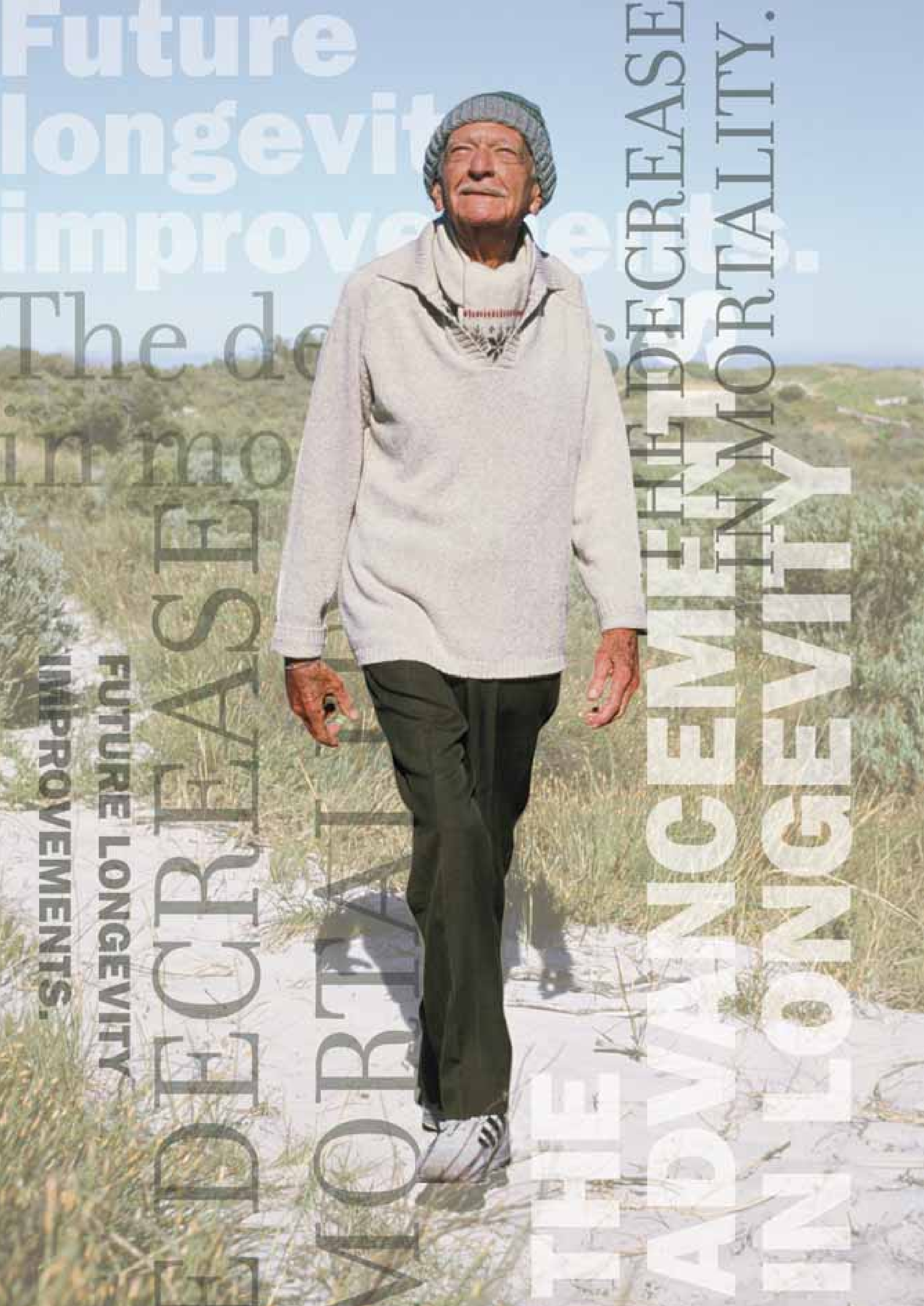
Future
FUTURE LONGEVITY
IMPROVEMENTS.
THE DECREASE
IN MORTALITY.
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# 1. EVOLUTION OF LONGEVITY

A recent study by James Vaupel[1] predicts that future longevity improvements will be such that half of the babies born in 2007 will reach the age of 102 in Germany, 103 in the United Kingdom, 104 in France and the USA, and even 107 in Japan. According to the authors, there would be no reason assume that this progress would not continue in light of the past improvements and considering that no indication of a slowdown of this progression has been detected thus far.

(1) Christensen, Vaupel et al. "Ageing Populations: the challenges ahead", The Lancet, 2009.

## *1.1. The main phases in the improvement of life expectancy*

Observing the increase in life expectancy over the last 150 years, consecutive gains due to the decrease in infant mortality are initially evident. These gains are followed by an improvement in mortality for adults, and then by a decrease most significantly impacting the elderly. Over the last twenty or so years, the decrease in mortality for women over the age of 80 has been the largest contributor to the higher life expectancy for women.

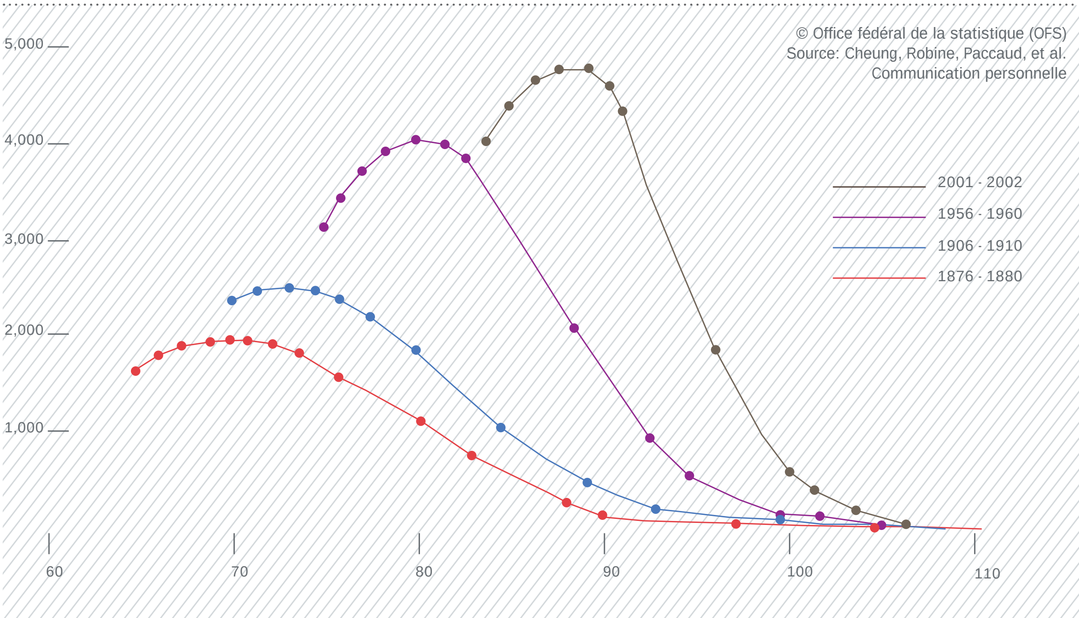
## Age-specific contributions to the increase of LE in women from 1850 to 2007

| | 1850-1900 | 1900-25 | 1925-50 | 1950-75 | 1975-90 | 1990-2007 |
|---|---|---|---|---|---|---|
| 0-14 years | 62.13% | 54.75% | 30.99% | 29.72% | 11.20% | 5.93% |
| 15-49 years | 29.09% | 31.55% | 37.64% | 17.70% | 6.47% | 4.67% |
| 50-64 years | 5.34% | 9.32% | 18.67% | 16.27% | 24.29% | 10.67% |
| 65-79 years | 3.17% | 4.44% | 12.72% | 28.24% | 40.57% | 37.22% |
| > 80 years | 0.27% | -0.06% | -0.03% | 8.07% | 17.47% | 41.51% |

Data derived from reference 12 and the Human Mortality Database. Source: Christensen, Vaupel et al.


Jean-Marie Robine presents an example of this progression in his article “The Future of Longevity in Switzerland”, with the graph below showing the shape of the distribution of age at death in Switzerland over different periods. We can clearly see that the curve shifts to the right, with peaks at increasingly higher ages. A similar pattern is also demonstrated for Japanese females.

## Age at Death - Distribution observed and smoothed – Women, Switzerland



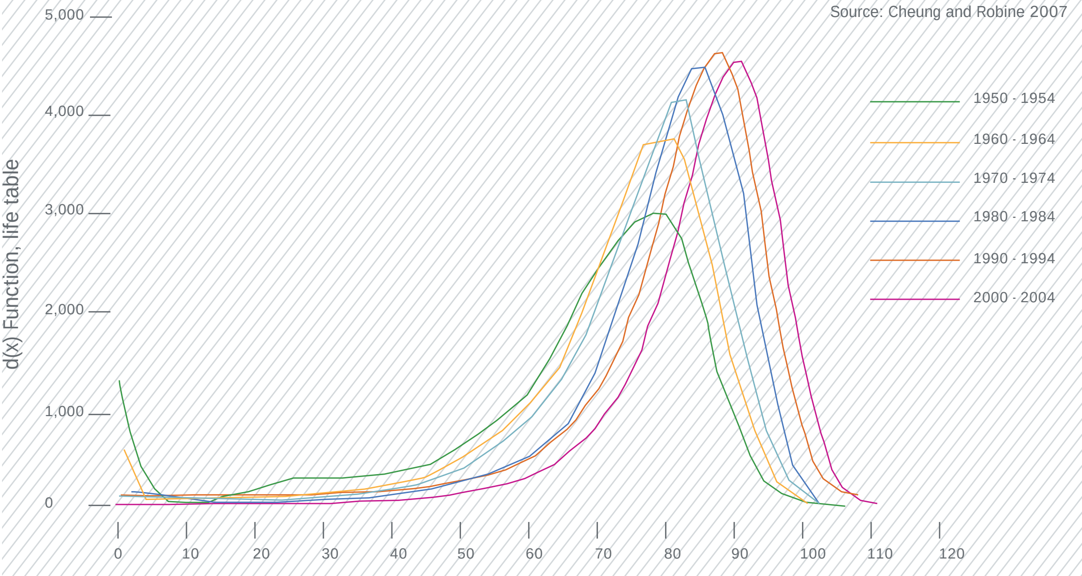
These different phases in the evolution of longevity also explain why life expectancy at birth is not always the best indicator of the trend, and that the analysis of life expectancy at ages 40 and higher could be more relevant.

A study by the National Office of Statistics in the United Kingdom shows that mortality reached a new low in 2008, with the rate of 700 deaths per 100,000 males and 499 deaths per 100,000 females. Over the last 40 years mortality has fallen 51% for males and 43% for females. During the 1960's and 1970's, the most significant gains in mortality were recorded for the ages between 35 and 59. Since 1980, the ages experiencing the largest decrease in mortality were those between 60 and 79.

This trend is widespread. The INED estimates that between 1952 and 2006 mortality between the ages of 40 and 70 has decreased nearly 50% in Western Europe (54% for females, 39% for males), though there are some significant disparities between countries. This decrease is mostly attributed to the decline in mortality from cardiovascular diseases for both men and women. Mortality from cancer, which remained stable before 1990, went up for males despite advancements in medicine, as did the rate of occurrence. However, mortality from cancer is currently decreasing for both sexes. The INED observes that behavior (alcohol, tobacco, physical exercise, nutrition) has a strong impact on the evolution of mortality.
With respect to the elderly population in countries having a high life expectancy, the rate of mortality continues to decline for ages 80 and higher, including for the countries having already experienced very low mortality for these advanced ages (e.g. France and Japan).

The result of this decrease in adult mortality for many countries is the quite significant increase in life expectancy around the world.

## Increase of the modal age at death for women in Japan from 1950-1954 to 2000-2004



Source: Cheung and Robine 2007


The CENSUS Bureau in the United States has projected that between 2008 and 2040 the population over age 80 will multiply by 223%.
Over the last 50 years, Japan has largely led the improvements in life expectancy at birth for both males and females.

nearly 10%

of the total population
in Western Europe will be
over the age of 80 in 2010.

### 1.2. A significant global trend

According to the latest available data for the Japanese population, life expectancy at birth is slightly more than 79 years for males and 86 years for females, a world record for both sexes. Over one year, the Japanese males have added on 37 days to their life expectancy and women 22 days. In the United States, the life expectancy in 2008 surpassed 78 years for the first time, and should reach 79 by 2015. The new mortality tables allow for an attainable age of 121.

This trend is observed worldwide; since 1900, life expectancy at birth has doubled in many countries (e.g. Spain, Greece, Austria) and has exceeded 80 years in 11 countries. In Eastern Asia, where the average life expectancy at birth was 45 years in 1950, is now higher than 73 years. Significant improvements have also been observed in Latin America, Eastern Europe and in some African countries.

One of the consequences of this increase in life expectancy is the increase in the number of centenarians. More than 40,000 centenarians are currently counted in Japan. 87% of these are women (the oldest woman being 114 years, and the oldest man 112). Similarly, there were 200 centenarians in France in 1950, which has surpassed 20,000 in 2008. This evolution is observable in the majority of industrialized countries.

The increase in life expectancy combined with the lower birth rate in virtually all countries is driving the aging of the global population. The CENSUS Bureau in the United States has projected that between 2008 and 2040, the population over age 80 will multiply by 223%, compared to 160% for the population over 65 years and 33% for the global population. This aging will affect all regions, including Sub-Saharan Africa.

In 2040, the portion of the population over the age of 65 should be more than 28% in Western Europe, around 25% in Eastern Europe, 20% in North America and Australia, 15% in Asia and South America, 13% in North Africa, 10% in the Middle East and 4% in Sub-Saharan Africa (compared to 3% today). Those over the age of 80 will represent nearly 10% of the total population in Western Europe (compared to 5% currently) and nearly 4% of the majority of the Asian population (compared to 1% currently).

### 1.3. Heterogeneous and contrasting experience across countries

The Human Mortality Database (HMD, data available at www.mortality.org), which provides general population data for 37 countries, the majority of which are developed, can be used for multiple analyses and comparisons across countries. The database is a result of the collaboration efforts between the Max Planck Institute and the University of Berkeley.

The first observation to be made in looking at the data is how specific the results are for each country. Over the last 50 years, Japan has largely led the improvements in life expectancy at birth for both males and females. Australia and Italy follow for men, and Spain and Italy for women. Some countries have relatively low improvements (USA, UK, Belgium). Looking at the life expectancy for a given age (age 65, age 40) also demonstrates the country-specificity of improvements.

*In Italy, males have realized an average annual gain of 3 months or a quarter of life expectancy at birth since 1960; and 4.2 months on the last ten years.*

## Annual improvement rates by country (months)

| | | Since 1960 | | Laste 10 years | |
|---|---|---|---|---|---|
| Country | Last available data | Males | Females | Males | Females |
| Australia | 2007 | 3.0 | 2.5 | 4.1 | 2.8 |
| Belgium | 2006 | 2.3 | 2.3 | 3.2 | 2.0 |
| Canada | 2005 | 2.6 | 2.3 | 3.4 | 1.8 |
| France | 2006 | 2.6 | 2.8 | 3.8 | 2.5 |
| Germany | 2006 | 2.7 | 2.6 | 4.0 | 2.6 |
| Italy | 2006 | 3.0 | 3.2 | **4.2** | **3.0** |
| Japan | 2007 | **3.5** | **4.1** | 2.4 | 2.7 |
| Luxembourg | 2006 | 2.8 | 2.5 | 4.3 | 2.6 |
| Spain | 2006 | 2.9 | 3.3 | 3.7 | 2.6 |
| Switzerland | 2007 | 2.7 | 2.5 | 3.7 | 2.4 |
| UK | 2006 | 2.4 | 2.0 | 3.6 | 2.6 |
| USA | 2006 | 2.2 | 1.9 | 2.8 | 1.6 |

Source: Human Mortality Database.

## Annual gain in life expectancy at birth by country (months)

| Country | Last available data | LEO Males | LEO Females | DIF Males Females |
|---|---|---|---|---|
| Australia | 2007 | **79.3** | 83.8 | 4.5 |
| Belgium | 2006 | 76.5 | 82.2 | 5.8 |
| Canada | 2005 | 77.9 | 82.5 | 4.7 |
| France | 2006 | 77.2 | 84.2 | **6.9** |
| Germany | 2006 | 77.2 | 83.2 | 5.1 |
| Italy | 2006 | 78.6 | 84.1 | 5.5 |
| Japan | 2007 | 79.2 | **86.0** | 6.8 |
| Luxembourg | 2006 | 76.7 | 81.8 | 5.1 |
| Spain | 2006 | 77.6 | 84.1 | 6.5 |
| Switzerland | 2007 | **79.3** | 84.1 | 4.8 |
| UK | 2006 | 77.5 | 81.7 | 4.3 |
| USA | 2006 | 75.5 | 80.7 | 5.2 |

Source: Human Mortality Database.

## Life expectancy at age 65

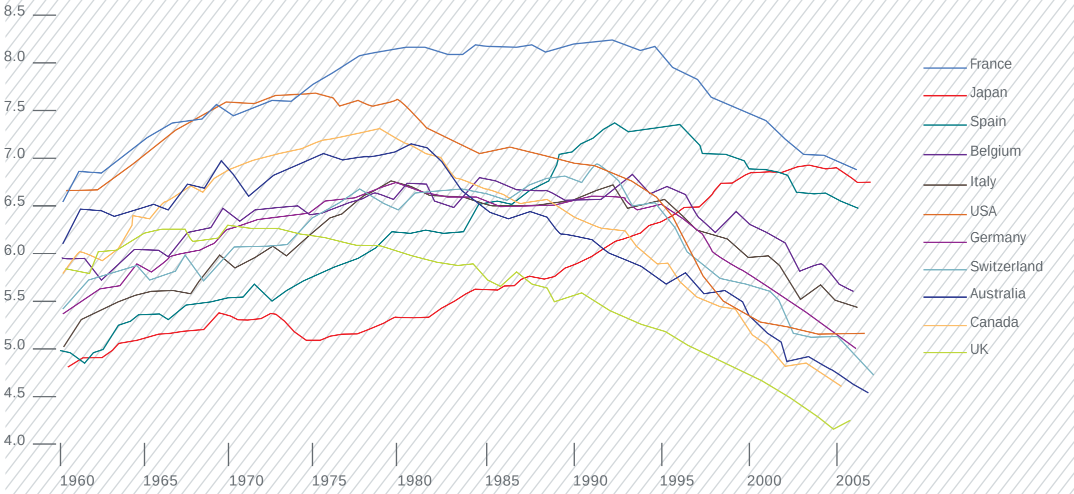
| Country | Last available data | LE 65 Males | LE 65 Females | DIF Males Females |
|---|---|---|---|---|
| Australia | 2007 | **18.7** | 21.7 | 3.0 |
| Belgium | 2006 | 16.9 | 20.5 | 3.6 |
| Canada | 2005 | 17.8 | 20.9 | 3.1 |
| France | 2006 | 18.0 | 22.4 | 4.3 |
| Germany | 2006 | 17.0 | 20.3 | 3.3 |
| Italy | 2006 | 17.8 | 21.6 | 3.8 |
| Japan | 2007 | 18.6 | **23.6** | **5.0** |
| Luxembourg | 2006 | 16.9 | 20.2 | 3.3 |
| Spain | 2006 | 17.7 | 21.6 | 3.9 |
| Switzerland | 2007 | 18.5 | 21.9 | 3.4 |
| UK | 2006 | 17.4 | 20.1 | 2.8 |
| USA | 2006 | 17.5 | 20.2 | 2.7 |

Source: Human Mortality Database.

Differences emerge within countries as well, such as India, where we observe significant persisting differences in life expectancy across regions; those in the South can expect to live longer than those in the North.

In all of the OECD countries, females have a higher life expectancy than males at every age. This difference reflects the fact that female mortality is lower than that of males for every age group and for most of the main causes of death. The reasons for this difference have not been clearly established, although the use of tobacco is often cited. The countries for which this difference is particularly striking are Japan (in 2007, a 6.8 year gap at birth and a 5 year gap at age 65) and France (in 2006, a 6.9 year gap at birth and 4.3 years at age 65). Not only is the difference between the sexes very specific by country, but the convergence of the gap also varies greatly. In some countries, such as Australia, the life expectancy of men seems to approach that of women, but this is not the case in others (notably ex-USSR countries in Eastern Europe).

## Convergence between males and females

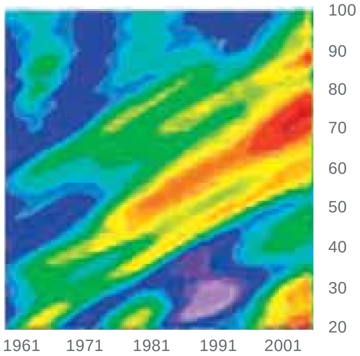



Source: Human Mortality Database.

### The cohort effect

Other trends are also emerging, such as the cohort effect, which is especially evident in the United Kingdom where the generation born between 1925 and 1945 has experienced impressive improvements in longevity, with improvement rates well above those born in previous generations, and even those born afterward. This cohort effect is not homogenous across countries or periods. Biomedical researchers are becoming more and more interested in the cohort effect, which could result from exposure from a young age to certain socio-environmental variables.

This graph represents the annual rate of improvement by year and by age, and the diagonal bands of colour clearly show the cohort effect for some generations. This implies that some generations experience more significant rates of improvement than others over periods of longer or shorter duration.




Cohort effect for England & Wales
Annual improvement rate [q(x,t)-q(x,t-1)] / q(x,t-1)

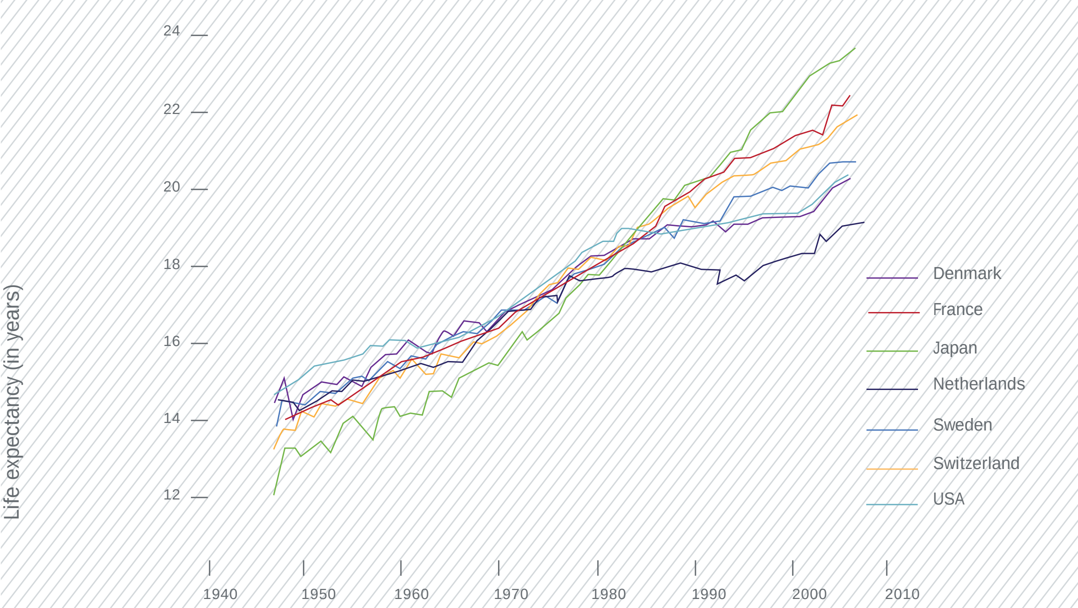
### Convergence across countries?

Beyond the convergence between males and females within a country, is there a convergence between countries? The trend is not clear—in some countries, life expectancy is even decreasing. According to OECD data, Russian males have seen nearly 4 years taken off of their life expectancy between 1985 and 2004 (59.9 years compared to 63.8; 72.3 years compared to 74 for Russian women). The reasons cited for the decrease is the decline in the quality of the health care system, the consumption of alcohol and a degradation of socio-economic conditions. In Africa (particularly in the south), we observe for several countries a stagnation, or even a decline in life expectancy at birth due to the AIDS epidemic, which affects many children and young adults. For example, WHO estimates in its *World Health Report 2003* that life expectancy at birth in Botswana has decreased by 29 years between 1990 and 2004.

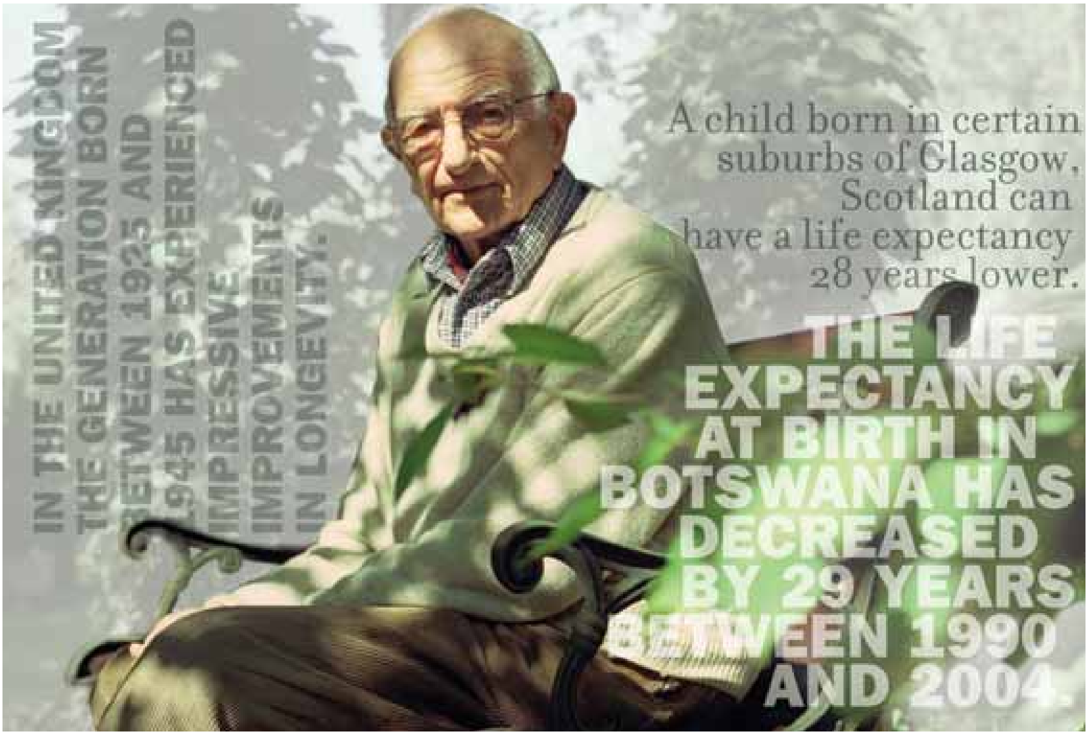
In general, convergence has not occurred. The graph shows, for example, that although life expectancy at age 65 for females in seven Western countries appear to converge until the 1980s, they then diverge afterward even though life expectancies continue to increase.

In studying the evolution of life expectancies at birth in European countries, Jean-Marie Robine, Carole Jagger et al. have been able to show that these divergences reappear starting in 1960. Countries are grouped into three categories: high convergence, meaning a rapid progression, low convergence (low progression) and divergent (stable progression, possible regression). It is possible for a country to have a low convergence for one sex and high convergence for the other, which is the case for France.

## Female life expectancy at age 65




Source: Jean-Marie Robine.




**Socio-economic inequalities and longevity**
We can observe notable differences in life expectancy within the same country. In 2008, one study by WHO established, among other things, that a child born in certain suburbs of Glasgow, Scotland can have a life expectancy 28 years lower than one born just 13 kilometers away, and that adult mortality is 2.5 times higher in more disadvantaged areas in the United Kingdom compared with more well-off areas.

This provides evidence as to what is driving the annuity pricing according to postal code in the UK, a movement initiated by Prudential, Legal & General and Norwich Union (Aviva).

The influence of socio-economic inequalities on mortality is supported by numerous other studies: for example, for English and Welsh women between 25 and 59 over the period 2001-2003, those belonging to disadvantaged classes have a higher rate of mortality than the others(2). Some causes of death are more sensitive to socio-economic variables (such as respiratory illness, gastro-intestinal diseases, blood disorders or lung cancer). Contrastingly, mortality from breast cancer is similar for women of both classes.

**Possible gains in longevity from the diffusion of good practices**
This heterogeneity indicates the possibility that longevity gains for the most advanced countries could increase with the diffusion of good practices in terms of health and alignment in recovery rates for the most frequent illnesses (cancer, cardiovascular, etc.) towards the standard reached in the highest performing countries. *Eurocare 4*, which compares the occurrence of and mortality from various types of cancer for several European countries, confirms the significant enduring differences between countries. For example, in France, nearly 59% of women with cancer recover, compared to only 38% in Poland. The most fatal cancer remains lung cancer—France is in the lead with only 10.3% recovery. Significant gains in mortality were driven by a convergence in these recovery rates, especially in Eastern Europe and the UK.

(2) ONS, Health Quarterly, Summer 2009.

# 2. MODELING LONGEVITY RISK

### *2.1. Longevity risk in insurance*

Longevity risk is made up of two components: the current mortality and the improvement rate for future mortality. There is much uncertainty around the trend in the rate of mortality improvement. If the improvement turns out to be much more significant than what was initially anticipated certain challenges quite specific to the insurance sector present themselves, such as reserving and solvency, going beyond simply the social implications like retirement. Insurance products covering longevity risk are for the most part life annuity-type products (immediate or deferred). However, long term care products also indirectly cover two types of longevity risk: that of autonomous and dependent people, which are linked by the compression, stability, or worsening of morbidity. For example, if people are living longer but as a result are spending more time in a dependant state, long term care costs would increase as well.

Longevity risk is requiring more and more capital for reserves, and new regulation such as Solvency II is likely to amplify this trend. It has therefore become critical for insurers and pension fund managers to transfer a portion of the risk to reinsurers or to the financial markets. However, in order to transfer this risk, insurers must be able to understand and manage it. This does not come without difficulty, especially due to the long term nature of longevity. One must also note that longevity and mortality risk do not naturally balance each other—even if they can be pooled to a certain extent—because they are not of the same inherent nature.

The recent creation of the “Life & Longevity Markets Association” (LLMA), which brings together insurers (including AXA, L&G and Prudential), reinsurers and banks, has an objective of encouraging the emergence of new financial products for managing the risk of longevity. This non-profit association aims in particular to develop standards for securitization products, specific indices for longevity and a valuation model for mortality. These goals are initially sought with the British market in mind, which is especially concerned with this risk, but eventually could be internationally applicable.

The regulatory tables for the reserving for life annuities are frequently revised in several countries, illustrating the tendency towards underestimation of longevity risk by actuaries. Several companies in the United Kingdom have had to allow for regular and significant increases in reserves for their annuity portfolios. In France the prospective tables were updated in 2006. As the improvements in terms of life expectancy were much more significant than those predicted by the previous tables in 1993, French insurers were obliged to increase their reserves by 8% on average to take this into account, illustrating the impact of an underestimation of the speed of the increase in life expectancy. This illustrates the costs linked to the misestimation of longevity risk. Again this year, in the United States a working group sponsored by the SOA and the AAA recommended that a new mortality table be developed for annuities due to the low margins and mortality improvement for retirement ages, and that the new table incorporate projected improvement factors.

In general, the regulatory tables for longevity risk have been established by generation and thus are frequently revealed to be insufficient in all the OECD countries.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Wom belongin
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mortality than the others.

## 2.2. Various projection methodologies

The estimation of longevity risk is a challenging task, and the predictions of future mortality improvements have often been underestimated.

Many different mortality models have been developed. The two main types of projection models currently used are the stochastic models, which are based on time series methods, and the P-Splines (penalized B-Splines) model based on a GLM (Generalized Linear Model) framework. These two families are classified as extrapolative models, which assume that future trends will essentially be a continuation of the past.

Other families also exist: the process-based methods model mortality trends according to causes of death, and the explanatory-based methods use causal forecasting approaches, for example econometric techniques based on variables such as economic or environmental factors. The most popular approaches in the actuarial field are the extrapolative models. However, even if we project historical trends of mortality into the future, these methods do not include any advances in medicine or the emergence of new diseases.

A last point regarding longevity modelling is setting values for high ages. Much of the data are not available or are inconsistent, especially for high ages, so it is necessary to close mortality tables, i.e. extrapolate the mortality rates for high ages. This has become important as these ages are currently experiencing quite high improvements. The tables can be closed by using methods from Denuit & Goderniaux (2005), Koale & Kisker (1990) or from Lindbergson (2001), which consist of applying a local parametric shape and making some exogenous assumptions for parameter fitting (for example, setting the central mortality rate at age 120 equal to 1).

## P-Splines and Stochastic Models

**(1) P-Splines model**

Introduced by I. Currie in 2004, the P-Splines model is a deterministic method based on the Generalized Linear Model framework. A spline represents a local peaked curve, taking positive values near the center, and tailing to zero away from the center. This method models the instantaneous mortality rate based on splines, i.e. a base set of cubic spline functions fitted to the historical curve. A penalty is added to balance the fit and the smoothness. This modeling takes into account cohort effect (year of birth) versus period effect (calendar year), smoothing over time.

**(2) Stochastic models**

Two families exist: the Lee Carter family, where the instantaneous mortality rate is modelled, and the CBD (Cairns Blake Dowd)-Perks family, where the initial mortality rate is modeled. The original Lee-Carter model, developed in 1992, was the first stochastic model and remains the simplest. The Renshaw-Haberman model developed in 2006 is an extension of Lee-Carter model which incorporates the cohort effect. The third model, the Age Period Cohort model, was developed by I. Currie and is a simplified version of the Renshaw-Haberman model. Within the CBD-Perks family, there are four models were developed in 2007 which are based on two factors with some variations, including a cohort effect.

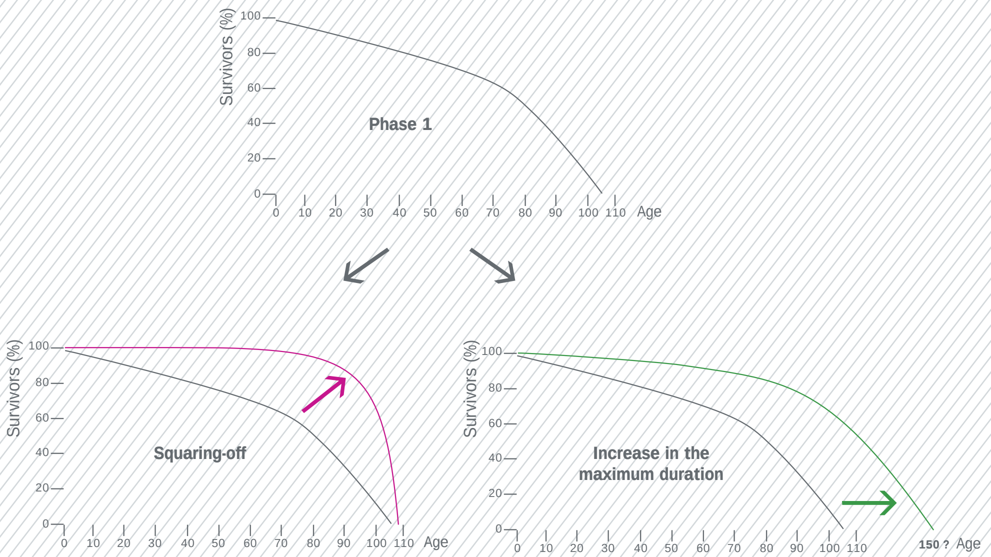
# 3. THE MAIN QUESTIONS SURROUNDING LONGEVITY

### 3.1. Is there a limit to life expectancy?

The Hayflick limit, the fact that cells cannot divide themselves indefinitely, actually imposes a limit to the life expectancy of an organism. However, the estimation of this limit for humans is quite challenging. Scientists who have attempted to define the limit have, for the most part, seen their predictions disproved. For example, at the end of the 18th century Buffon estimated that at best a human could expect to live a hundred years. The expectations as to the limit to life have since been revised to 110, then 120, and currently some even raise this number to 150 years in anticipation of significant medical progress.

The graph below illustrates two possibilities in the evolution of life expectancy. The first is a squaring-off of the distribution of survivors per age, which corresponds to having a population that nearly reaches the maximum age possible, an age which remains constant. The second is an increase in the maximum duration of life. The second scenario appears to be less probable unless major medical advances occur.

## Two possible scenarios for life expectancy
## Squaring-off or increase in the maximum duration



The components of longevity are socio-behavioral (social environment, medical care, nutrition, tobacco and alcohol consumption, physical activity) and genetic. Studies on twins show that a quarter of the total variation in the length of life can be attributed to genetics. Currently, some researchers are attempting to pinpoint where the genes for longevity are located (some candidates have already been identified), with the aim of eventually being able to stimulate them.

The spread of good medical practices would very likely contribute to the lengthening of life in the majority of countries. In addition to the medical progress already achieved, that which is still to come is expected to be equally promising: genetic therapy for diseases such as Parkinson's, a vaccine against Alzheimer's disease, which if preventative (not simply stabilizing progression) would be a considerable advance considering the prevalence of the disease. Prevention could also play a large role for a number of diseases by reducing the contributing risk factors.

### *3.2. Emerging risks*

New emerging risks could have a significant impact on longevity (cell phones, asbestos, pollution, etc.). Regarding cell phones, there is not currently any consensus on their possible impact on health or on life expectancy. Some studies have concluded that there is an increased risk of certain types of cancer (especially glioma and meningioma), and others have found no correlation.

The results from Interphone, an international study (13 countries) launched in 1998 to try to determine the dangers from cell phones, should soon finally be published, according to several reports. However, it seems that the uncertainty surrounding the risk will still not be completely resolved.

The difficulty in reaching an agreement regarding the harmful effects of cell phones illustrates the challenge in evaluating the effect of low levels of exposure (toxic products, electromagnetic waves, radiation) because of a lack of tools available to do so. Furthermore, some substances (tobacco, asbestos) do not lead to cancer until nearly 20-30 years after the first exposure.

Pollution, it seems, is clearly associated with a higher level of mortality. Using data from 51 metropolitan zones in the United States from different periods between 1970 and the early 2000s, American researchers[(3)] have been able to estimate that the reduction of air pollution could contribute to an increase of 15% for the global life expectancy. French researchers have confirmed the short term effects of pollution, showing that mortality risk is significantly associated with all of the indicators of pollution.

### *3.3. The obesity epidemic – what will the consequences be?*

For researchers such as Olshansky, the increase in the number of people with obesity (and the diseases associated with it, such as diabetes) calls into question the progression of life expectancy in the United States and some other Western countries.

**Epidemiology and costs**

Epidemiological studies show a significant progression in the number of people suffering from obesity around the world. In the USA, which is particularly impacted, a third of adults are obese, another third are overweight, and the prevalence of severe obesity among children between the ages of 2 and 19 has gone from 0.8% over the period 1976-1980 to 3.8% in 1999-2004. Similarly, the number of diabetics in the United States is expected to nearly double by 2034, going from 24 million to 44 million. A joint study conducted by the Research Triangle and the CDC estimated the annual cost of obesity in the USA to be 147 billion dollars.

(3) C. Arden Pope et al.


The progression of obesity is widespread. The study ObEpi Roche, carried out by TNS Sofres, produced an alarming assessment of the situation in France: 32% of the French over the age of 18 were found to be overweight, and 15% were obese. These numbers are constantly increasing. Published statistics in the United Kingdom estimate that in 2025, 41% of the British will be obese, and this proportion will surpass 50% by 2050. One adult out of three is overweight or obese in Korea (32.8%). At a global level, WHO estimates that there are a billion overweight people, of which at least 300 million are clinically obese.

**Obesity and Mortality**

The link between obesity and a variety of chronic diseases (diabetes, cardiovascular disease, certain types of cancer) has been clearly established. Researchers from UCLA have even established a link between being overweight (even more so for obesity) and brain degeneration, which implies that obesity is a risk factor for brain disorders such as Alzheimer's.

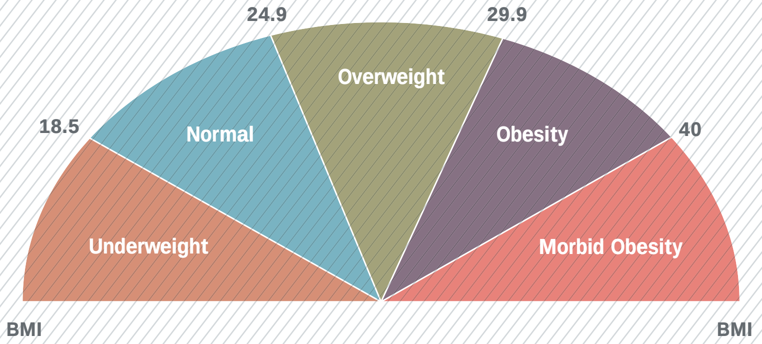
Nevertheless, not only is life expectancy continuing to increase despite the growing numbers of people suffering from obesity (especially recently in the US), but epidemiological studies fail to definitively show the effects of obesity on mortality. A longitudinal study on middle and older aged Americans, the HRS (Health Retirement Study) showed that obesity has as much of a negative impact on life expectancy as being underweight, and that mortality linked to obesity seems limited compared with that linked to tobacco use or correlated with a low level of education. A Canadian longitudinal study reached a similar conclusion. An under-weight and severely obese person both had an elevated risk of mortality, but not those who were only mildly obese. Moreover, those who were overweight but not obese were found to have a lower risk of mortality than those of the population of normal weight.

### Diet and longevity

While obesity seems to be a risk factor for a number of diseases, scientists have known for quite a while of the link between a very low calorie but well-balanced diet (60% of the normal calorie amount) and an increase in longevity. However, this increase in the length of life comes at a cost to fertility. A British team has recently discovered that methionine (an amino acid) plays a key role in longevity and fertility and that it would be possible to live longer by reducing the intake of methionine within a normal diet.

## Body Mass Index

$$\text{Body Mass Index} = \left(\frac{\text{Weight (kg)}}{\text{Height}^2\text{ (m)}}\right)$$



### 3.4. Disability-free life expectancy

Disability-free life expectancy at birth is a concept that was introduced in the 1970s with the objective of reflecting the real gains in terms of the health of a population when the increase in longevity could also translate into an increase in chronic illness, so would not necessarily be the best indicator of health.

INSEE defines good health by an absence of limitations to normal daily activity and absence of disability. At the European Union level, the calculation of the number of years in good health relies on two factors: mortality tables and the prevalence of disability, which is determined via health surveys (Eurostat European Community Household Panel or ECHP). There is no completely objective and normalized indicator.

Healthy life expectancy at older ages in Europe varies according to the country. Males and females in Austria can expect to live on average until age 79 and 84, respectively, but only half their years after the age of 50 will be free from disease. On the other hand, in the United Kingdom, where life expectancy is generally lower than in many other European countries, the healthy life expectancy is relatively good. New entrants into the EU bring low life expectancies and chronic diseases at older ages. Thus, the countries benefiting from a high life expectancy are not necessarily those in which the population is in the best health. In addition, there are also disparities between men and women across countries.

Vaupel studied a cohort of Danish people born in 1905 over a period of 8 years, which allowed him to estimate the physical and mental loss of autonomy between the ages of 92 and 100. Since there is an increase in the probability of loss of autonomy in each additional year of life, but a higher probability of death for those in poor health, the resulting effect is that the proportion of dependants remains at a relatively stable level. The proportion of dependents is around 60-70% for centenarians.

Compression or expansion of morbidity is also affected by medical advances. For example, a vaccine against Alzheimer's disease that only slows down the progression of the disease without leading to recovery would not at all have the same impact on morbidity as a curative vaccine.

### 3.5. The French Paradox

The French Paradox (the fact that the French in the South-west have a longer life and lower rate of heart attacks despite the consumption of wine and a diet rich in fat) brings up the question of the role of nutrition in longevity.
Other "longevity" diets that have been mentioned are those from Crete and Okinawa.

The variables influencing the evolution of longevity are diverse: socio-economic environment, genetic factors, lifestyle (diet, alcohol and tobacco consumption, physical activity, etc.). It is difficult to estimate exactly the contribution of each of these variables in longevity.

When we compare the rate of mortality associated with certain socio-economic variables for 22 European countries, the worst states of health and the highest rates of mortality are associated with a disadvantaged socio-economic position, and socio-economic conditions vary greatly from one country to another.

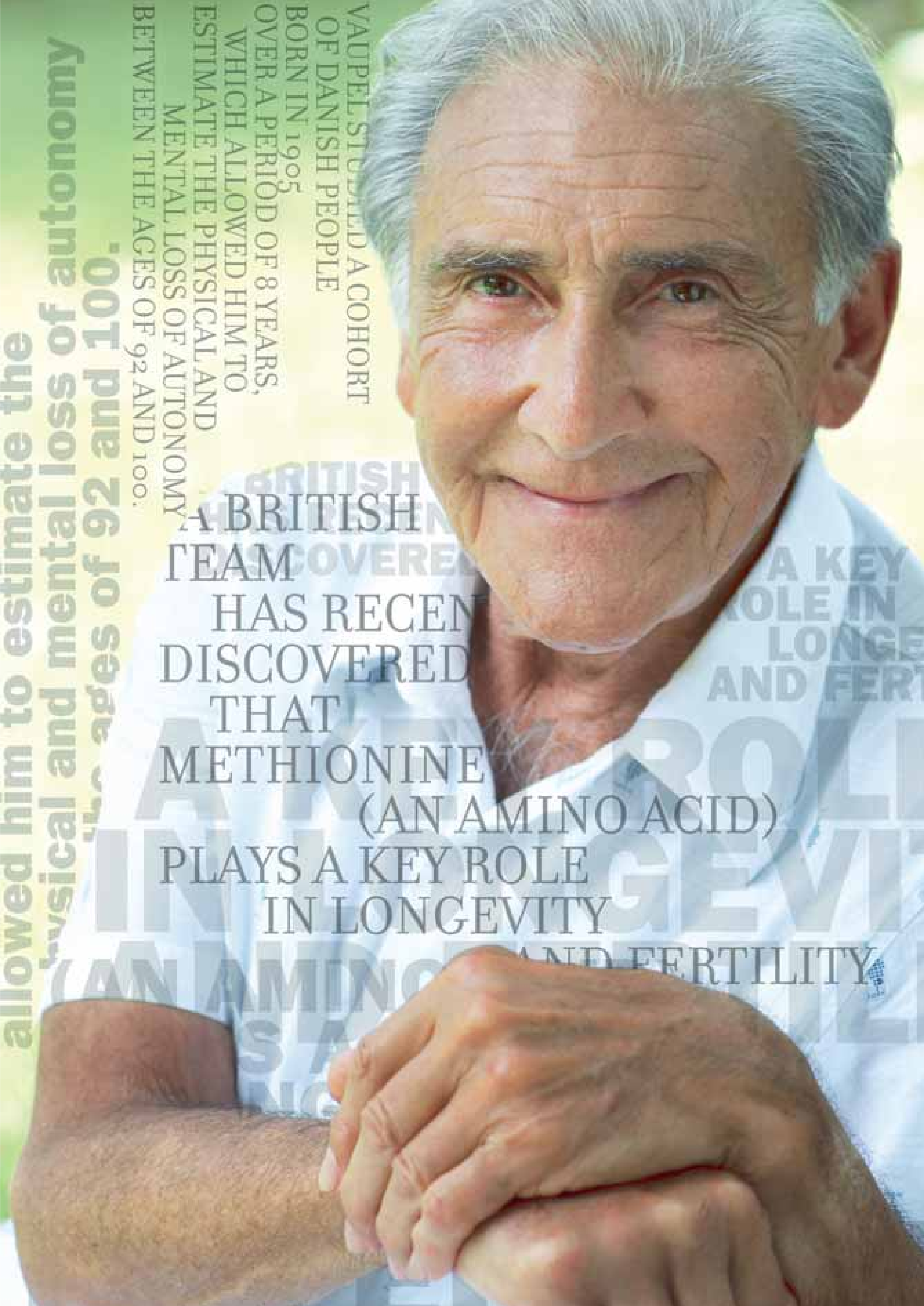
The inequalities in terms of mortality were lower in Southern European countries (Spain, Italy) and quite significant in the Eastern countries (Hungary, Poland, Czech Republic). This is especially due to the mortality linked with the consumption of alcohol and tobacco, as well as access to medical care. ONS has shown that for retired British, tobacco addiction is the main predictive factor in mortality, and the moderate consumption of alcohol is less of a risk factor. This could be explained by the fact that the total avoidance of alcohol is often due to medical necessity and thus more frequent among those in poor health, but we also know that certain components in wine have anti-inflammatory effects. As for nutrition, an American epidemiological study concluded that the consumption of calcium protects against cancer of the digestive system.

Finally, there is also a correlation shown between well being and happiness and longevity.

### 3.6. AXA Research Fund

With the aim of better understanding the factors associated with longevity and aging, AXA has launched a Longevity Chair, which has as a major benefit an extremely multi-disciplinary approach. It is driven by globally recognized researchers (Linda Partridge, Thomas Kirkwood, François Taddei and James Vaupel) coming from various different scientific backgrounds: demography, genetics, nutrition, biology, etc. This diversity of approaches leads to a thorough study of the parameters influencing the longevity of an individual and a better understanding of the mechanisms of aging.

www.axa-research.org/en/


VAUPEL STUDIED A COHORT OF DANISH PEOPLE BORN IN 1905 OVER A PERIOD OF 8 YEARS, WHICH ALLOWED HIM TO ESTIMATE THE PHYSICAL AND MENTAL LOSS OF AUTONOMY BETWEEN THE AGES OF 92 AND 100.
A BRITISH TEAM HAS RECEN DISCOVERED THAT METHIONINE (AN AMINO ACID) PLAYS A KEY ROLE IN LONGEVITY AND FERTILITY

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