Lecture 1: Measuring ageing

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Measuring ageing

1. **What is ageing ?**
   - Ageing : to age, process of adding years of life, growing older
   - Ageing : process of declining functionalities, and declining productivity

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   - Ageing : to age, process of adding years of life, growing older
   - Ageing : process of declining functionalities, and declining productivity
2. **Demography, biology, economics**
   - Measuring ageing as the demographic process
   - Measuring ageing as the change in health
   - Measuring ageing as the change in productivity

Outline of the lecture

I. Measuring demographic ageing

II. Theories of population ageing

III. Ageing as a health process

I. Measuring demographic ageing

1. Short history of demography
2. Representing age structure of population
3. Life tables
4. Ageing in historical perspective
5. Demographic projections

Short history of demography

- **Demography as a new field**
  - First mortality, then fertility, later migration (Vilquin, 2006)

- **1662 and All That**

John Graunt, British haberdasher (1620–1674).

Natural and Political Observations Made upon the Bills of Mortality (1662)

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- **Data : "Bills of Mortality"**
  - Mortality rolls in London parishes to warn against bubonic plague
  - Graunt exploits these data to build statistics on births and mortality rates

Short history of demography

- **The first demographers (17th-18th c.)**
  - Edmund Halley (England) : modern life table
  - Pehr Wargentin (Sweden) : the *Tabellverket*
  - Antoine Deparcieux (France) : life annuity
  - Johann Peter Süßmilch (Prussia) : male/female birth ratio
  - Jean-Louis Muret (Swiss, Vaud) : crude birth/death rates
- **Development of demographic analyses**
  - Critical analysis of the data
  - Life table
  - Statistical regularities

Age structure

- **Population pyramid**
  - Histogram by age and sex of current population
  - Detailed view of age structure
  - Clear impact of historical accidents

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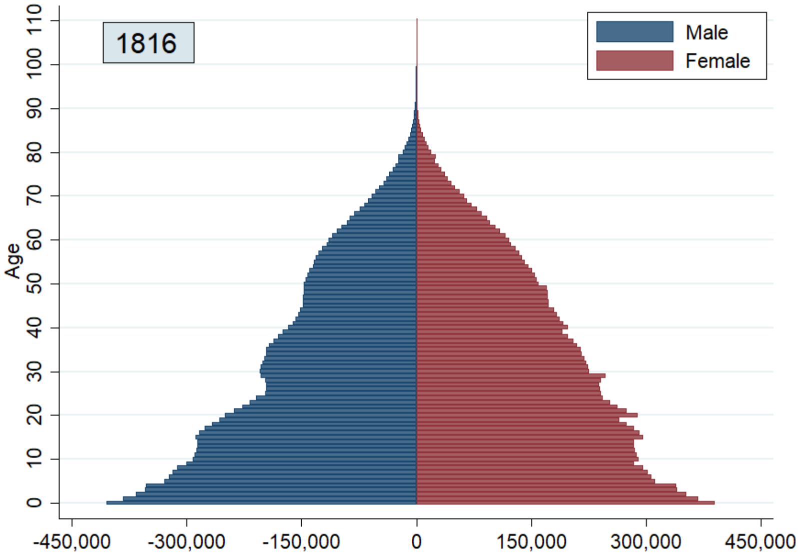
  - Histogram by age and sex of current population
  - Detailed view of age structure
  - Clear impact of historical accidents
- **No longer pyramids...**
  - Historically, large bases, thin top
  - Drop in mortality and fertility led to other forms (mushrooms, pear, etc.)

Figure 1 – Population pyramid (France)



Age structure

- **Demographic ratios**
  - P_{a-b} : population aged a to b
  - Child dependency ratio :

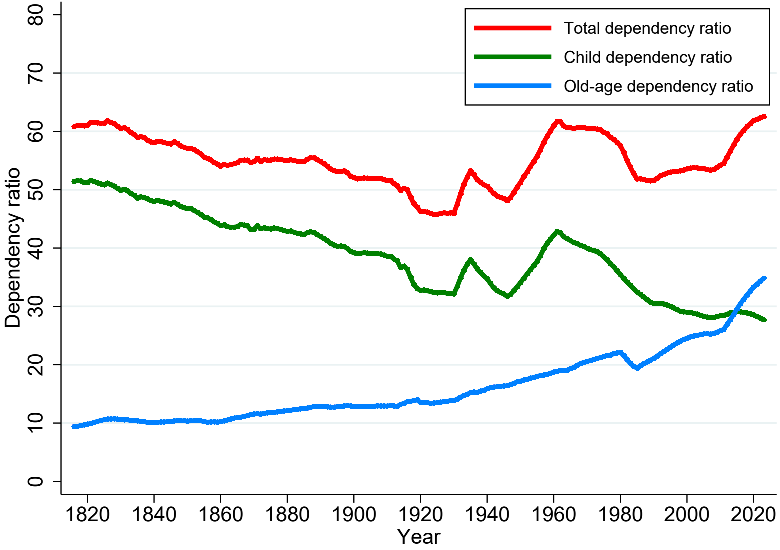
$$d_c = \frac{P_{0-14}}{P_{15-64}}$$

  - Old-age dependency ratio :

$$d_o = \frac{P_{+65}}{P_{15-64}}$$

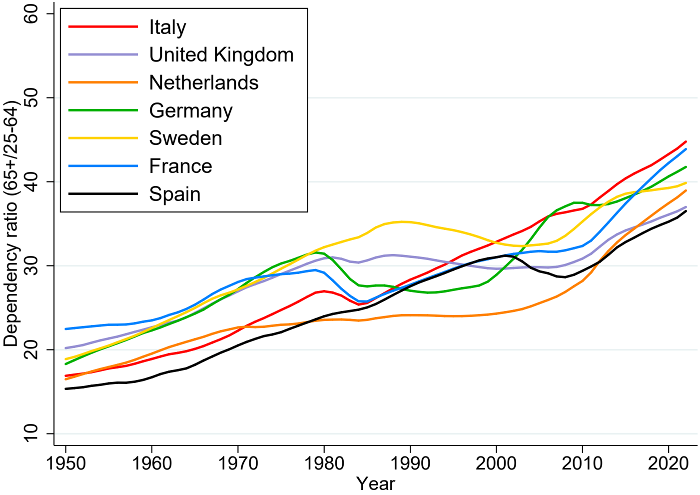
  - Total dependency ratio : $d = d_c + d_o$

Figure 2 – Dependency ratios (France, 1816–2023)



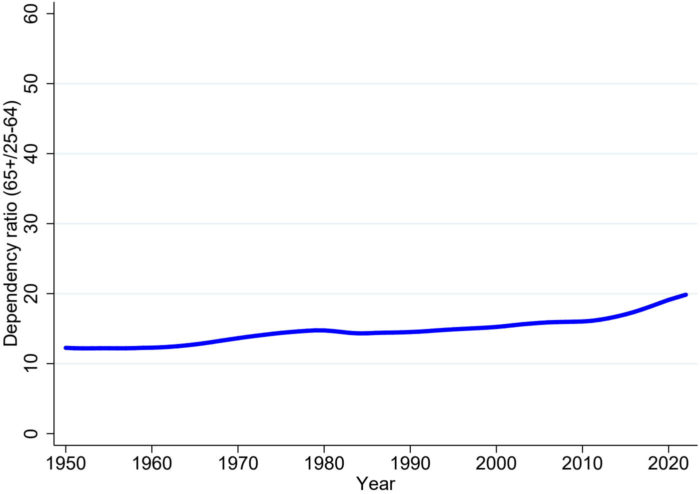
SOURCE : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Figure 3 – Old-age dependency ratio (65+/25-64) for some European countries



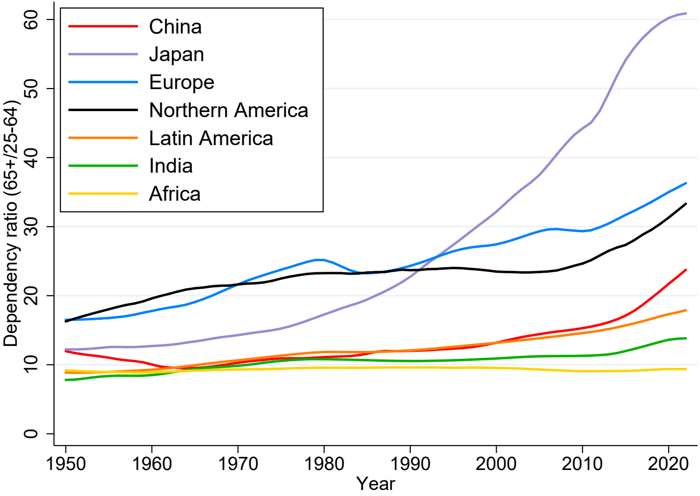
SOURCE : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Figure 4 – World old-age dependency ratio (65+/25-64)



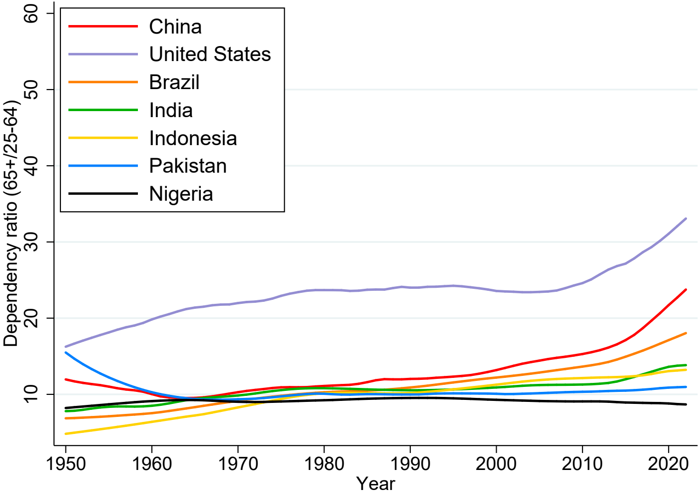
Source : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Figure 5 – Old-age dependency ratio by main world regions (65+/25-64)



Source : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Figure 6 – Old-age dependency ratio by largest countries (65+/25-64)



SOURCE : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Life tables

- **Definitions**

  Period life tables : mortality experience of an entire population during a period of time

  Cohort life tables : mortality experience over the entire lifetime of a cohort

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- **From mortality statistics to life expectancy**
  - Life tables provide various statistics built from death rates up to life expectancies
  - Main references are Chiang (1979, 1985)

Life tables : crude death rate

- **Raw statistics and sources**

  D_x : number of deaths by age x and sex from registry data
  P_x : population estimates by age x and sex from census
  m_x : crude death rate

$$m_x = \frac{D_x}{P_x}$$

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- **Measurement issues**
  - Population estimates and death from different sources
  - Records of death of new born
  - Between census estimates of population
  - Fragile estimation at oldest age (few obs.)

- **Not a probability**
  - Some in D_x will not be in P_x

Life tables : conditional death rates

- **Conditional death rates q_x by age x**

  q_x : probability of death between age x and $x+1$ for individuals alive at age x

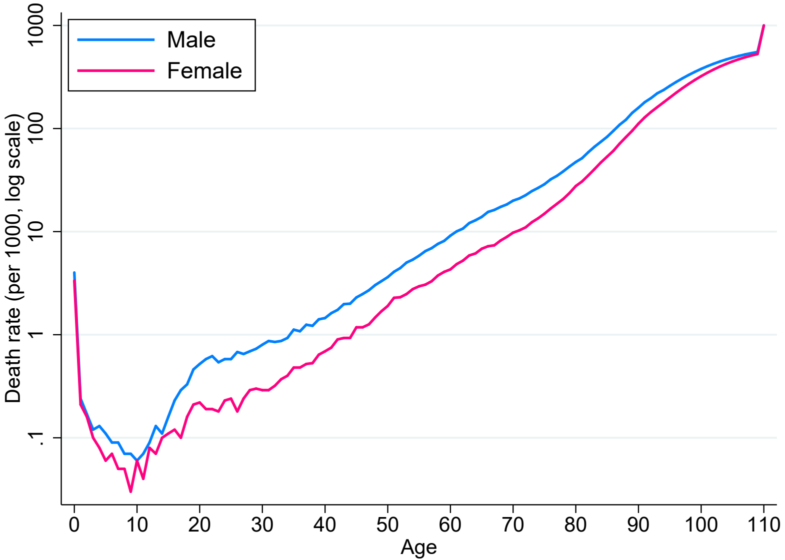
  N_x : the number of people alive at age x among whom D_x death occurs in $[x, x+1)$

$$q_x = \frac{D_x}{N_x}$$

- **Relationship between q_x and m_x**
  - people alive in x and who die in $[x, x+1)$ live a fraction a_x of the last year, and the survivors live $N_x - D_x$ live full years : $P_x = (N_x - D_x) + a_x D_x$

$$q_x = \frac{D_x}{N_x} = \frac{D_x}{P_x + (1-a_x)D_x} = \frac{m_x}{1+(1-a_x)m_x}$$

Figure 7 – Death rates by Age (France, 2022)



Source : Human mortality database [www.mortality.org].

Life tables

- **Construction of life tables**

  a_x : average years lived between age x and $x + 1$

  - Assume a_x is 0.5 for all ages, except $a_0 \in [0.1, 0.15]$
  - Set radix $l_0 = 100,000$

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- **Survival curve**

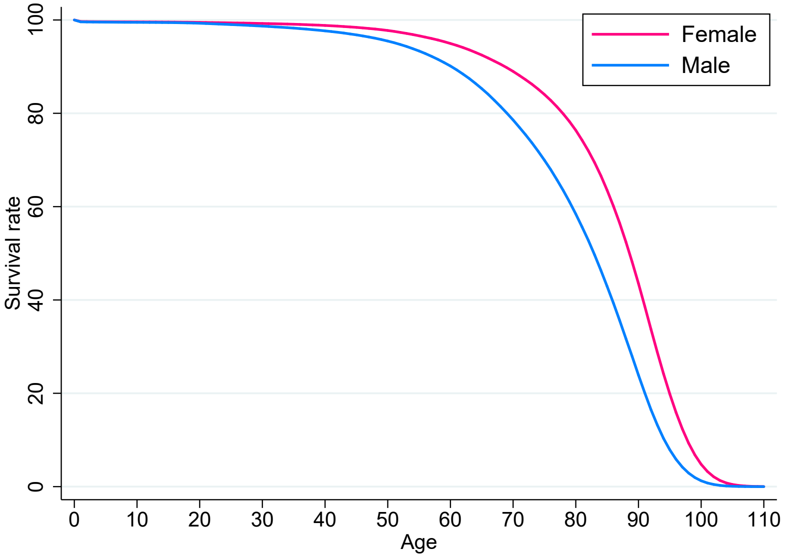
  l_x : number of survivors at age x

$$l_x = l_0 \cdot \Pi_{i=0}^{x-1}(1 - q_x)$$

  d_x : number of deaths at age x from life-table

$$d_x = l_x \cdot q_x$$

Figure 8 – Survival curve (France, 2022)



SOURCE : Human mortality database [www.mortality.org].

Life tables

- **Person-years**

  L_x : person-years lived between age x and $x+1$

$$L_x = l_x - (1 - a_x) \cdot d_x$$

  T_x : person-years remaining for individuals aged x

$$T_x = \sum_{i=x}^{\omega} L_i$$

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  $$T_x = \sum_{i=x}^{\omega} L_i$$

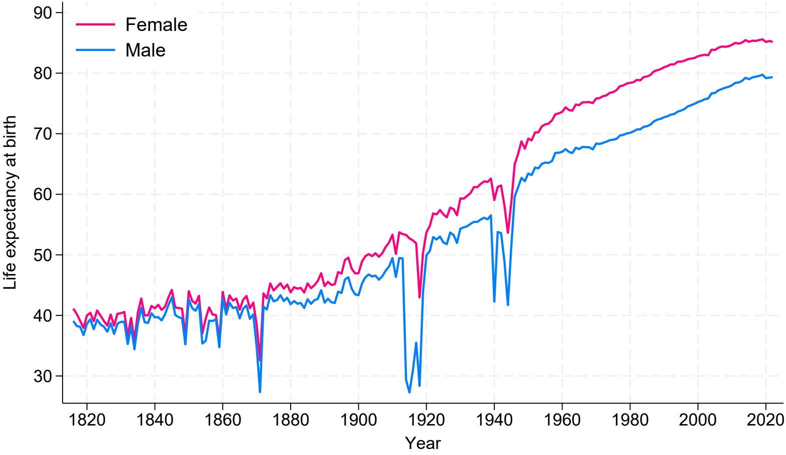
- **Life expectancy**

  e_x : life expectancy at age x

  $$e_x = \frac{T_x}{l_x} = 0.5 + \frac{1}{l_x} \sum_{i=x+1}^{\omega} l_i$$

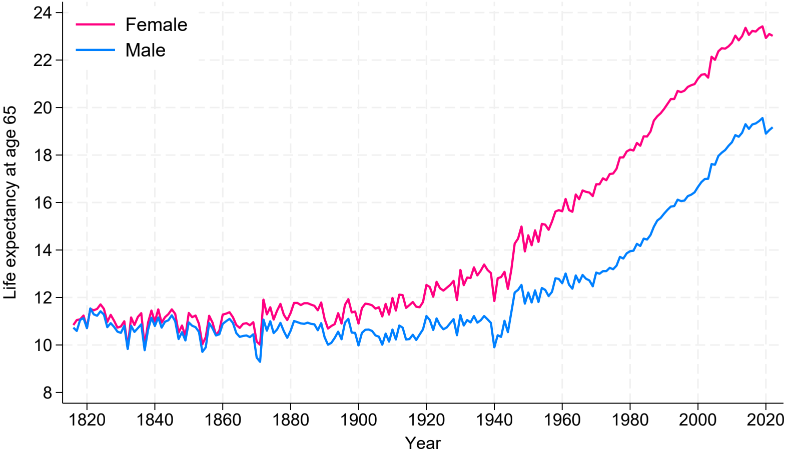
  - Main reference to life expectancy at birth (e_0) : heavily influenced by mortality at earlier ages

Figure 9 – Life expectancy at birth (France, 1816–2022)



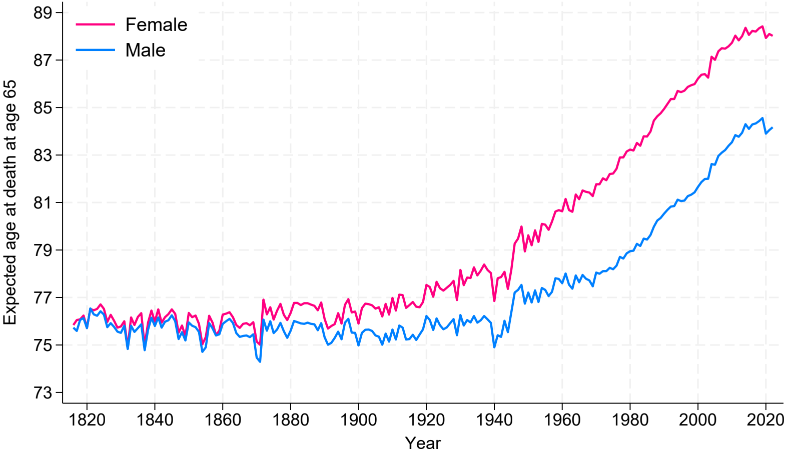
Source : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Figure 10 – Life expectancy at age 65 (France, 1816–2022)



SOURCE : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Figure 11 – Expected age at death at age 65 (France, 1816–2022)



Source : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Table 1 – Life table equations

Symbol	Description	Formula
D_x	number of death at age x	
P_x	mid-year population at age x	
m_x	crude death rate at age x	$\frac{D_x}{P_x}$
l_0	radix	100'000
q_x	death rate	$\frac{m_x}{1+(1-a_x)m_x}$
a_x	average years lived $[x\,;\,x+1]$	0.5
l_x	number of survivors at age x	$l_x = l_0 \cdot \Pi_{i=0}^{x-1}(1-q_x)$
d_x	deaths at age x from life-table	$d_x = l_x \cdot q_x$
L_x	person-years lived $[x\,;\,x+1]$	$l_x - (1-a_x)\cdot d_x$
T_x	person-years remaining at age x	$\sum_{i=x}^{\omega} L_i$
e_x	life expectancy at age x	$\frac{T_x}{l_x}$

Table 2 – Period life table for France (male and female, 2015)

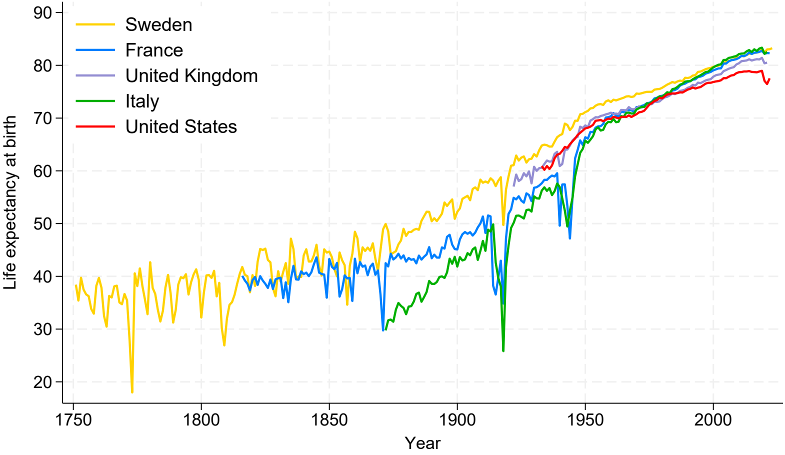
Age	q_x	a_x	l_x	d_x	L_x	T_x	e_x
0	0.00359	0.14	100000	359	99692	8215084	82.15
1	0.00026	0.50	99641	26	99628	8115392	81.45
2	0.00016	0.50	99615	16	99608	8015764	80.47
3	0.00015	0.50	99600	15	99592	7916156	79.48
4	0.00010	0.50	99585	10	99580	7816564	78.49
20	0.00038	0.50	99358	38	99339	6224466	62.65
21	0.00044	0.50	99320	44	99298	6125128	61.67
22	0.00035	0.50	99276	35	99259	6025830	60.70
23	0.00041	0.50	99241	40	99221	5926571	59.72
24	0.00044	0.50	99201	43	99179	5827350	58.74
25	0.00044	0.50	99157	43	99135	5728171	57.77
40	0.00112	0.50	98186	110	98132	4247019	43.25
41	0.00126	0.50	98077	124	98015	4148888	42.30

SOURCE : Human mortality database [www.mortality.org] ; Insee data.

Sources for life tables

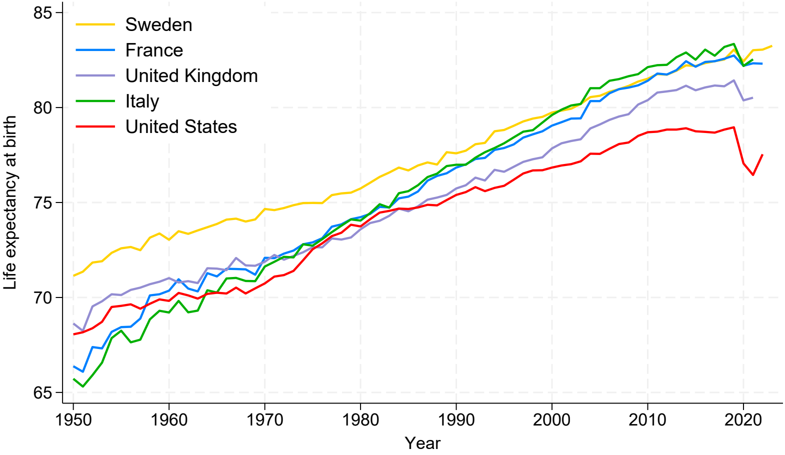
- **Modern State registry**
  - French revolution transferred Church registry to the State : *état civil* (1792)
  - Northern Europe opted for national registry : all demographic events are registered live in the state registry
- **The rise of census**
  - Exhaustive survey of population
  - Early modern census : Sweden (1755)
  - Prussia, Austria, France, Russia, Netherlands and Belgium in early 19th century

Figure 12 – Life expectancy at birth (1750–2022)



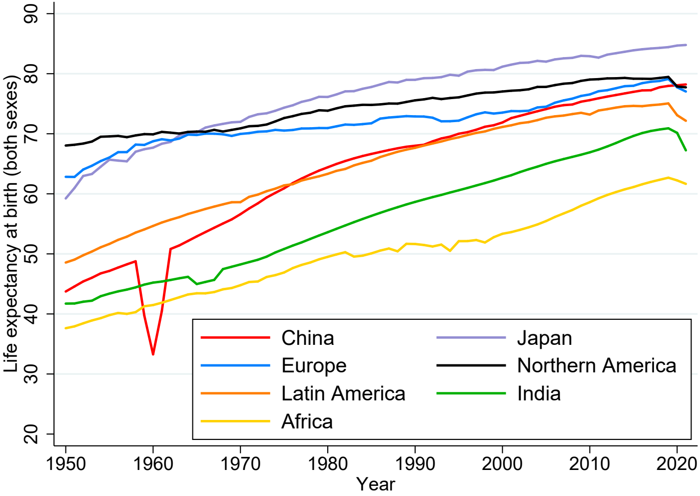
Source : Human mortality database [www.mortality.org].

Figure 13 – Life expectancy at birth (1950–2022)



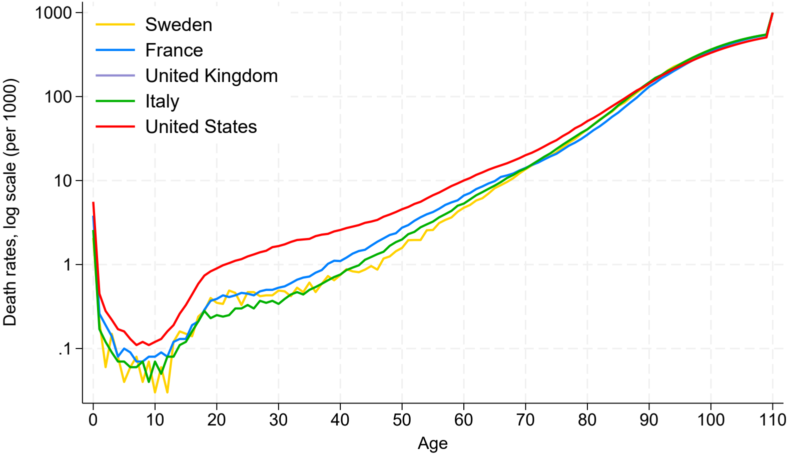
SOURCE : Human mortality database [www.mortality.org].

Figure 14 – Life expectancy at birth (1950–2020)



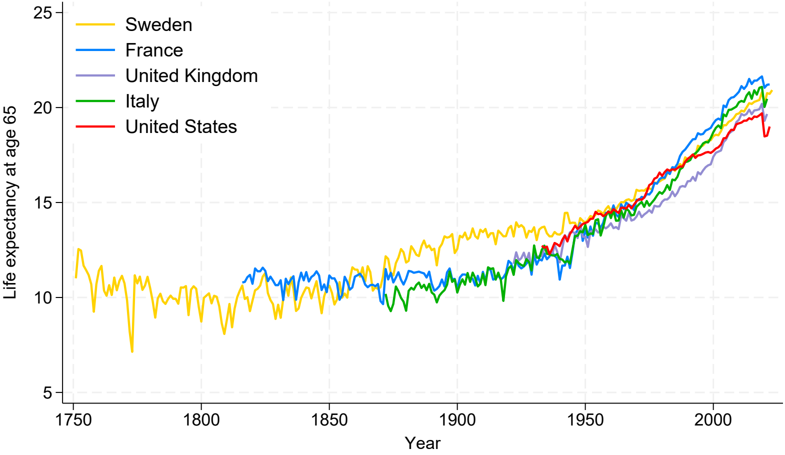
Source : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Figure 15 – Death rates by age, male and female (2022)



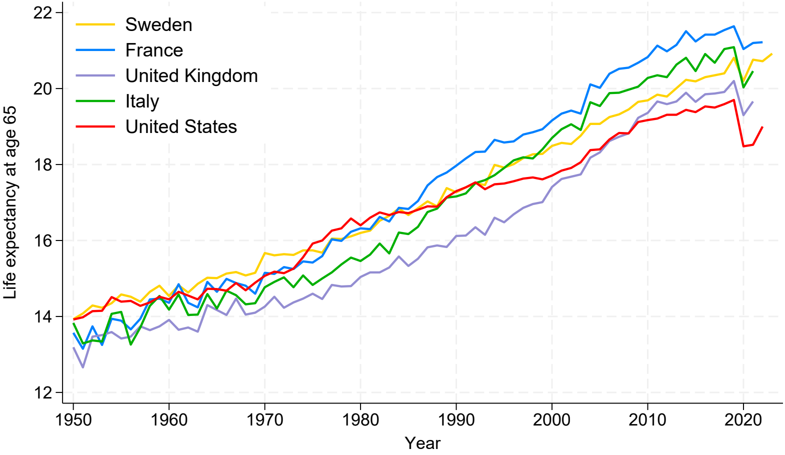
SOURCE : Human mortality database [www.mortality.org].

Figure 16 – Life expectancy at age 65 (1750–2022)



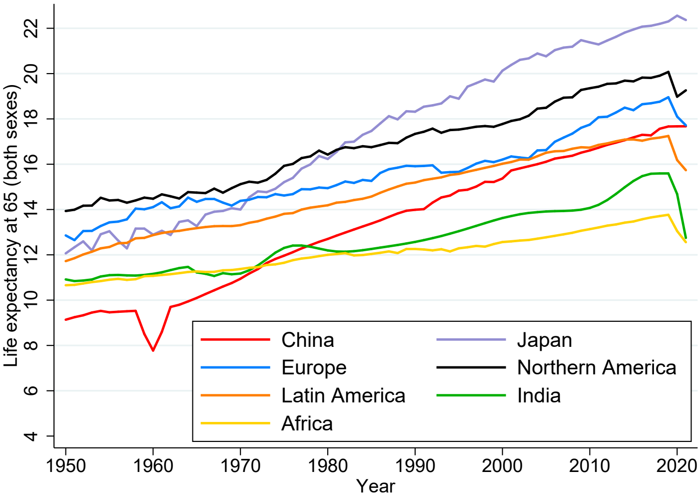
SOURCE : Human mortality database [www.mortality.org].

Figure 17 – Life expectancy at age 65 (1950–2022)



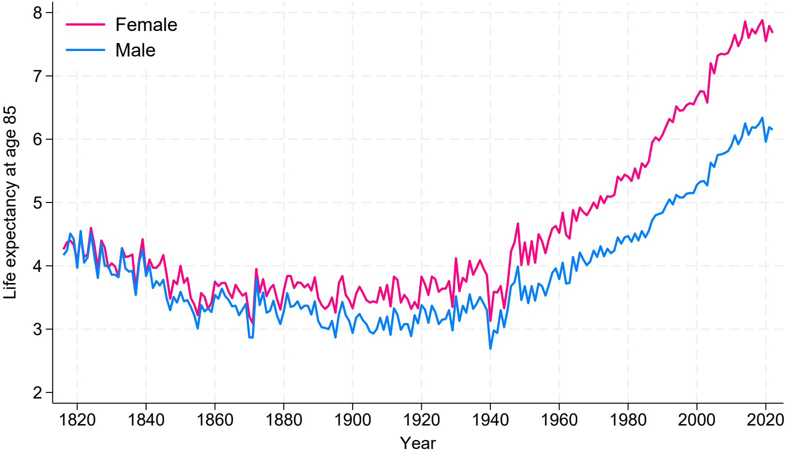
SOURCE : Human mortality database [www.mortality.org].

Figure 18 – Life expectancy at age 65 (1950–2020)



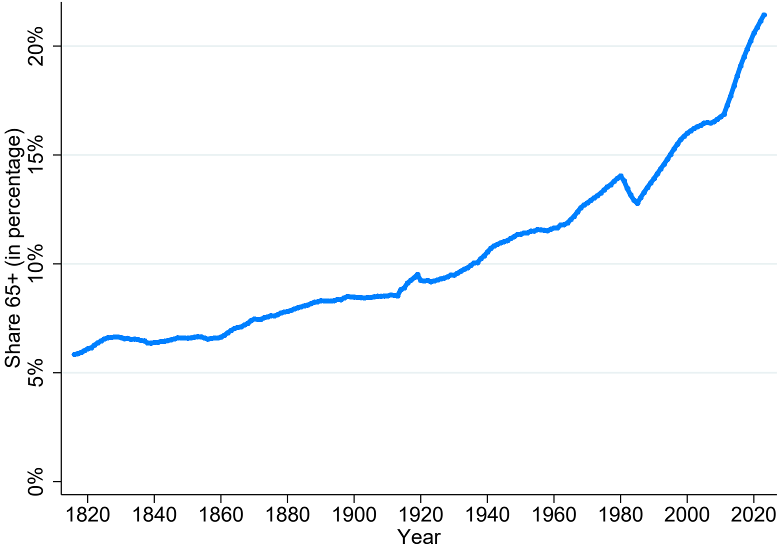
Source : United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects 2022*.

Figure 19 – Life expectancy at age 85 (France, 1816–2022)



SOURCE : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Figure 20 – Share of population aged 65+ (France, 1816–2023)



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Long-term history of ageing

- **Historical demography**
  - A field in development since the 1960s
  - Demographic analysis based on ancient documents
  - Often partial coverage/information
  - Debate on the reliability of the estimates

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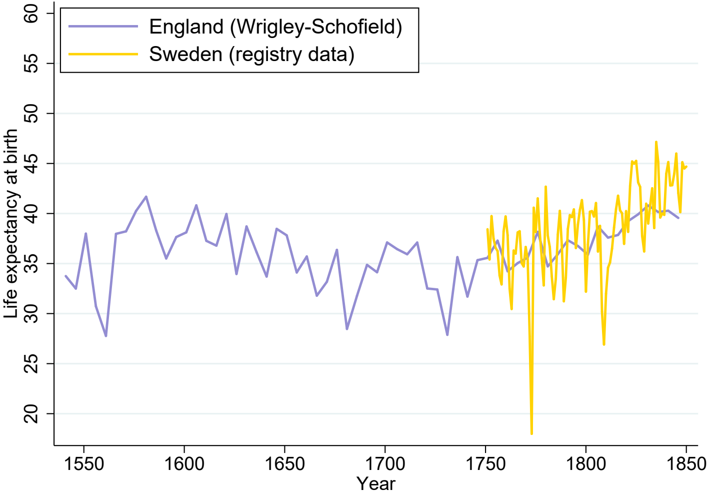
- **Sample of the best studies**
  1. France 18th c. (Blayo, 1975)
  2. Geneva 16th-17th c. (Perrenoud, 1978)
  3. England 1541-1800 (Wrigley and Schofield, 1981)
  4. Roman Egypt (Bagnall and Frier, 1994)
  5. Neolithic (Biraben, 1988 ; Masset 2002)

Sources for historical demography

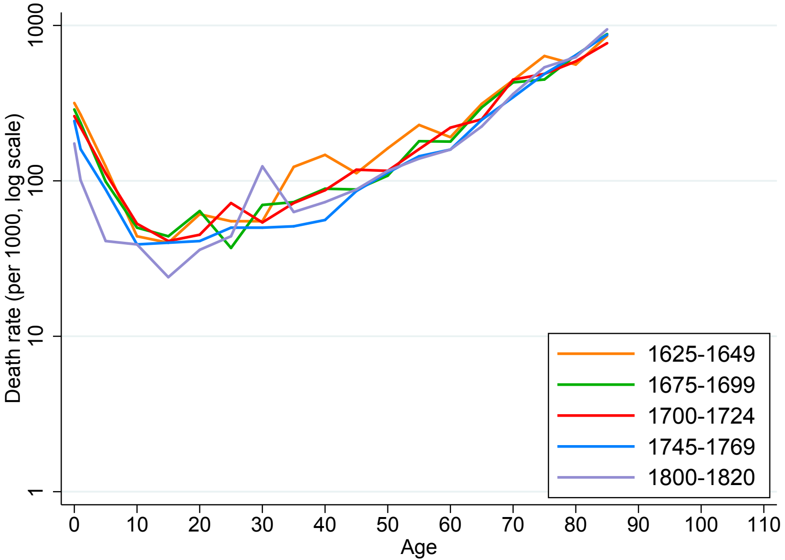
- **England 1541-1871**
  - Cambridge group (Wrigley and Schofield, 1981)
  - Anglican parish registers in England since 1538
  - Record baptisms, burials and marriages
- **Geneva 16th-17th c.**
  - Protestant parish registry since 1550 (Perrenoud, 1978)
  - Detailed information on age, socio-occupational status
- **France 18th c.**
  - Catholic registry since 17th
  - Enquête INED Louis Henry (Blayo, 1975)

Figure 21 – Life expectancy at birth (England and Sweden, 1550–1850)



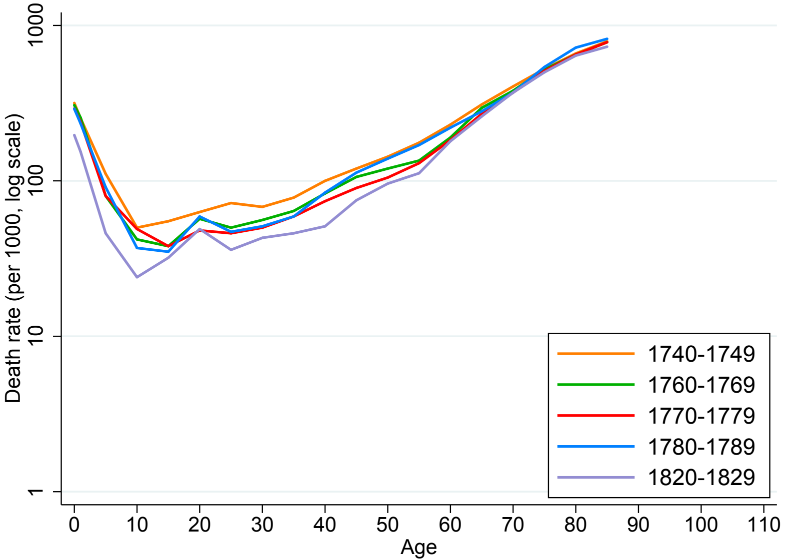
SOURCE : Wrigley and Schofield (1981) ; human mortality database for Sweden.

Figure 22 – Death rate by age (Geneva, 17th–18th c.)



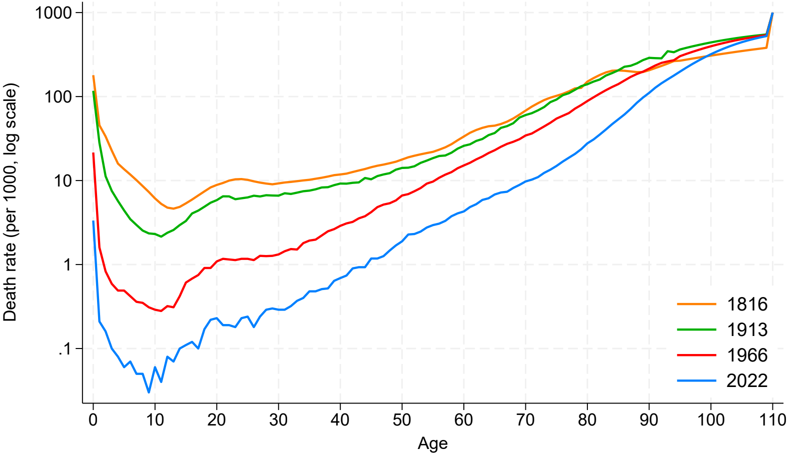
SOURCE : Perrenoud (1978), tableau 2, p. 219.

Figure 23 – Death rate by age (France, 18th c.)



Source : Blayo (1975), tableaux 11 et 12, p. 138.

Figure 24 – Death rates from period life tables (France)



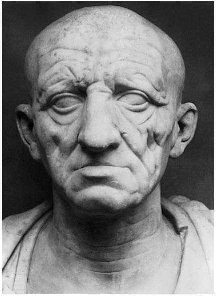
SOURCE : Human mortality database [www.mortality.org] ; Vallin-Meslé (2001).

Ageing in Antiquity

- **Bagnall and Frier (1994)**
  - Set of papyri from Roman Egypt
  - Use census information and demographic model to fill gaps
- **Roman Census**
  - Census carried over from AD 12 to AD 259
  - Information on age, sex, status
- **Findings**
  - High infant mortality
  - Mortality rates similar to that of 18th c.
  - Still large uncertainties (large selection bias possible)

Ageing in Antiquity

- **Old Romans**

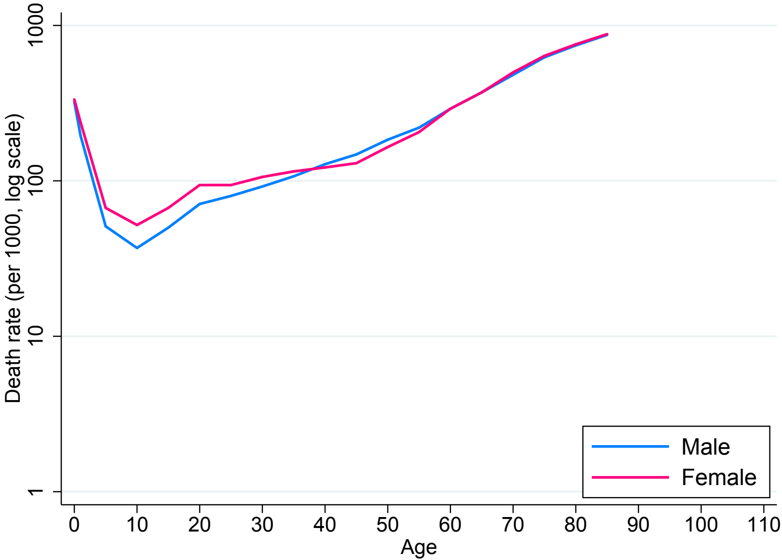


Head of a Roman Patrician from Otricoli, c. 75-50 BCE, marble (Palazzo Torlonia, Rome).

Example of verism of the late Roman Republic.

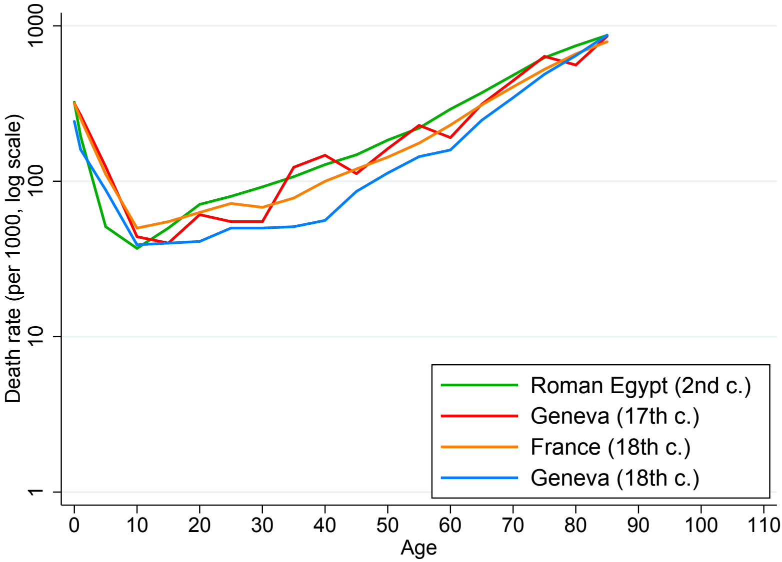
- **Cicero : old at age 60**
  - In *de Senectute*, defense of old age as providing reason, wisdom, and *auctoritas*

Figure 25 – Death rates in Roman Egypt (33–328 AD)



SOURCE : Bagnall and Frier (1994), Tab. 4.2, p. 77 (female), Tab. 5.3, p. 100 (male).

Figure 26 – Death rate by age before 18th century



SOURCE : Bagnall and Frier (1994) ; Perrenoud (1978) ; Blayo (1975)

Long-term history of ageing : Recap

Table 3 – Life expectancy, 33 AD–1800

Country and period	Life expectancy	Infant mortality	Sources
Roman Egypt, 33–258	24.0	329	Bagnall and Frier (1994)
England, 1301–1425	24.3	218	Russell (1948)
England, 1541–1556	33.7	n.d.	Wrigley et al. (1997)
England, 1620–1626	37.7	171	Wrigley et al. (1997)
England, 1726–1751	34.6	195	Wrigley et al. (1997)
England, 1801–1826	40.8	144	Wrigley et al. (1997)
France, 1740–1749	24.8	296	Blayo (1975)
France, 1820–1829	38.8	181	Blayo (1975)
Sweden, 1751–1755	37.8	203	Gille (1949)
Japan, 1776–1875	32.2	277	Saito (1997)

SOURCE : Maddison (2001), Table 1.4, p. 29.

Long-term history of ageing : Recap

- **Life expectancy at birth**
  - Around 25-40 before 18th c.
  - But because large infant mortality
    $\simeq$ 50% mortality before age 5
  - Romans didn't die at age 25 !

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  - There were old people in the past
  - Cicero "old age starts at 60"
- **Major change since 17th-18th c.**
  - Drop in infant mortality since 17th c.
  - Drop in mortality at older age much more recent (after 1945)

Demographic projections

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- **The component method**
  - Old method (Leslie, 1945)
  - Also named macrosimulation
  - Used with matrix algebra, hence the "Leslie matrix"
- **Principles**
  - Population P_t at time t, split by age and sex
  - Population P_{t+1} is P_t aged by one year : affected by mortality rates, births, and migration

Demographic projections

- **Notations**
  - $P_{a,t}$: population age a at time t
  - $q_{a,t}$: age specific mortality rates
  - $f_{a,t}$: age specific fertility rates
  - N_t : births at time t
  - $M_{a,t}$: migration by age a at time t

- **Recurrence equation**

$$P_{a,t} = P_{a-1,t-1}(1 - q_{a,t})$$

$$P_{0,1} = N_t = \sum_{a=15}^{50} f_{a,t} P_{a,t}$$

Demographic projections

- **Matrix representation**

$$P_{t+1} = A_t P_t + M_t$$

- **The Leslie matrix**

$$A_t = \begin{bmatrix} 0 & f_{15} \ldots f_{50} & 0 & 0 \\ 1 - q_0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 \\ 0 & 0 & 1 - q_{110} & 0 \end{bmatrix}$$

Demographic projections

- **Assumptions needed**
  - Projecting fertility rates by age
  - Projecting mortality rates by age
  - Migration trends by age

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  - Projecting mortality rates by age
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- **Fertility**
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    - she were to survive from birth through the end of her reproductive life

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  - Projecting mortality rates by age
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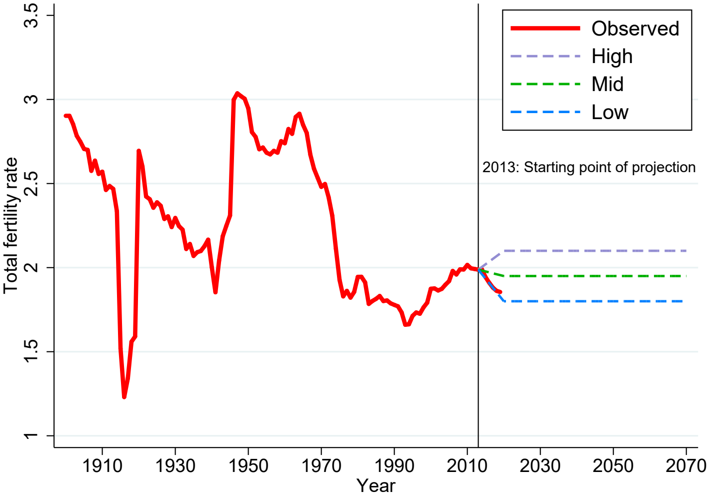
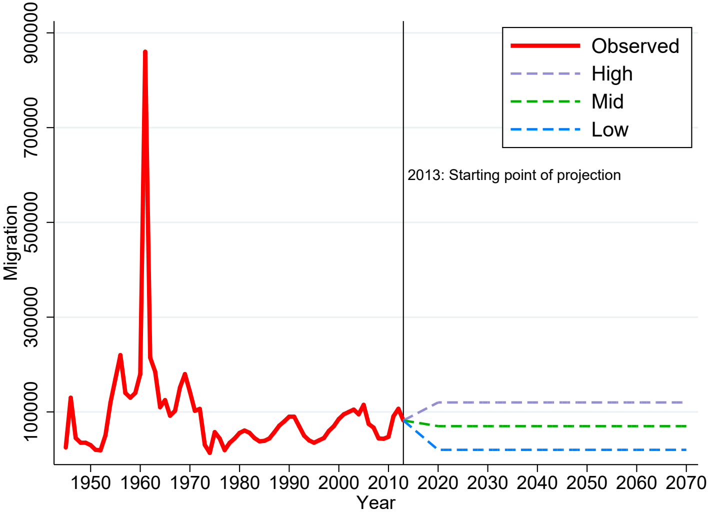
    - she were to experience the exact current age-specific fertility rates
    - she were to survive from birth through the end of her reproductive life
- **Migration**
  - Different scenarios of total migrant flow

Figure 27 – Total fertility rate and assumptions for projections (France, 2016 projections)



SOURCE : Blanchet and Le Gallo (2008, 2014), with 2016 Insee projection (Blanpain et Buisson, 2016), and observed data between 2013 and 2019 from Papon and Baumel (2020) *Bilan démographique 2019*.

Figure 28 – Net migration flows and assumptions for projections (France, 2016 projections)



SOURCE : Blanchet and Le Gallo (2008, 2014), updated with 2016 Insee projection (Blanpain et Buisson, 2016).

Demographic projections

- **Methods for mortality forecasts**
  1. Using life expectancy targets
  2. Using past trends to extrapolate
  3. Using epidemiological explanations

Demographic projections

- **Methods for mortality forecasts**
  1. Using life expectancy targets
  2. Using past trends to extrapolate
  3. Using epidemiological explanations
- **Targeting**
  - Set target of life table
  - Use expert judgement for path to target
  - Useful for predicting changes in mortality when other population experience provides good target
  - Past experience shows very large errors

Demographic projections

- **Extrapolation**
  - Extrapolation methods from past trends
  - Component methods, APC, etc.
  - Lee-Carter model
  - Most popular forecasting methods

Demographic projections

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  - Extrapolation methods from past trends
  - Component methods, APC, etc.
  - Lee-Carter model
  - Most popular forecasting methods
- **Epidemiological explanations**
  - Epidemiological models
  - Little use so far in mortality forecasting

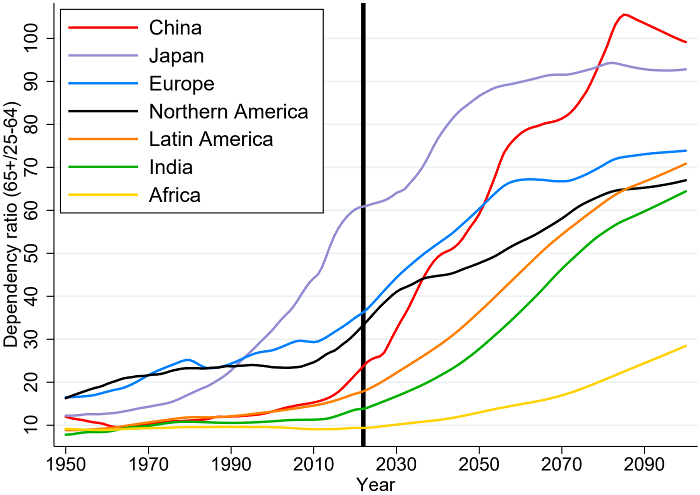
Demographic projections

- **United Nations projections**
  - World coverage, updated every two years
  - Estimates provided since 1950s
  - Assessment of past accuracy is possible

Demographic projections

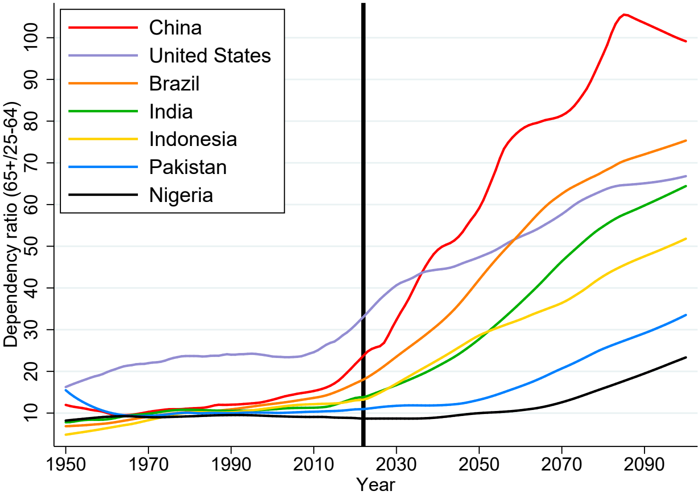
- **United Nations projections**
  - World coverage, updated every two years
  - Estimates provided since 1950s
  - Assessment of past accuracy is possible
- **Main facts**
  - Increase in world population from 7 to 11 billion by 2100
  - Large increase in the share of older group
    - 60+ : from 0.7 to 3 bn
    - 80+ : from 0.1 to 0.9 bn
  - Large heterogeneity in the timing of ageing across regions

Figure 29 – Old-age dependency ratio (65+/25-64)



SOURCE : United Nations, *World Population Prospects : The 2022 Revision*.
NOTE : Medium estimates.

Figure 30 – Old-age dependency ratio (65+/25-64)



Source : United Nations, *World Population Prospects : The 2022 Revision*.
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Demographic projections

- **Ex post tests of projections**
  1. Large errors in past predictions
  2. Large under-estimation of mortality decline
  3. In all countries (cf. Lee, JEP 2003)

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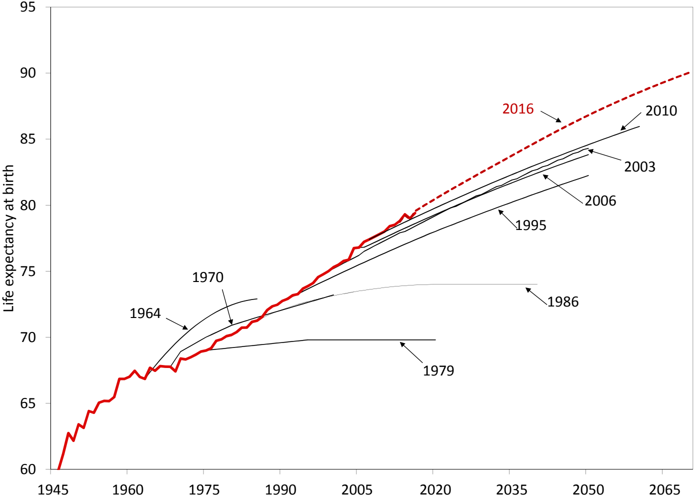
  - Recent changes matter a lot, but are not incorporated in models

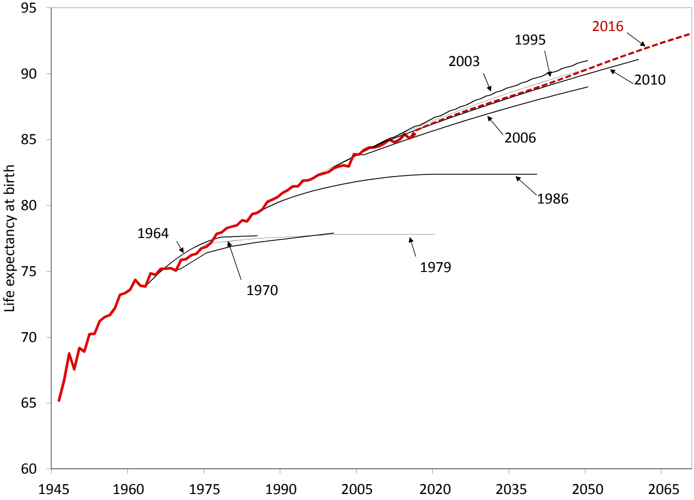
- **How to deal with uncertainty**
  - Be explicit about the level of uncertainty (cf. Blanchet and Le Gallo, 2008)
  - Use variants of scenarios or stochastic projections

Figure 31 – Past life expectancy and assumptions for projections (France, male)



SOURCE : Blanchet and Le Gallo (2008, 2014) updated with 2016 projections.
NOTE : For all projections apart 2016, projections are for metropolitan France.

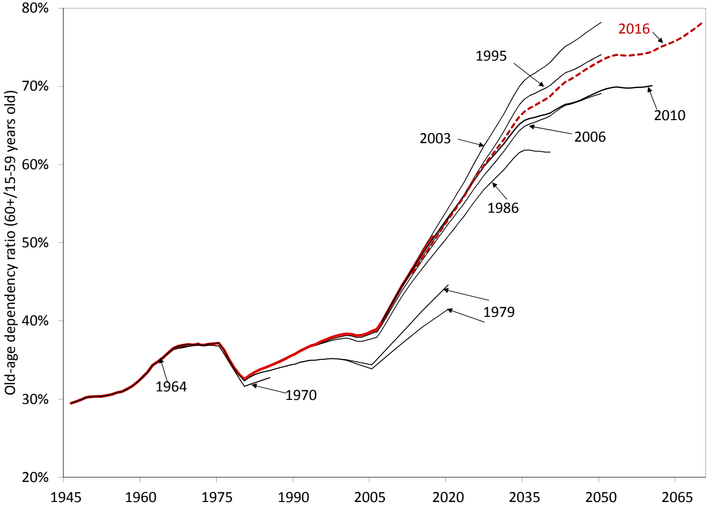
Figure 32 – Past life expectancy and assumptions for projections (France, female)



Source : Blanchet and Le Gallo (2008, 2014) updated with 2016 projections.

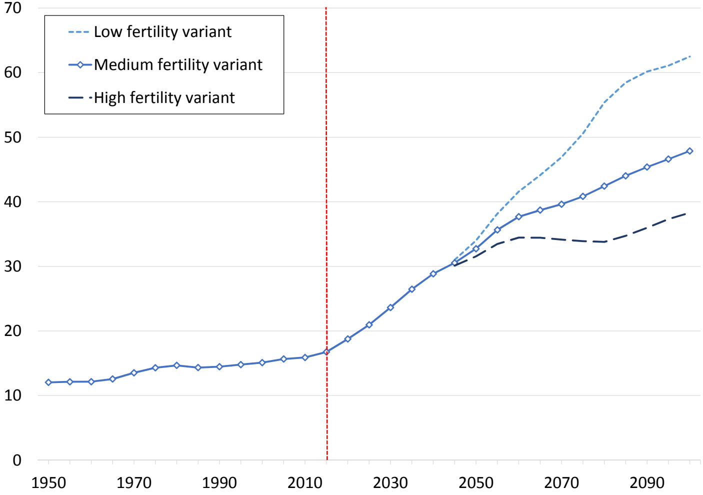
Note : For all projections apart 2016, projections are for metropolitan France.

Figure 33 – Old-age dependency ratio (60+/15-59) (France)



SOURCE : Blanchet and Le Gallo (2008, 2014) updated with 2016 projections.
NOTE : For all projections apart 2016, projections are for metropolitan France.

Figure 34 – World old-age dependency ratio with fertility variants



Source : United Nations, *World Population Prospects : The 2015 Revision*.
Note : Medium estimates.

II. Theories of population ageing

1. Malthusian model
2. Demographic transition
3. Baby-boom and *papy-boom*
4. Ageing by the top
5. Which limit to human life ?

Malthusian model

- **Rev. Thomas Robert Malthus (1766–1834)**

English cleric and scholar, published *An Essay on the Principle of Population* (1798, 1803)

Malthusian model

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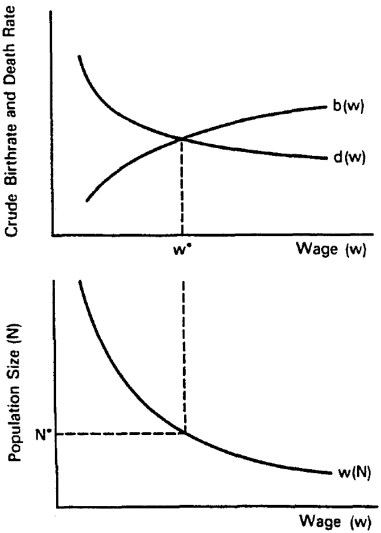
English cleric and scholar, published *An Essay on the Principle of Population* (1798, 1803)

- **"Principles of population"**
  - Population growth expands in period of plenty
  - Population growth leads to lower wages
  - Lower wages lead to poverty

- **"positive and preventive checks"**
  - "positive checks" : higher mortality (notably child mortality)
  - "preventive checks" : lower fertility (through delayed marriage)

Figure 35 – Malthusian model



SOURCE : Lee (1997), Fig. 1, p. 1067.

Malthusian model

- **Popularity of the malthusian model**
  - Prehistoric population (anthropologists), animal population (biologists) ; historical population (social historians)

Malthusian model

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- **Was the pre-industrial world malthusian ?**
  - Evidence of "malthusian trap" : little gains in standard of living before 1800
  - Some empirical support for malthusian model (Lee, 1997 ; Lee and Anderson, 2002)
  - Wages reacted strongly to changes in population (e.g., Black Death in 1348)
  - But weak tests for the "positive checks"

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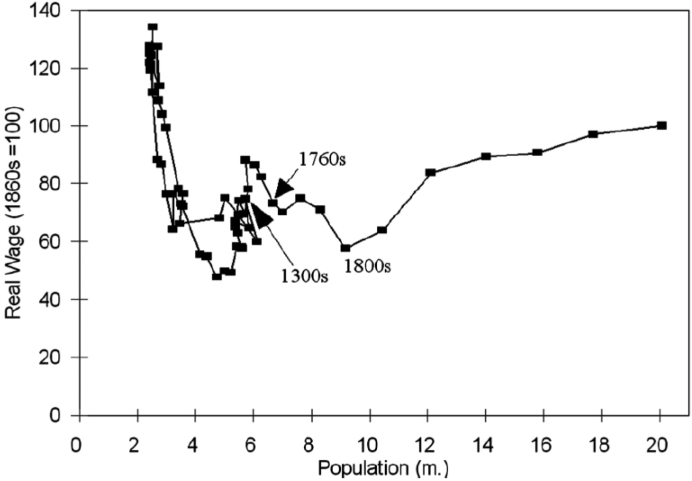
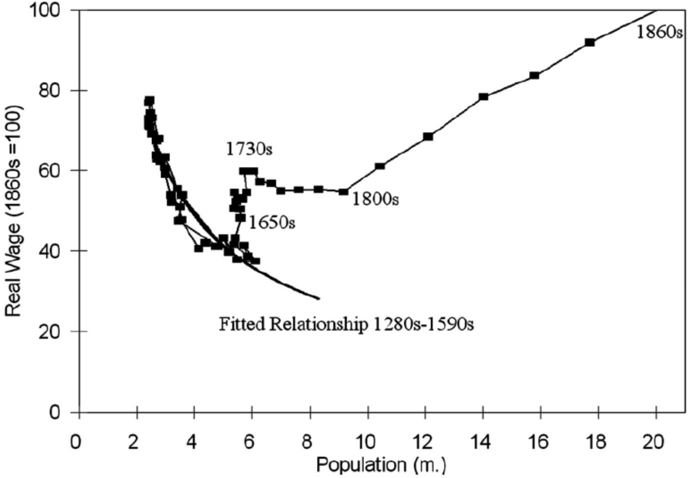
  - Wages reacted strongly to changes in population (e.g., Black Death in 1348)
  - But weak tests for the "positive checks"
- **Debate around series for England**
  - England has uniquely good wage and price history
  - Debate among economic historians

Figure 36 – Real wages vs population in England (1280–1860) : PBH wage series



SOURCE : Clark (2005), fig. 3.

Figure 37 – Real wages vs population in England (1280–1860) : Clark wage series



SOURCE : Clark (2005), fig. 5.

Demographic transition

- **The concept of "demographic transition"**
  - Warren Thompson (1929)
  - French Adolphe Landry (1934) : *révolution démographique*
  - U.S. scholars, Davis (1945) and Notestein (1945) coined the phrase
  - See survey by Vallin (2006)

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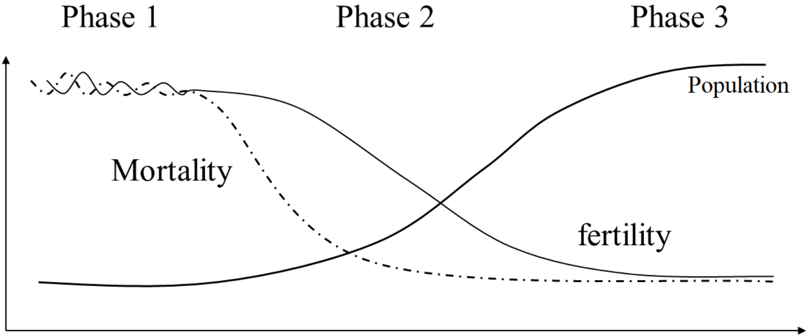
  - See survey by Vallin (2006)

- **Basic model**
  1. Phase 1 : high mortality, high fertility, no growth
  2. Phase 2 : drop in mortality, high fertility, growth
  3. Phase 3 : drop in fertility, no growth

Demographic transition

Figure 38 – Demographic transition model



SOURCE : courtesy of Didier Blanchet.

Demographic transition

- **Health transition in Europe (1800–1940)**
  - Order of magnitude : from 3-4% to 1-1.5%
  - Reductions in famine mortality
  - Reductions in infectious diseases

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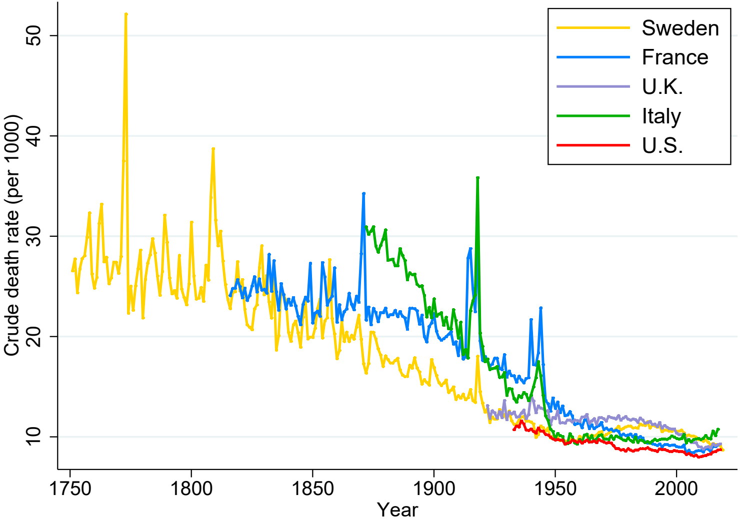
- **Determinants of decline in mortality**
  - See Cutler, Deaton and Lleras-Munet (JEP, 2006)

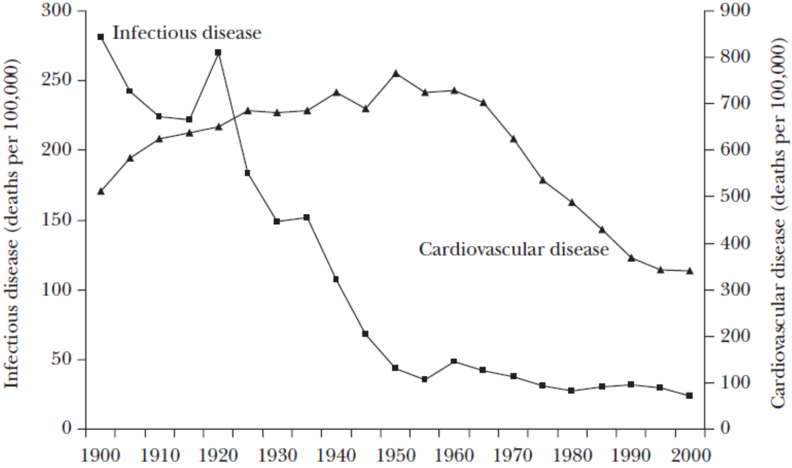
  1. **Improved nutrition** (Fogel, 1997) : improvement in storage, transportation, market integrations
  2. **Public health** (Preston, 1975) : sanitation systems, draining swamps, personal hygiene
  3. **Vaccination :** smallpox vaccine (Jenner, 1798) ; germ theory of disease (Pasteur, 1860s)
  4. **Medical treatments :** antibiotics (1930s, 1940s)

Figure 39 – Crude death rates, 1750–2020



SOURCE : Human mortality database, own computations.
NOTE : crude death rates for both sexes, per 1000 individuals.

Figure 40 – Mortality from infectious disease and cardiovascular disease (US)



SOURCE : Cutler, Deaton and Lleras-Munet (2006), fig. 3.

Female-Male mortality gap

- **Female advantage appears in the late 19th c.**
    - No life expectancy gap in 19th c.
    - Increased gap up to the 1970s
    - Since then a slow reduction in the F/M gap

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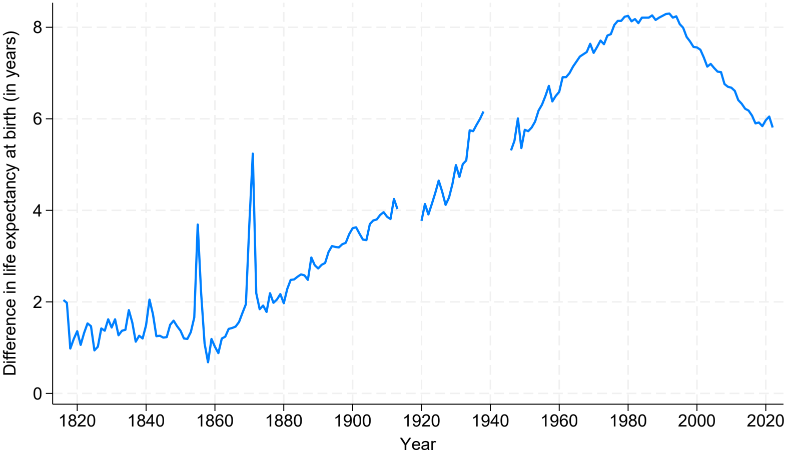
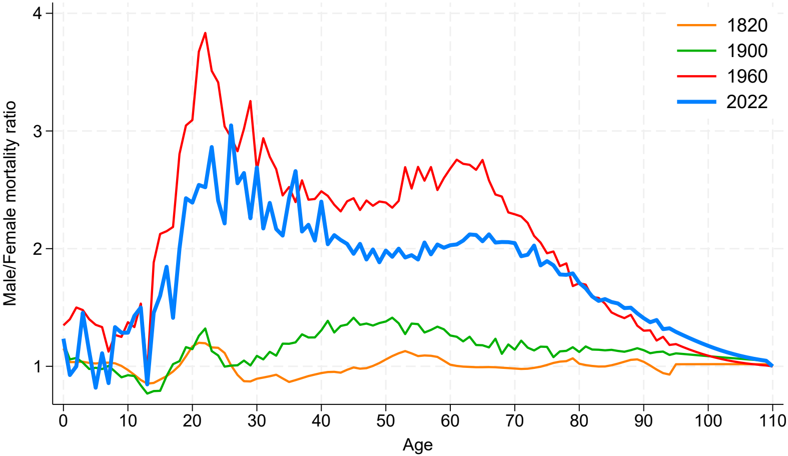
  - No life expectancy gap in 19th c.
  - Increased gap up to the 1970s
  - Since then a slow reduction in the F/M gap
- **Presumable causes ?**
  - Smoking explains 30% excess mortality (Beltrán-Sáncheza et al. 2016)
  - Reduction in infectious diseases have benefited female more (Goldin and Lleras-Muney, 2019)
  - Cardio-vascular diseases affected male more

Figure 41 – Difference in life expectancy at birth between female and male (France, 1816–2022)



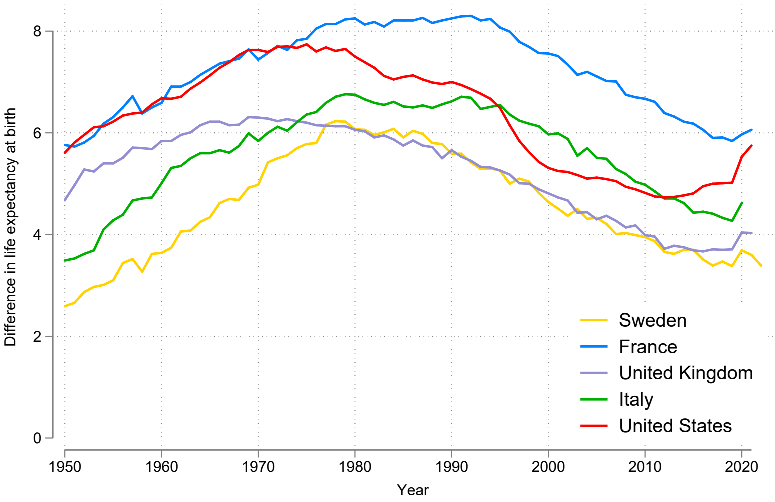
SOURCE : human mortality.org.

Figure 42 – Male/Female mortality ratio by age (France)



SOURCE : human mortality.org.

Figure 43 – Difference in life expectancy at birth between female and male (1950–2022)



SOURCE : human mortality.org.

Demographic transition

- **Fertility transition in Europe (1800–1940)**
  - Cohort fertility rate declined from 4-5 in 19 c. to 2-2.5 after mid-20 c.
  - Different timing of fertility reduction
  - French fertility dropped earlier in the 19c.

Demographic transition

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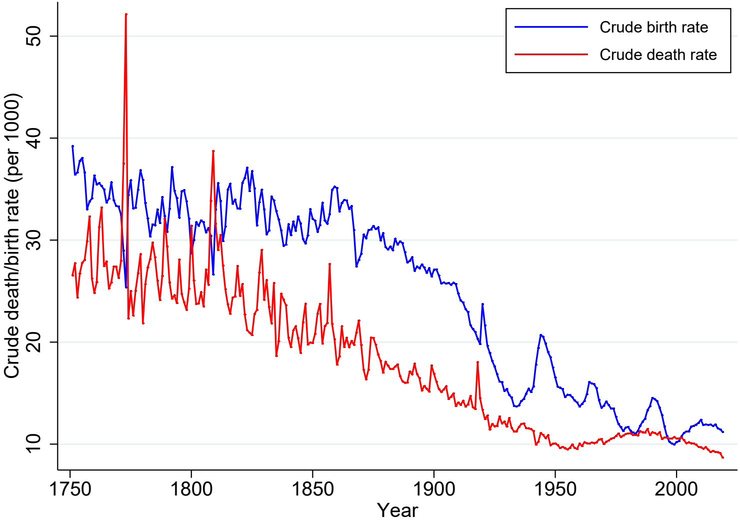
- **Determinants of decline in fertility**
  - Still debated : see Guinnane (JEP, 2011)

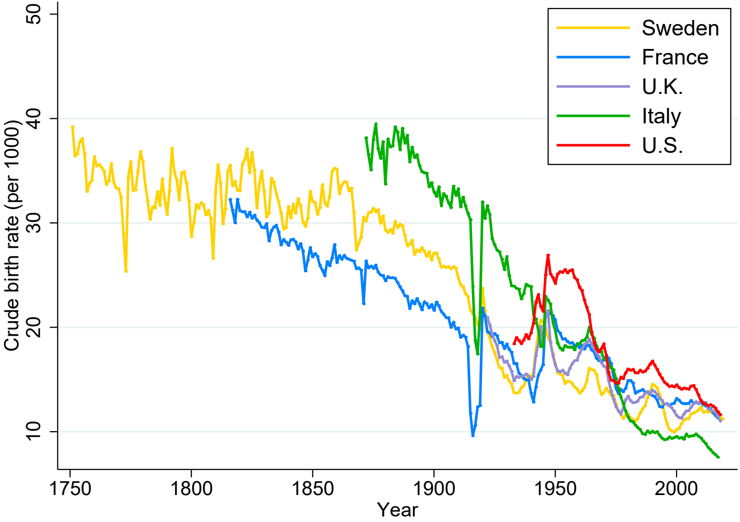
  1. **Decline in infant mortality** : but France and US outliers (fertility declined before)
  2. **Contraception** : *coitus interruptus* and abstinence
  3. **Costs/returns to having children** : housing costs, child-labour law, better work opportunities for women, education, social-insurance systems

Figure 44 – Demographic transition in Sweden (1750–2020)



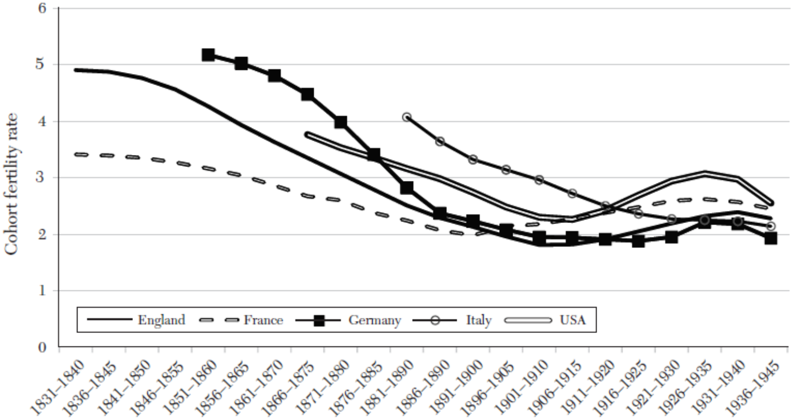
SOURCE : Human mortality database, own computations.
NOTE : crude death rates and fertility rates for both sexes, per 1000 individuals.

Figure 45 – Crude birth rates, 1750–2020



SOURCE : Human mortality database, own computations.
NOTE : crude birth rates for both sexes, per 1000 individuals.

Figure 46 – Cohort fertility rates, 1820–1970



Source : Guinnane, JEP 2011, fig. 3.
Note : cohort fertility rate is the mean number of children born to women belonging to the birth cohort on the horizontal axis.

Baby-boom

- Increase in fertility in the US and Europe (1946-1970)
- **Modeling baby-booms**
  - Higher population growth
  - First younger population, increase in child dependency ratio
  - Then, more active population, reduction in old-age dependency ratio
  - With ageing of babyboomers, back to previous trend
  - Baby-boom : U-shaped old-age dependency ratio, rather than hump-shaped

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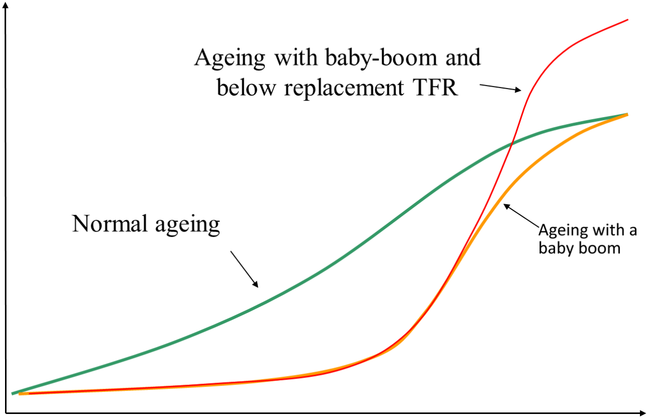
- **Baby-bust**
  - A baby bust followed the baby boom
  - Hump-shaped old-age dependency ratio

Baby-boom

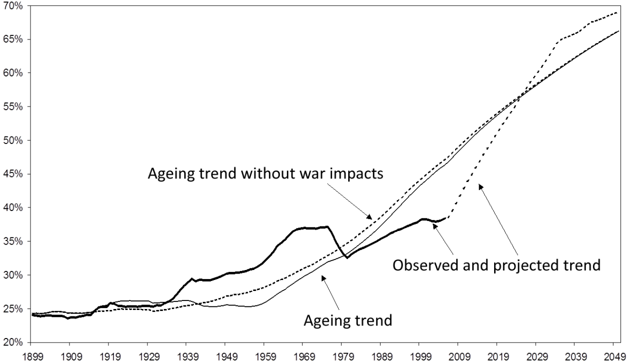
Figure 47 – Modeling baby-booms



SOURCE : Courtesy of Didier Blanchet.

Baby-boom

Figure 48 – Decomposing ageing in France (old-age dependency ratio)



SOURCE : Blanchet and Le Gallo, *Insee Analyses*, Sept. 2013.

Ageing by the bottom

- **Ageing by the bottom**
  - Ageing driven by fertility decrease : reductions in number of youths or prime aged individuals
  - Historically decline in infant mortality led to increase in the share of the 60+

Ageing by the bottom

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  - Ageing driven by fertility decrease : reductions in number of youths or prime aged individuals
  - Historically decline in infant mortality led to increase in the share of the 60+
- **French debate in late 19th c. (Bourdelais, 1993)**
  - Jacques Bertillon of *Alliance pour l'accroissement de la population française*), a pro-natality lobby deplored low fertility as the cause of an aged and feeble population
  - Alfred Sauvy (1928), a French demographer, used the term "population ageing", establishing the scientific explanations for ageing by the bottom

Ageing by the top

- **A prolonged view despite demographic change**
    - Ageing by the bottom became the prevailing orthodoxy in demography after WWII
    - Debate in the 1990s on ageing, with focus on low fertility rate (Blanchet and Le Gallo, 2008)
    - Pension debate concentrated on need to increase fertility or favour immigration

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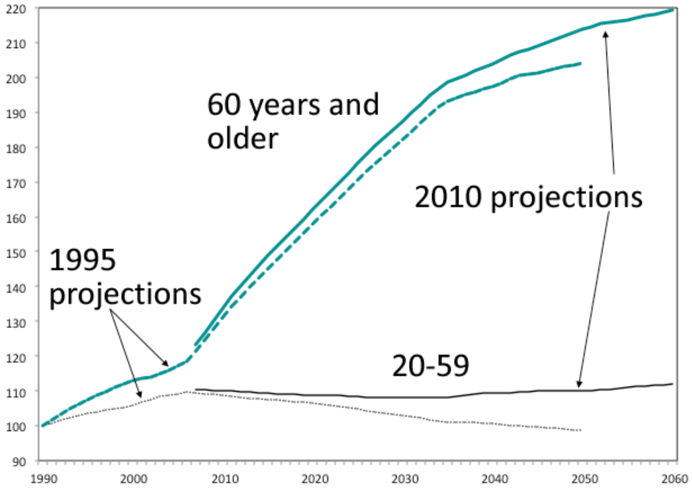
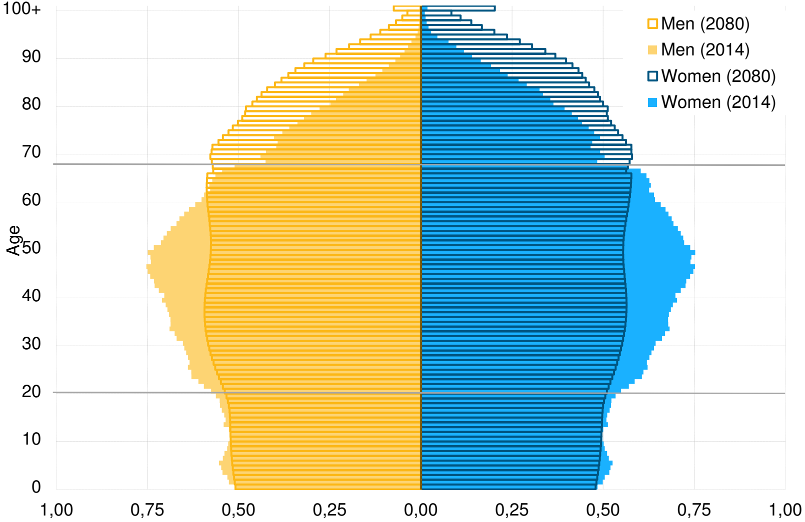
- **Ageing by the top**
  - More recent realisation that recent ageing process is essentially ageing by the top
  - Recent gains in life expectancy come from gains at older ages
  - Variety of experience at international level

Figure 49 – Ageing by the top in France



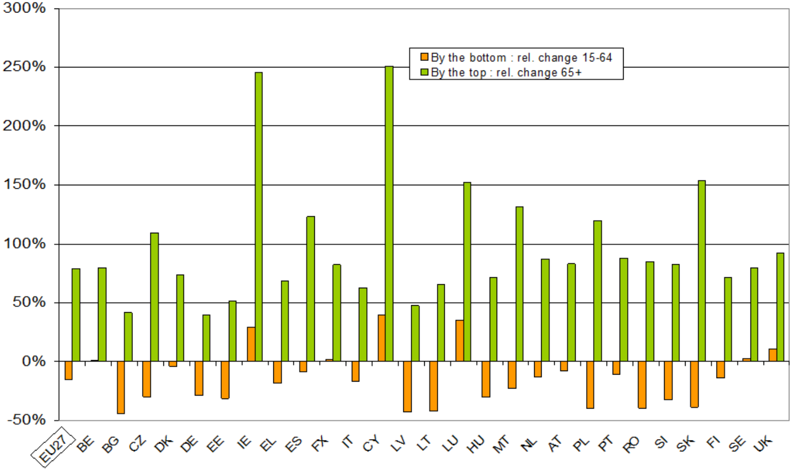
Source : Blanchet and Le Gallo, 2013.

Figure 50 – Ageing by the top in the EU (2014-2080)



SOURCE : Eurostat *People in the EU : who are we and how do we live ?* (June 2015).

Figure 51 – Relative growth of 15-64 vs 65 + (EU 27)

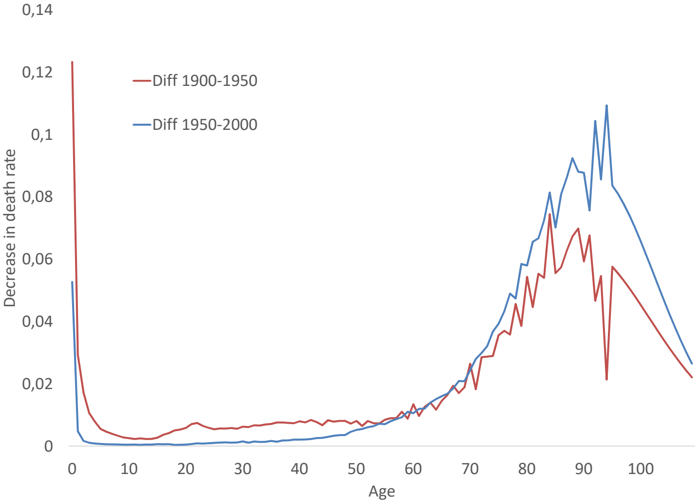


SOURCE : Eurostat.

Ageing by the top

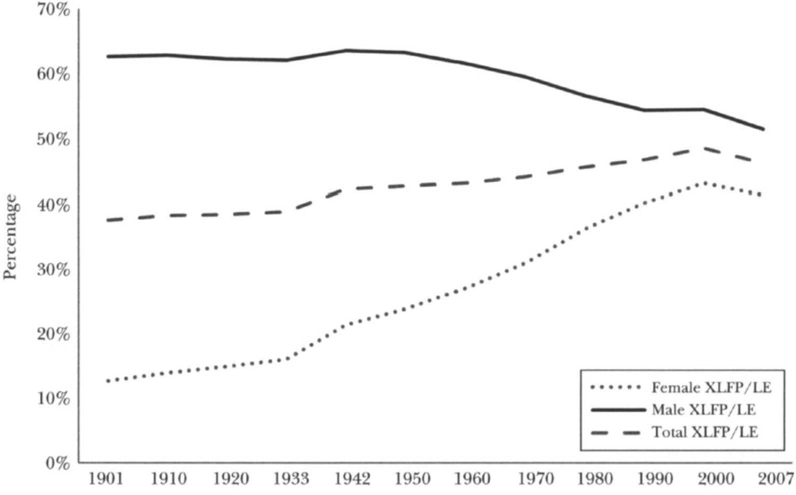
- **New demographic transition**
  - Eggleston and Fuchs (JEP 2012)
  - Ageing at older ages change the demographic dynamics
- **Traditional demographic transition**
  - Decrease in mortality rates at productive ages
  - No change in the likelihood to end up in retirement
  - Debate around "demographic dividend" (Bloom, Canning and Sevilla, 2003)
- **Longevity transition**
  - Decrease in mortality at older "unproductive" ages
  - Potential negative impact on labour force participation, innovation, public finances, etc.

Figure 52 – Change in death rates by age (French male, 1900-1950 vs 1950-2000



SOURCE : Human mortality database.

Figure 53 – U.S. expected labour force participation as a share of life expectancy



SOURCE : Eggleston and Fuchs, JEP 2012, fig. 4B.

Which limit to human life ?

- **Biological limit**
  - Idea of biological limit to human lifespan (Fries, 1980)
  - But leaves open further gains to this limit
  - Implies a rectangularisation of the survival curve an compression of morbidity

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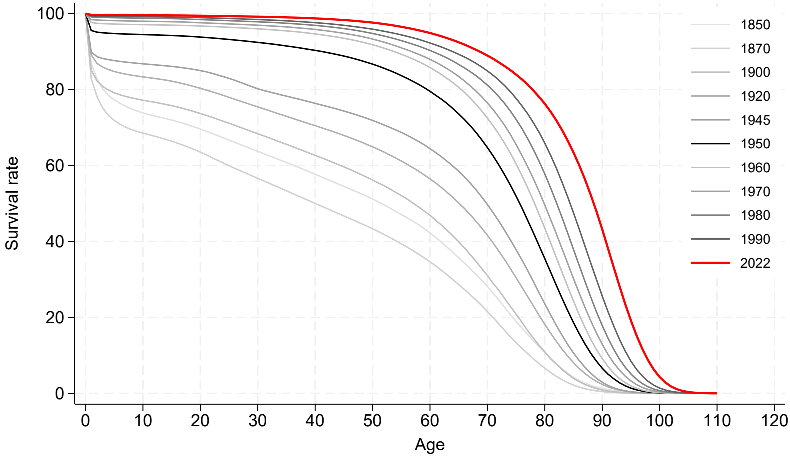
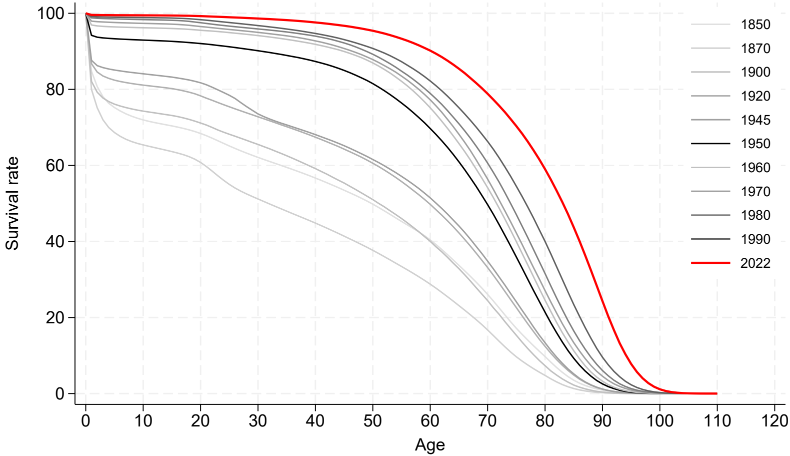
  - But leaves open further gains to this limit
  - Implies a rectangularisation of the survival curve an compression of morbidity
- **Rectangularisation of the survival curve**
  - Evidence is mixed : rectangularisation up to 1970s
  - But still gains in maximum life expectancy
  - Inequality in life expectancy limits rectangularisation of the survival curve

Figure 54 – French female survival curve (1850–2021)



Source : Human mortality database.

Figure 55 – French male survival curve (1850–2021)



Source : Human mortality database.

Which limit to human life ?

- **Maximum life expectancy : past predictions**
  - Dublin (1928) : 65 years
  - Bourgeois-Pichat (1952) : 75-78 years
  - Olshanski *et al.* (1990) : 85 years
  - UN forecasts have repeatedly failed

Which limit to human life ?

- **Maximum life expectancy : past predictions**
  - Dublin (1928) : 65 years
  - Bourgeois-Pichat (1952) : 75-78 years
  - Olshanski *et al.* (1990) : 85 years
  - UN forecasts have repeatedly failed
- **Oeppen and Vauper (Science, 2002)**
  - Linear increase in highest life expectancy since 1880
  - According to trend : 109 years by 2100 ?
  - But not over the long term, growth of highest life expectancy not so linear (Vallin and Mesle, 2010)

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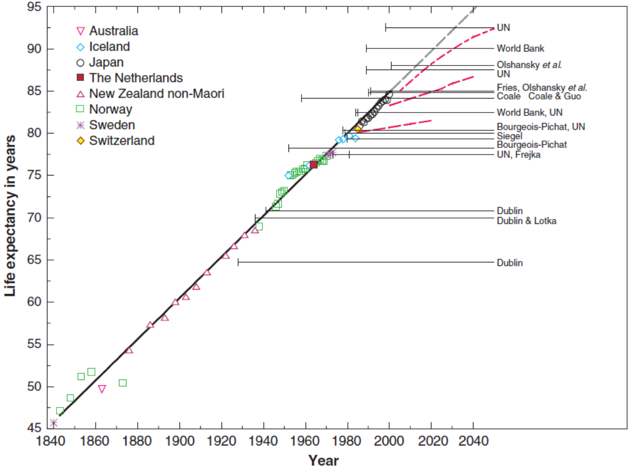
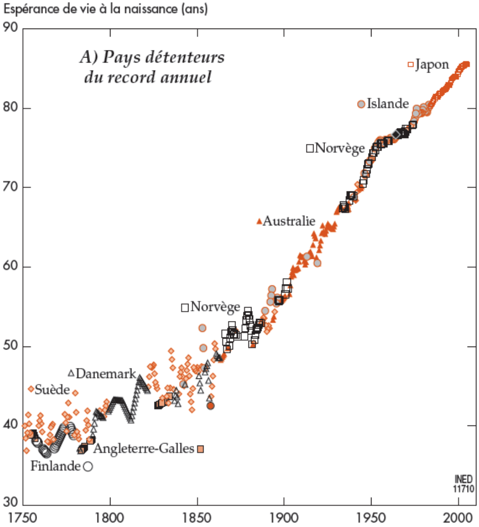
  - But not over the long term, growth of highest life expectancy not so linear (Vallin and Mesle, 2010)
- **Is there a limit ?**
  - Slowdown of mortality rates at older ages
  - Roy Walford (1984) : 150 years with calorie restriction

Figure 56 – Record female life expectancy (1840–2001)



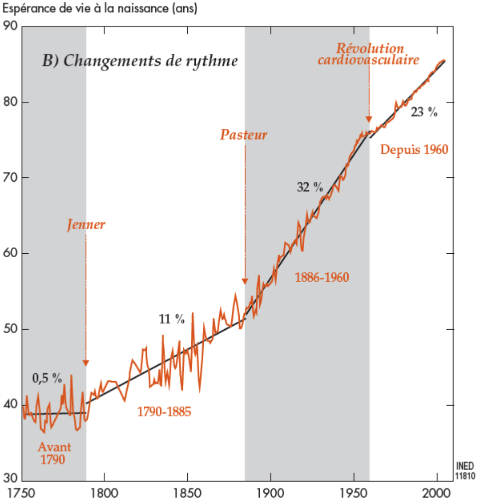
Source : Oeppen and Vaugel (2002), fig. 1.
Notes : The linear-regression trend is depicted by a bold black line and the extrapolated trend by a dashed gray line. The horizontal black lines show asserted ceilings on life expectancy, with a short vertical line indicating the year of publication. The dashed red lines denote projections of female life expectancy in Japan published by the United Nations in 1986, 1999, and 2001.

Figure 57 – Highest female life expectancy at birth



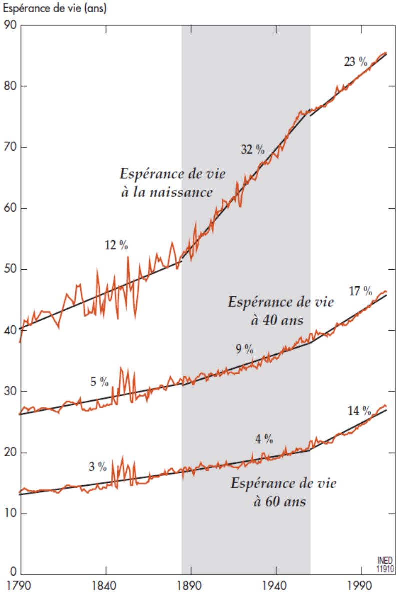
SOURCE : Vallin and Meslé (2010), Fig. 1.A

Figure 58 – Growth of highest female life expectancy



Source : Vallin and Meslé (2010), Fig. 1.B

Figure 59 – Growth of highest female life expectancy



SOURCE : Vallin and Meslé (2010), Fig. 2

Which limit to human life ?

Table 4 – Top 10 longest living person recorded

Rank	Name	Sex	Birth date	Death date	Age	Country
1	Jeanne Calment	F	21/02/1875	04/08/1997	122 years, 164 days	France
2	Kane Tanaka	F	02/01/1903	19/04/2022	119 years, 107 days	Japan
3	Sarah Knauss	F	24/09/1880	30/12/1999	119 years, 97 days	United States
4	Lucile Randon	F	02/01/1903	17/01/2023	118 years, 340 days	France
5	Nabi Tajima	F	04/08/1900	21/04/2018	117 years, 260 days	Japan
6	Marie-Louise Meilleur	F	29/08/1880	16/04/1998	117 years, 230 days	Canada
7	Violet Brown	F	10/03/1900	15/09/2017	117 years, 189 days	Jamaica
8	Emma Morano	F	29/11/1899	15/04/2017	117 years, 137 days	Italy
9	Chiyo Miyako	F	02/05/1901	22/07/2018	117 years, 81 days	Japan
10	Delphia Welford	F	09/09/1875	14/11/1992	117 years, 66 days	United States

SOURCE : Wikipedia as of 23 Jan. 2024. Case of Lucy Hannah invalidated in 2020.

III. Ageing as a health process

1. Ageing is becoming younger
2. Morbidity vs mortality
3. Measuring health
4. Indicators of healthy ageing

Is ageing an obsolete notion ?

- **Ageing, a misleading concept**
    - Standard reference to a fixed age (e.g., 60 or 65)
    - Reference determined in late 18th c.
    - Health and social position of the 60+ have dramatically changed

Is ageing an obsolete notion ?

- **Ageing, a misleading concept**
  - Standard reference to a fixed age (e.g., 60 or 65)
  - Reference determined in late 18th c.
  - Health and social position of the 60+ have dramatically changed
- **Ageing as health deterioration**
  - Reduction in death rates is an *improvement* in health
  - Population ageing is connoted negatively (deterioration of health of population)
  - Reduction in death rates means being younger at a given age

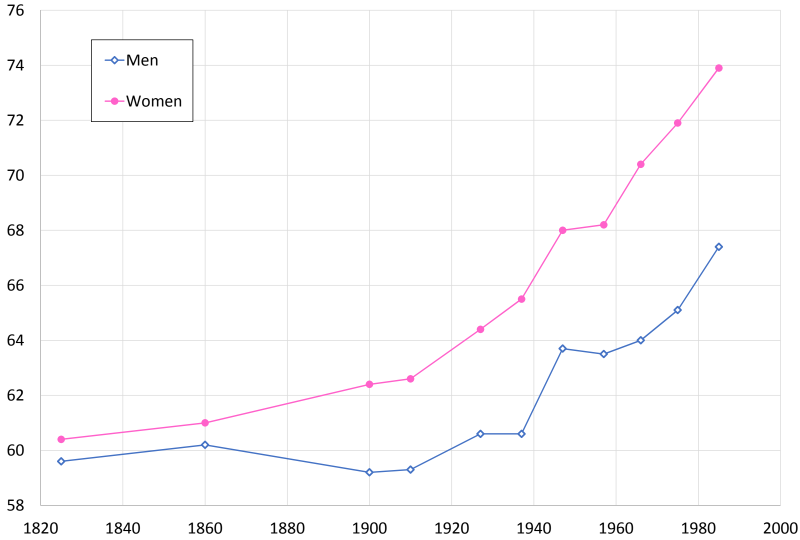
Ageing is becoming younger

- **Redefining age ?**
  - New Age thinking (Shoven, 2010)
  - Age should be defined as "remaining life expectancy"
  - Cultural evolution of ageing : 40s are the new 30s
  - But mortality is not morbidity

Ageing is becoming younger

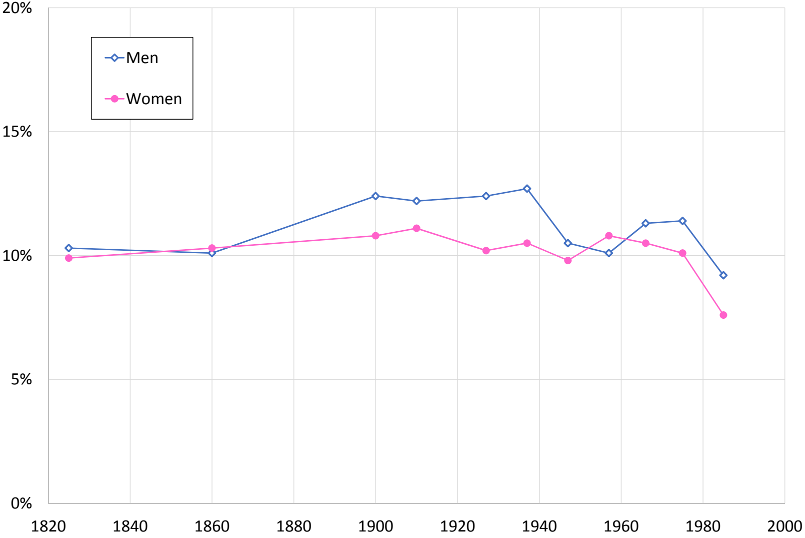
- **Redefining age ?**
  - New Age thinking (Shoven, 2010)
  - Age should be defined as “remaining life expectancy”
  - Cultural evolution of ageing : 40s are the new 30s
  - But mortality is not morbidity
- **Measuring age of old-age**
  - Patrice Boudelais *L’âge de la vieillesse* (1993)
  - Synthetic indicator for the age of old age
    - age when 10 years left to live
    - 5-y survival prob. at 65 (ref. 1985 for men)
  - Old-age is at ever older age

Figure 60 – The age of old age in France (Bourdelais, 1993)



SOURCE : Bourdelais (1993), Table 7.3, p. 231

Figure 61 – Share of the old in France (synthetic indicator)



Source : Bourdelais (1993), Table 7.4, p. 233

Morbidity vs mortality

- **Expansion or compression of morbidity ?**
  - Chronic diseases have replace infectious diseases
  - Is increase of LE linked with deterioration of health ?
  - Three theories developed

1. **Compression of morbidity (Fries, 1980 ; 1989)**
   - Postponement of morbid event, compressed disability into shorter time
2. **Expansion of morbidity (Gruenberg, 1977 ; Olshansky et al, 1991)**
   - Decrease in fatality rate of chronic diseases, but not their incidence
3. **Dynamic equilibrium (Manton, 1982)**
   - Increase prevalence of chronic diseases but less severe

Measuring health declines

- **Three approaches to health measurement**
  1. Medical assessment of diseases
  2. Functional model : incapacities
  3. Self-perceived health, quality of life

- **Medical approach**
  - Surveys of medical professions
  - Surveys of population with medical tests
  - Surveys of population with self-assessment

Measuring health declines

- **Functional models**
  - Saad Nagi (1965) ; WHO (1980, 2001)
  - Handicap model (Fougeyrollas, *et al.* 1998)
  - General model (Philip Wood, 1975)
- **Disablement process (Wood, 1975)**
  1. Disease
  2. Impairment
  3. Functional limitations
  4. Activity restriction
  5. Handicap

Indicators of healthy ageing

- See survey by Robine and Jagger (2005)
- **Health state life expectancies**
  - Measure different years of live with different levels of health
  - Life expectancy without diseases : e.g. without dementia
  - Life expectancy without impairment
  - Life expectancy without activity restrictions
  - Life expectancy in good perceived health
- **Health-adjusted life expectancies**
  - Life expectancies weighted by the social value given by different states of health
  - Disability adjusted life life-year (DALY)
  - Quality-adjusted life-year (QALY)

Indicators of healthy ageing

- **Disability free life expectancy (DFLE)**
  - Functional approach : disability as a robust comparison point
  - Severe disability even less prone to interpretation
- **Active life expectancy (ALE)**
  - Life expectancy free of problems of Activities in daily living (ADL)
  - ADL are ability to accomplish without help basic activities

Sullivan method

- **Sullivan (1971)**
  - Use data from life-table and data from current prevalence of disability (or other health indicator) to compute

π_x : prevalence of disability
$(1-\pi_x)L_x$: total person-years without disability
$DFLE_x$: disability free life expectancy (DFLE)

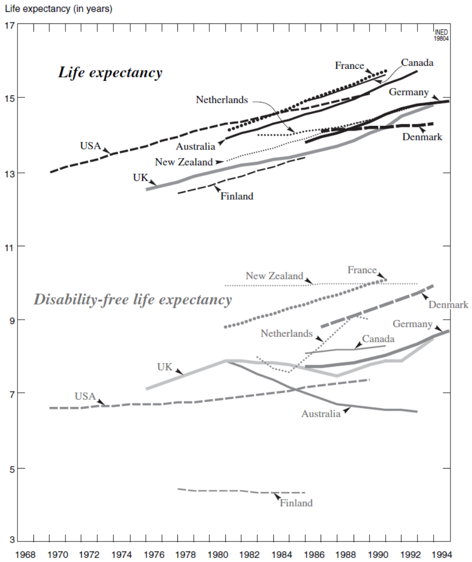
Table 5 – Life table to obtain DFLE

Age	q_x	l_x	L_x	T_x	e_x	π_x	$(1-\pi_x)L_x$	$DFLE_x$
75	0.023161	78786.43	77874.04	936200.22	11.9	0.431	44310.33	6.5
80	0.048305	65741.36	64153.54	571593.91	8.7	0.431	36503.37	4.6

Recent trends in healthy life expectancy

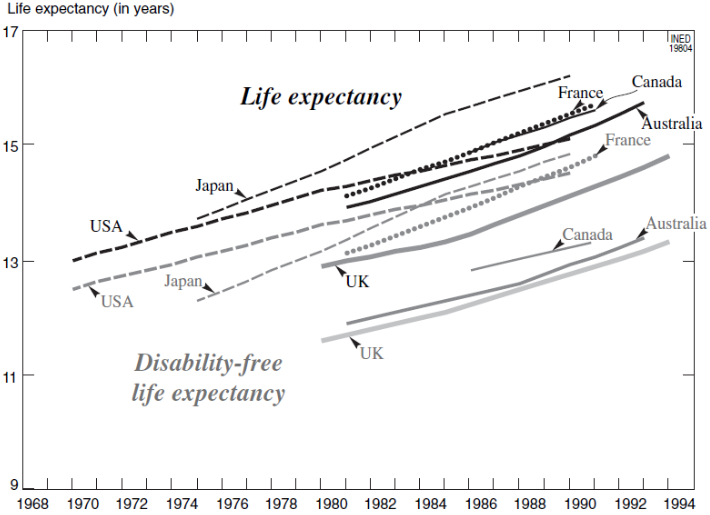
- **Strong improvement in the 1980s and 1990s**
  - Faster growth in healthy life expectancy (than with limitations)
  - See Robine J-M, Mormiche, P. and Cambois E. (1994) ; Cambois, Clavel and Robine (2006, 2008)
- **Recent slowdown**
  - Slower improvement of healthy life expectancy in France (Cambois et al. 2011, 2013) : increase in limitations at age 50-59, reductions at ages 65+
  - Reductions in life expectancy in the U.S.

Figure 62 – Life expectancy and disability-free LE



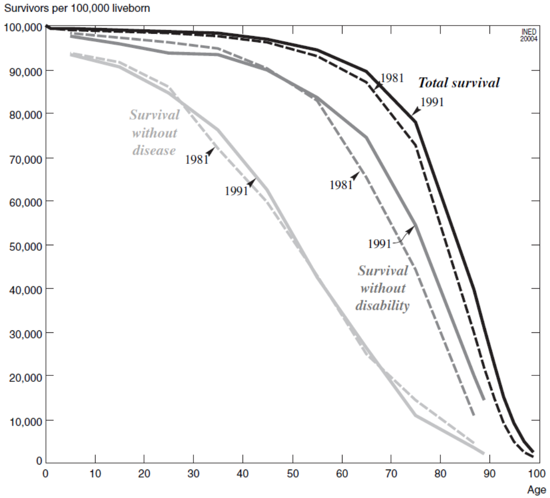
SOURCE : Robine and Jagger (2005), fig. 80-6.

Figure 63 – Life expectancy and life expectancy without severe disability



SOURCE : Robine and Jagger (2005), fig. 80-7.

Figure 64 – Survival without disease or disability (French female)



SOURCE : Robine and Jagger (2005), fig. 80-8.

Figure 65 – Contrasting pattern of change in healthy life-expectancy in France, 2003–2008

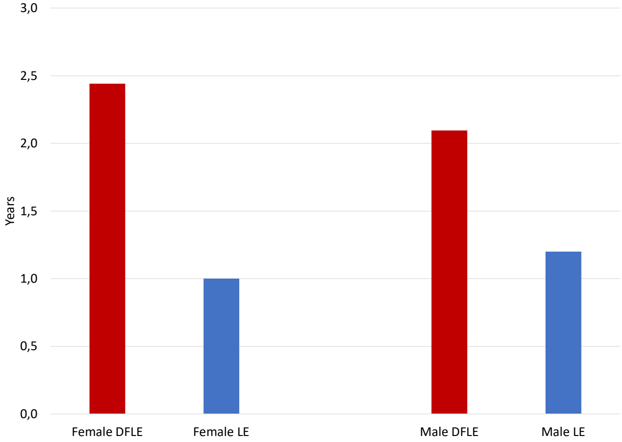
Table 4 Percentage change between 2003 and 2008 for life expectancies (%ΔLE) and the estimated disability-free life expectancies (%ΔDFLE′) calculated from linear regression (2003–08). Corresponding change in the proportion of estimated years with disability (↓: compression; ↑: expansion in DLE′/LE)[a]

	ΔLE and ΔDFLE at age 50			ΔLE and ΔDFLE in 50–65 age group			ΔLE and ΔDFLE at age 65		
	%ΔLE	%ΔDFLE′	ΔDLE′/ΔLE ↑/↓	%ΔLE	%ΔDFLE′	ΔDLE′/ΔLE ↑/↓	%ΔLE	%ΔDFLE′	ΔDLE′/ΔLE ↑/↓
Men									
DFLE_FLcog	+4.1	−1.0	↑ +0.045	+0.4	−2.7	↑ +0.029	+6.7	+0.2	↑ +0.052
DFLE_FLsens	+4.1	−0.8	↑ +0.033	+0.4	−3.7	↑ +0.033	+6.7	−2.5	↑ +0.025
DFLE_FLphy	+4.1	+1.7	↑ +0.017	+0.4	+1.3	↓ −0.008	+6.7	−1.4	↑ +0.025
DFLE_GALI	+4.1	+0.2	↑ +0.023	+0.4	−0.4	↑ +0.006	+6.7	+0.8	↑ +0.013
DFLE_IADL	+4.1	+4.8	↓ −0.006	+0.4	<0.0	↑ +0.004	+6.7	+4.3	↓ −0.020
DFLE_ADL	+4.1	+6.6	↓ −0.021	+0.4	+1.0	↓ −0.006	+6.7	+5.9	↓ −0.040
Women									
DFLE_FLcog	+2.8	+3.6	↓ −0.006	+0.1	−0.7	↑ +0.007	+4.6	+7.1	↓ −0.019
DFLE_FLsens	+2.8	−5.2	↑ +0.057	+0.1	−5.5	↑ +0.048	+4.6	−5.1	↑ +0.059
DFLE_FLphy	+2.8	−1.7	↑ +0.026	+0.1	−2.5	↑ +0.020	+4.6	−0.9	↑ +0.022
DFLE_GALI	+2.8	+2.9	↓ −0.001	+0.1	−1.1	↑ +0.008	+4.6	+7.6	↓ −0.012
DFLE_IADL	+2.8	+5.3	↓ −0.017	+0.1	<0.0	↑ +0.001	+4.6	+11.5	↓ −0.038
DFLE_ADL	+2.8	+4.3	↓ −0.012	+0.1	+1.4	↓ −0.012	+4.6	+6.7	↓ −0.016

Information source used in the linear regression:
Disability indicators: DFLE, FLphy, FLsens, FLcog, GALI, IADL and ADL.
Data sources: ESPS: Enquête santé et protection sociale 2006 and 2008; EU-SILC: Study on income and living conditions 2005–08; SHARE: Survey on health, aging and retirement in Europe 2004 and 2006; HSM: Handicap santé en menage 2008; HID: Handicaps, incapacites, dependance 1999; ESSM: Enquete santé et soins médicaux 2003.
a: DFLE′ and DLE′ estimates are computed for the years 2003 and 2008 using the linear regression parameters.
$\%\Delta LE = (LE_{2008} - LE_{2003})/LE_{2003}$ || $\%\Delta DFLE' = (DFLE'_{2008} - DFLE'_{2003})/DFLE'_{2003}$ || $\Delta(DLE'/LE) = (DLE'_{2008}/LE_{2008}) - (DLE'_{2003}/LE_{2003})$.

Source : Cambois et al. (2013), Table 4.

Figure 66 – Changes in disability-free life-expectancy vs life-expectancy in France from 2005 to 2020



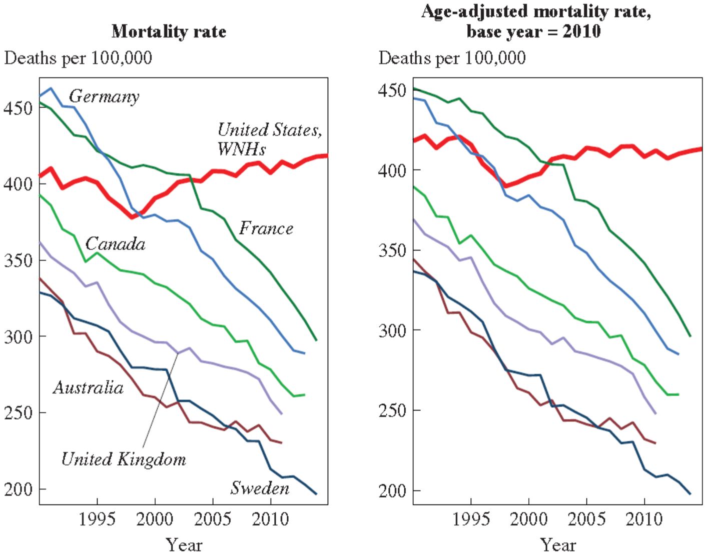
SOURCE : Thomas Deroyon, "En 2020, l'espérance de vie sans incapacité à 65 ans est de 12,1 ans pour les femmes et de 10,6 ans pour les hommes", Drees, *Etudes & Résultats*, n°1213, Oct. 2021.
DATA : Insee, civil registry statistics and data from the survey *Statistiques sur les ressources et les conditions de vie* (SRCV).

Mortality and morbidity in the U.S.

- **Case and Deaton (PNAS 2015, Brookings 2017)**
  - Document increasing mortality rates for 45-54 years old white non hispanics (WNH)
  - Leading to stagnating or even decreasing life expectancy at birth in the U.S.
  - Trend at odds with other European countries where mortality is still decreasing

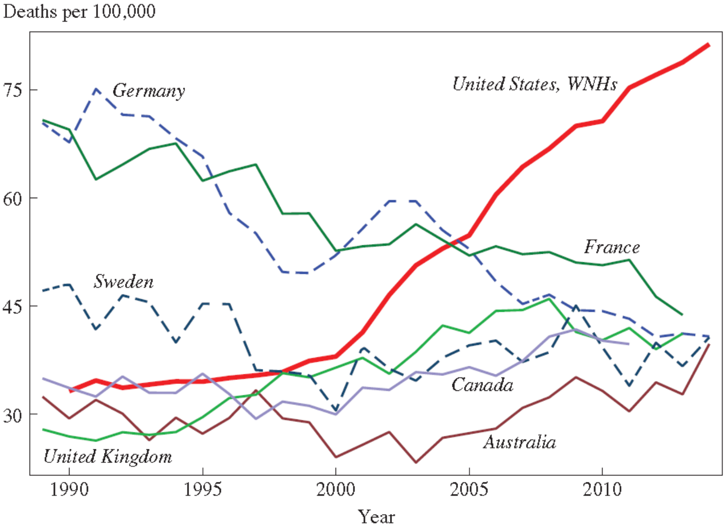
- **Increasing deaths of despair**
  - Increasing cause of death : drugs, alcohol, suicide
  - Immediate culprit : opioids overprescription, obesity
  - Underlying causes : labor market outcomes, mariage, life-style choice of low educated white Americans

Figure 67 – Mortality by Country for Age 45-54, 1990–2015



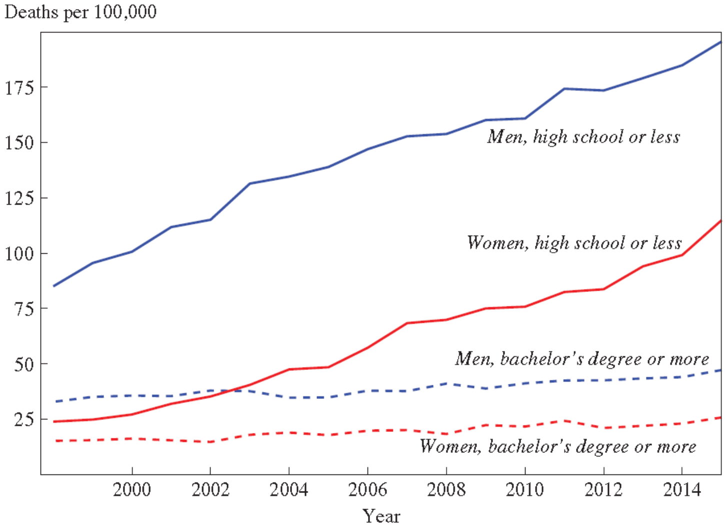
NOTE : WNHs refers to white non hispanic Americans.
SOURCE : Case and Deaton (2017), Fig. 3.

Figure 68 – Deaths of Despair by Country for Age 50-54, 1989–2014



NOTE : Deaths of despair refer to deaths by drugs, alcohol, or suicide.
SOURCE : Case and Deaton (2017), Fig. 5.

Figure 69 – Deaths of Despair for White Non-Hispanics Age 50-54, by Level of Education, 1998–2015



NOTE : Deaths of despair refer to deaths by drugs, alcohol, or suicide.
SOURCE : Case and Deaton (2017), Fig. 11.

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English-French glossary

- Life table = table de mortalité
- Period life table= table du moment
- cohort life table = table de la génération
- Death rate = quotient de mortalité
- Old-age dependency ratio = ratio démographique
- AD 12 = 12 après J.C. (*anno domini*)
- Haberdasher = mercier