Human longevity limits: a demographic data driven approach

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MAX PLANCK INSTITUTE FOR DEMOGRAPHIC RESEARCH
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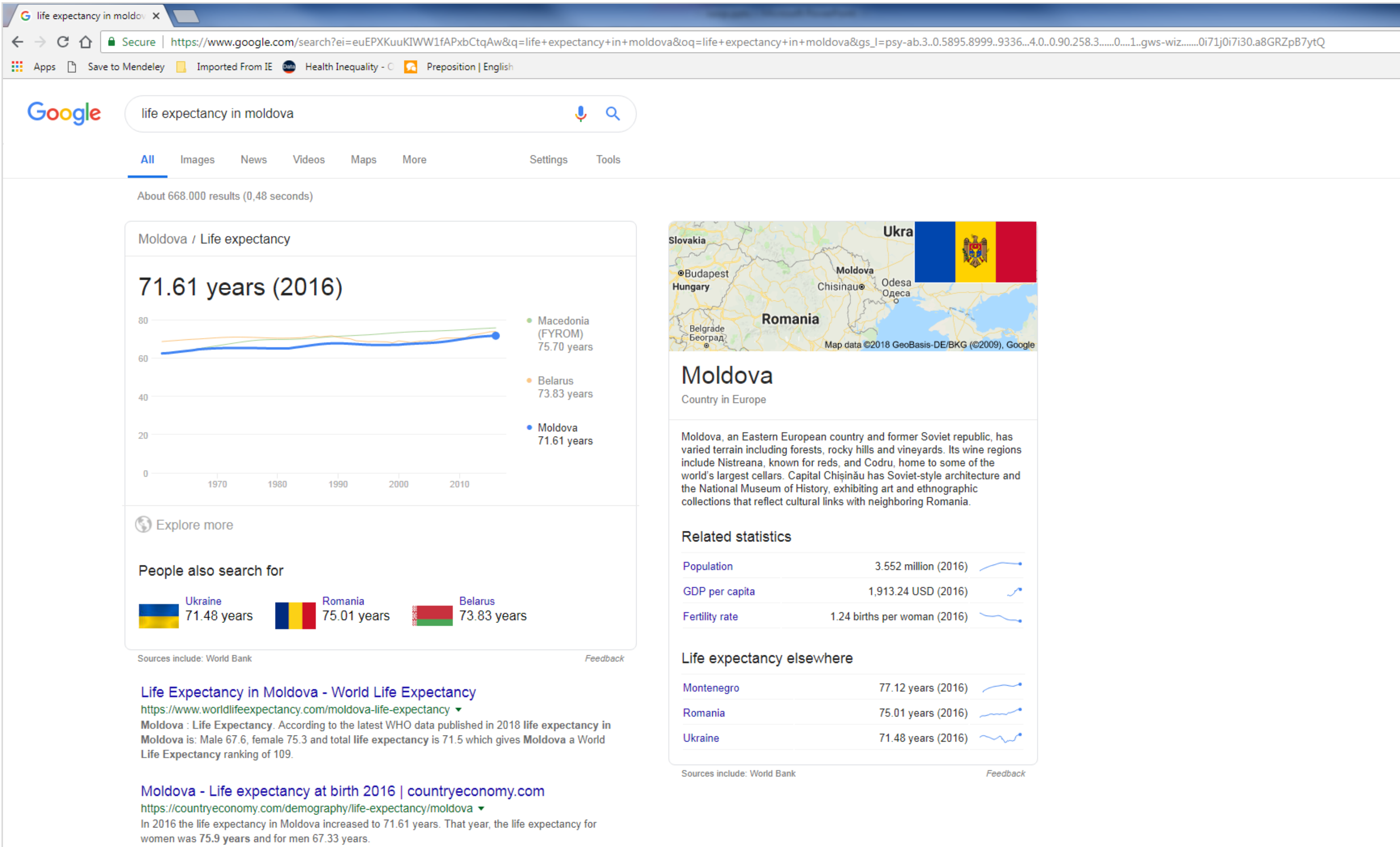
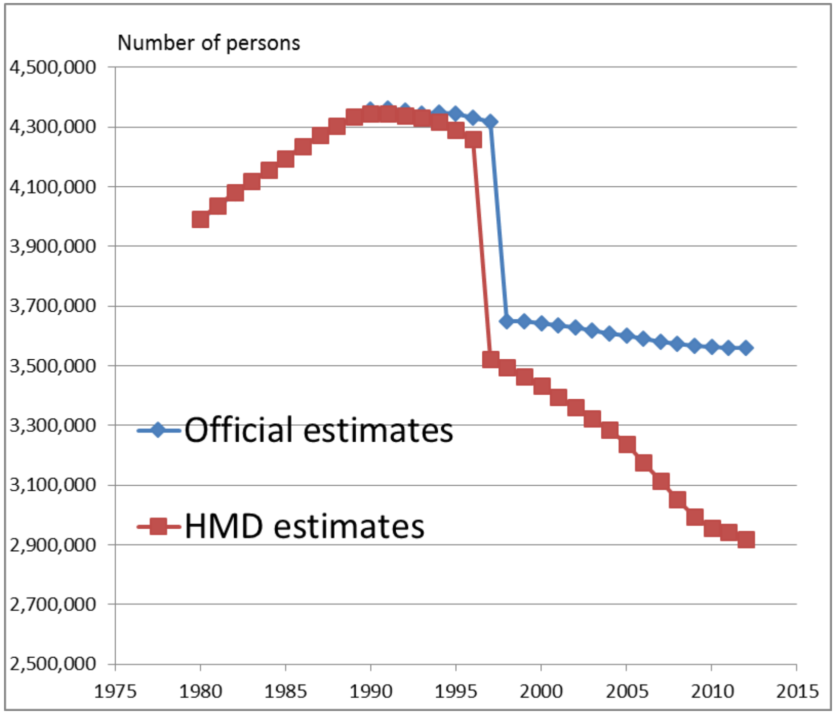
An example: life expectancy in Moldova

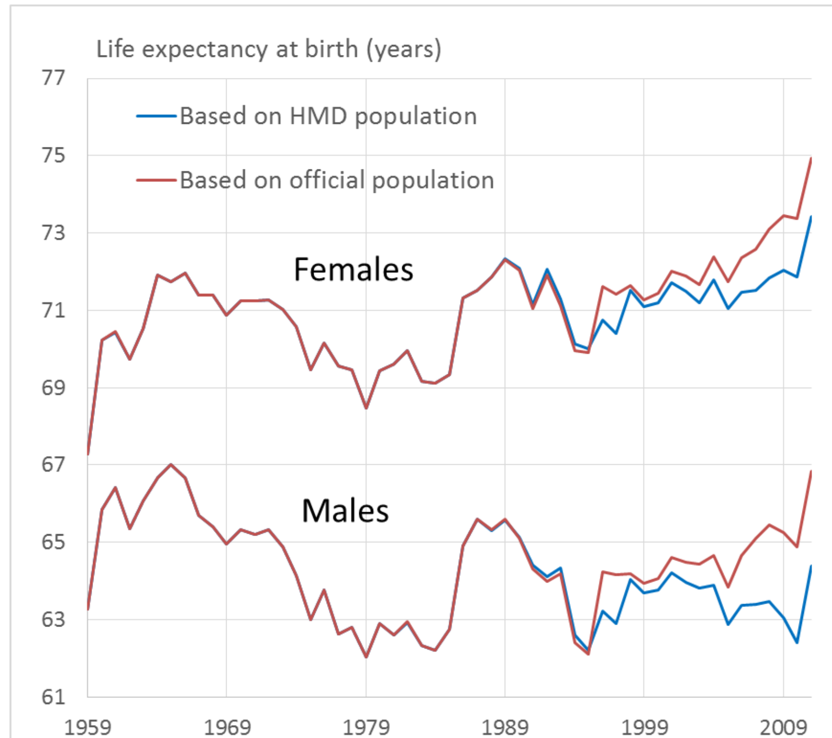


Numerator-denominator bias: an example of Moldova



* Since 1998 official population counts do not include Transnistria region

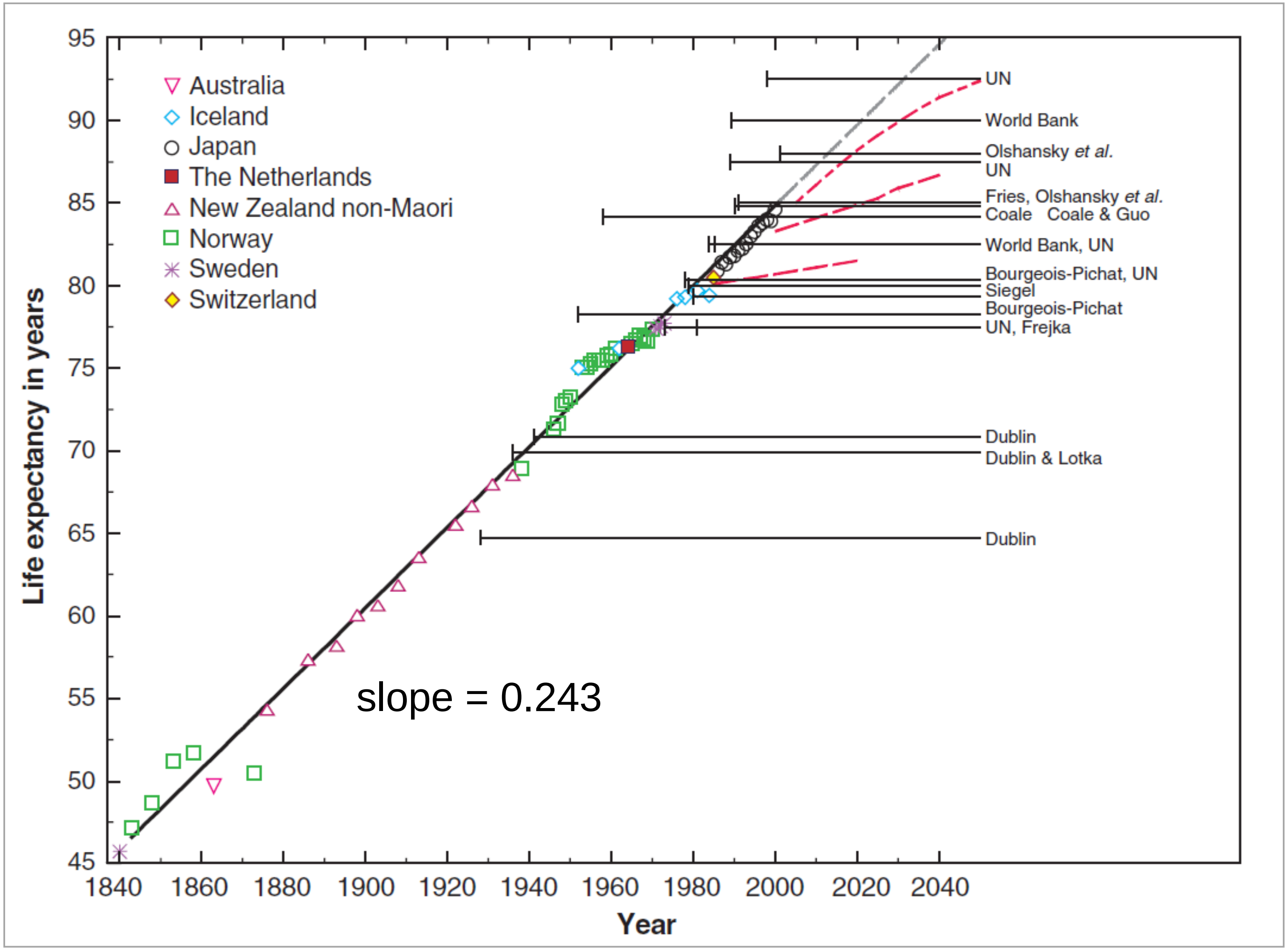
The problem: systematic bias (deaths and births refer to the *de facto* population, (.e. occurred within the country, while population estimates also include long-term emigrants - Moldavian citizens living abroad) leads to an under-estimation of mortality and fertility



The solution: population estimates were corrected using data on border crossing and additional data collected at the census 2004

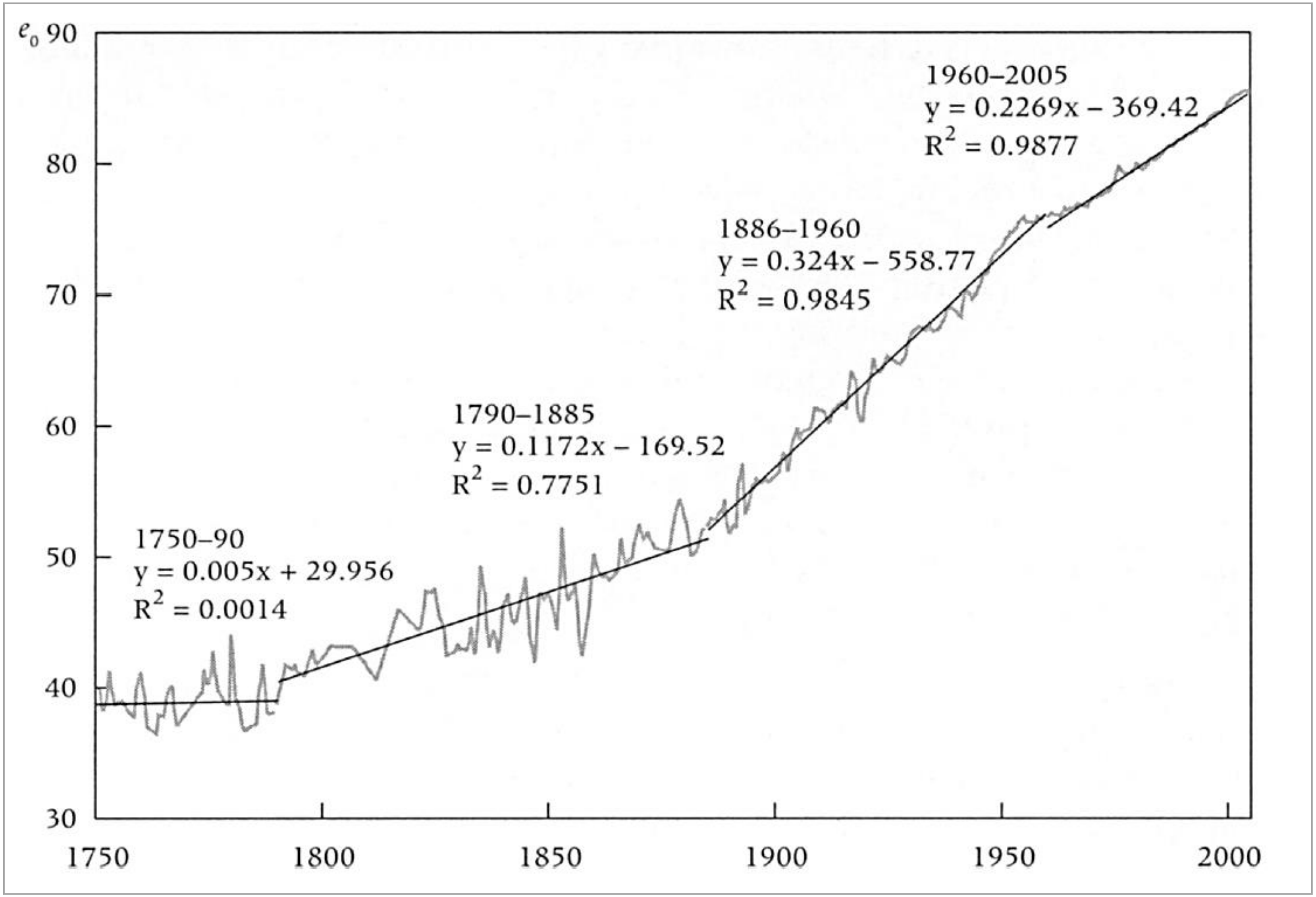
Source: Penina, Jdanov, Grigoriev (2015)

Steep increase in best-practice (period) life expectancy at birth



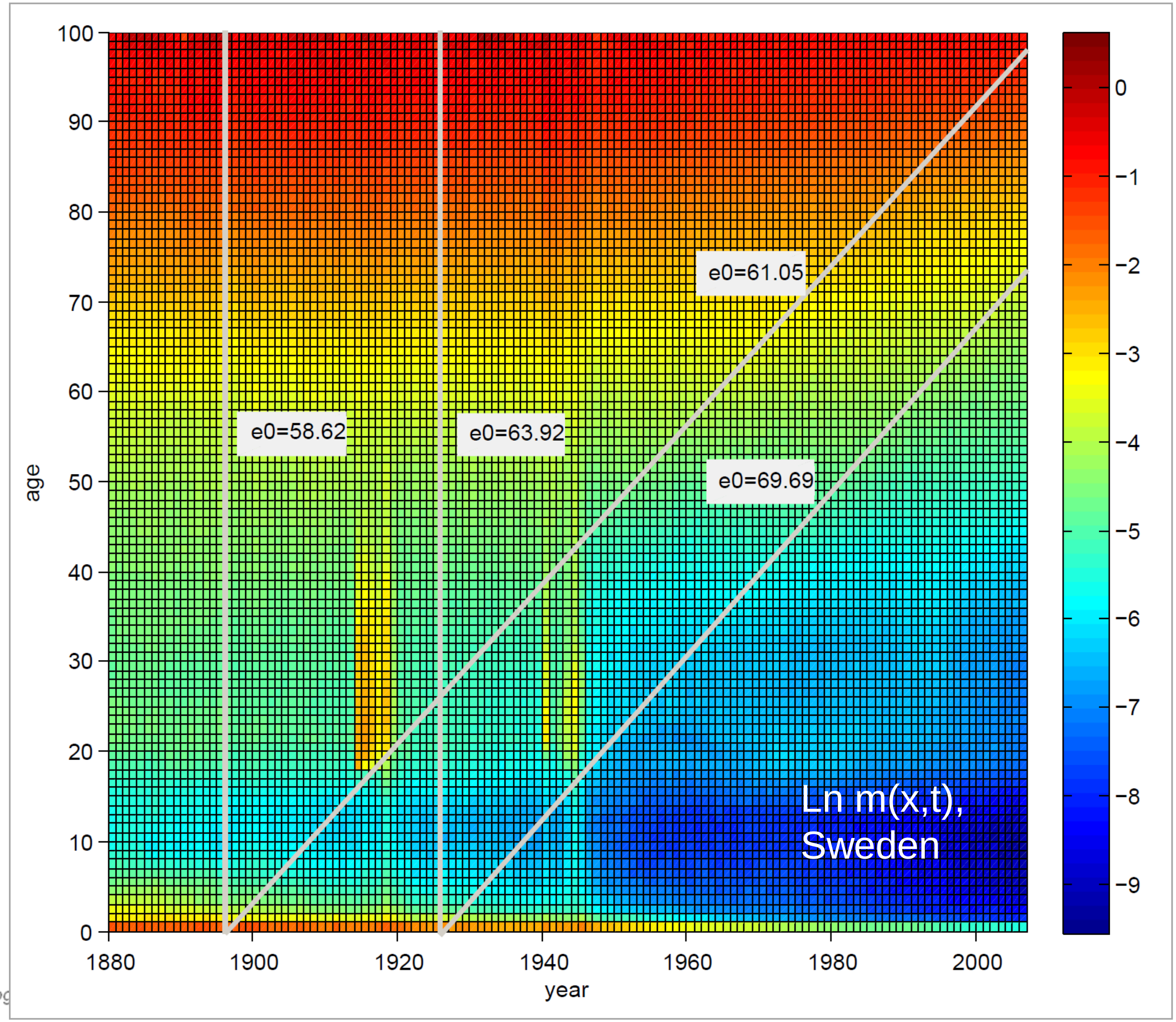
Источник: Oeppen, Vaupel, 2002; WHO, 2011

Steep increase in best-practice (period) life expectancy at birth - update

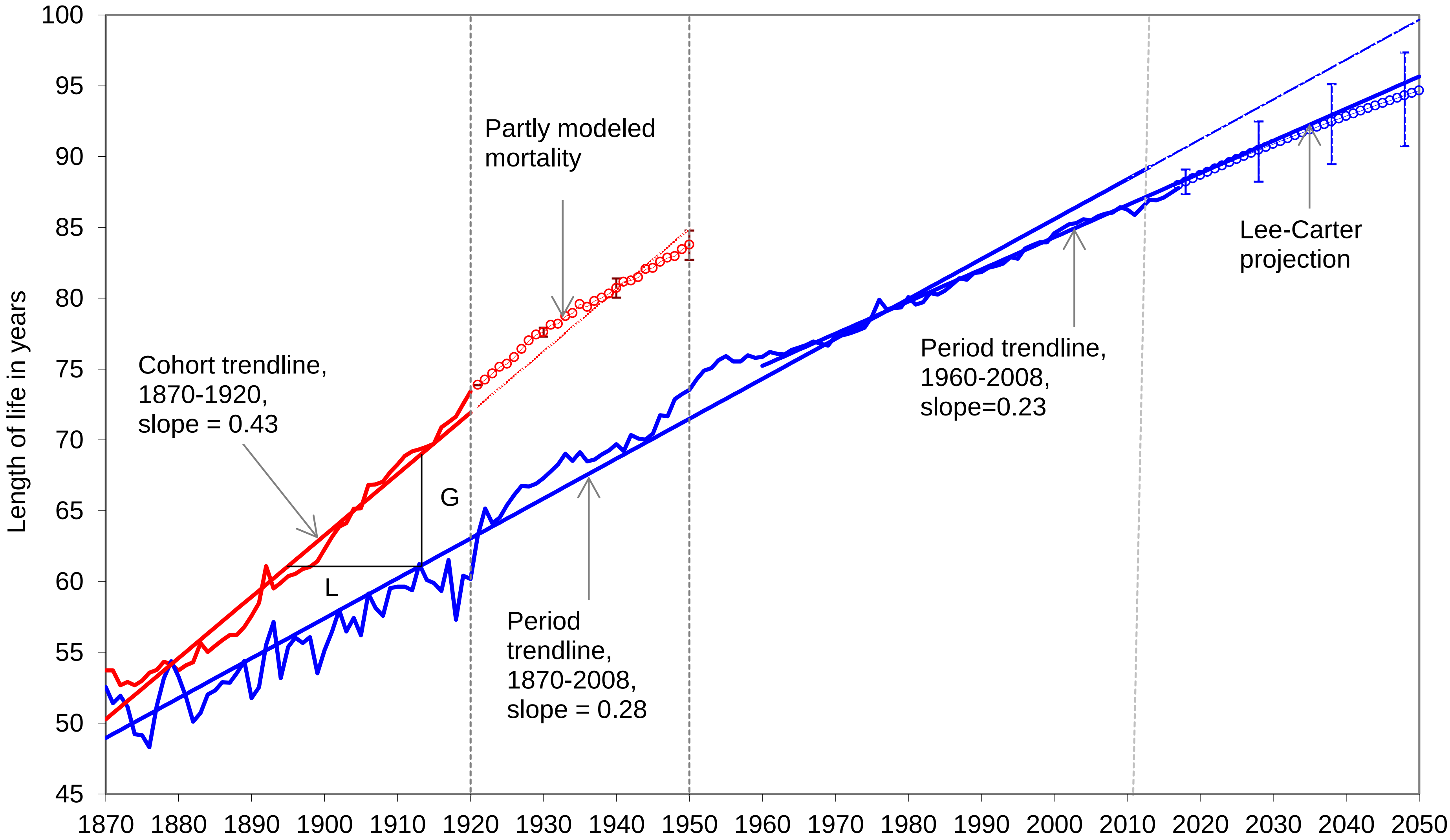


Источник: Vallin, Mesle (2009)

Cohort vs. Period



Steep increase in best-practice cohort life expectancy at birth

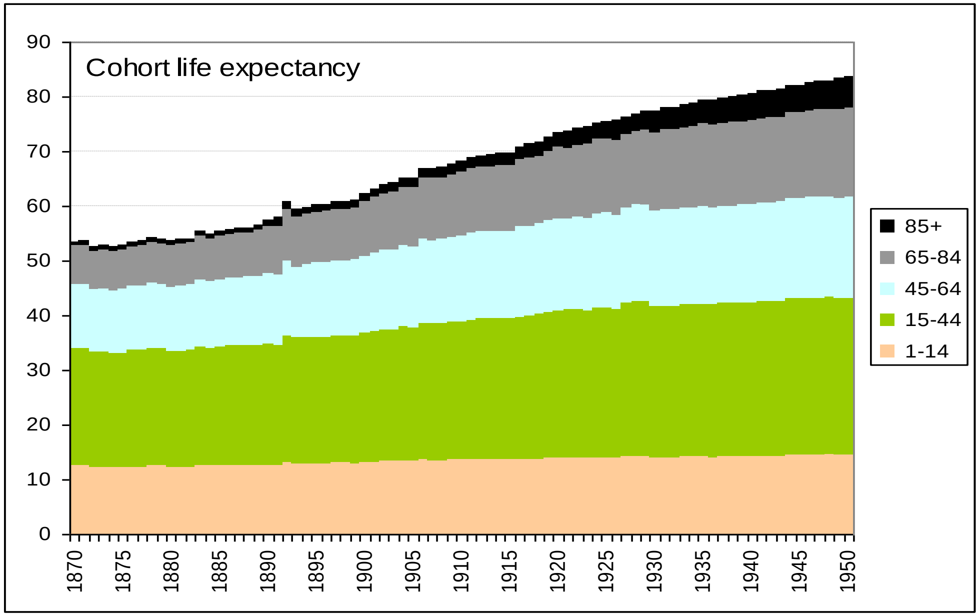


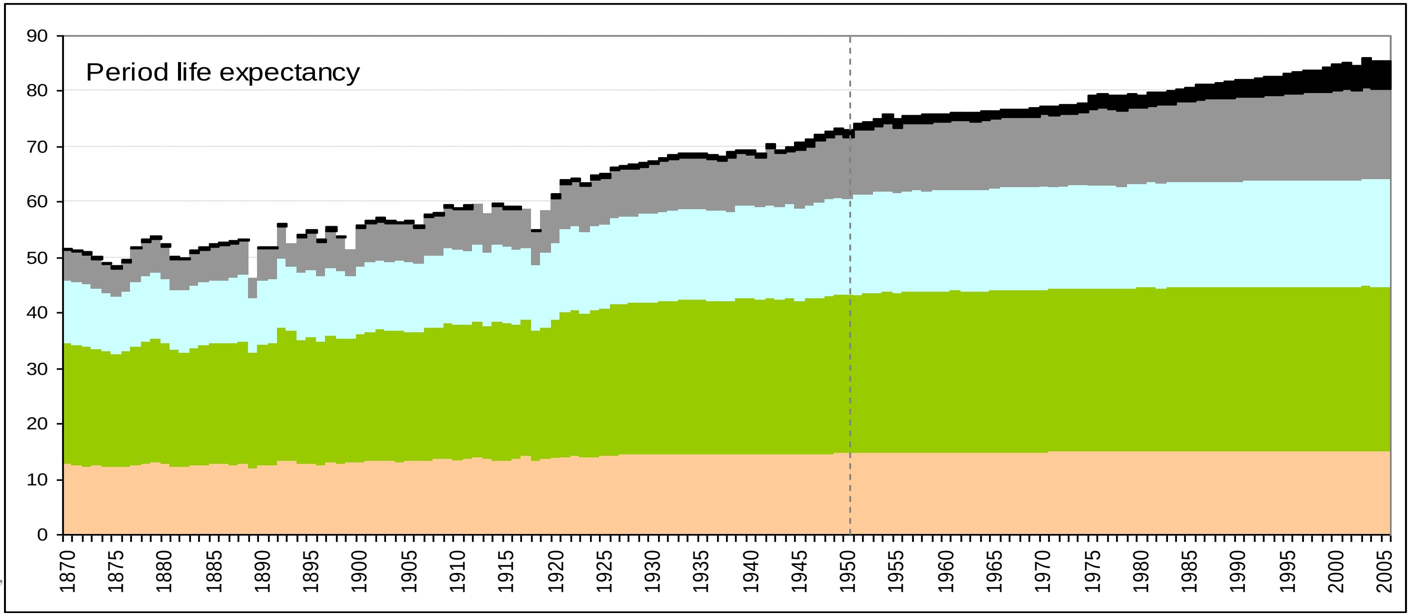
Countries with record LE

Country	Years of birth	Total years on top
Norway	1870-1887, 1889,1890, 1894-1904, 1906-1920, 1924-1925	58
Switzerland	1888, 1905, 1923	3
Iceland	1891-1893	3
Australia	1921-1922	2

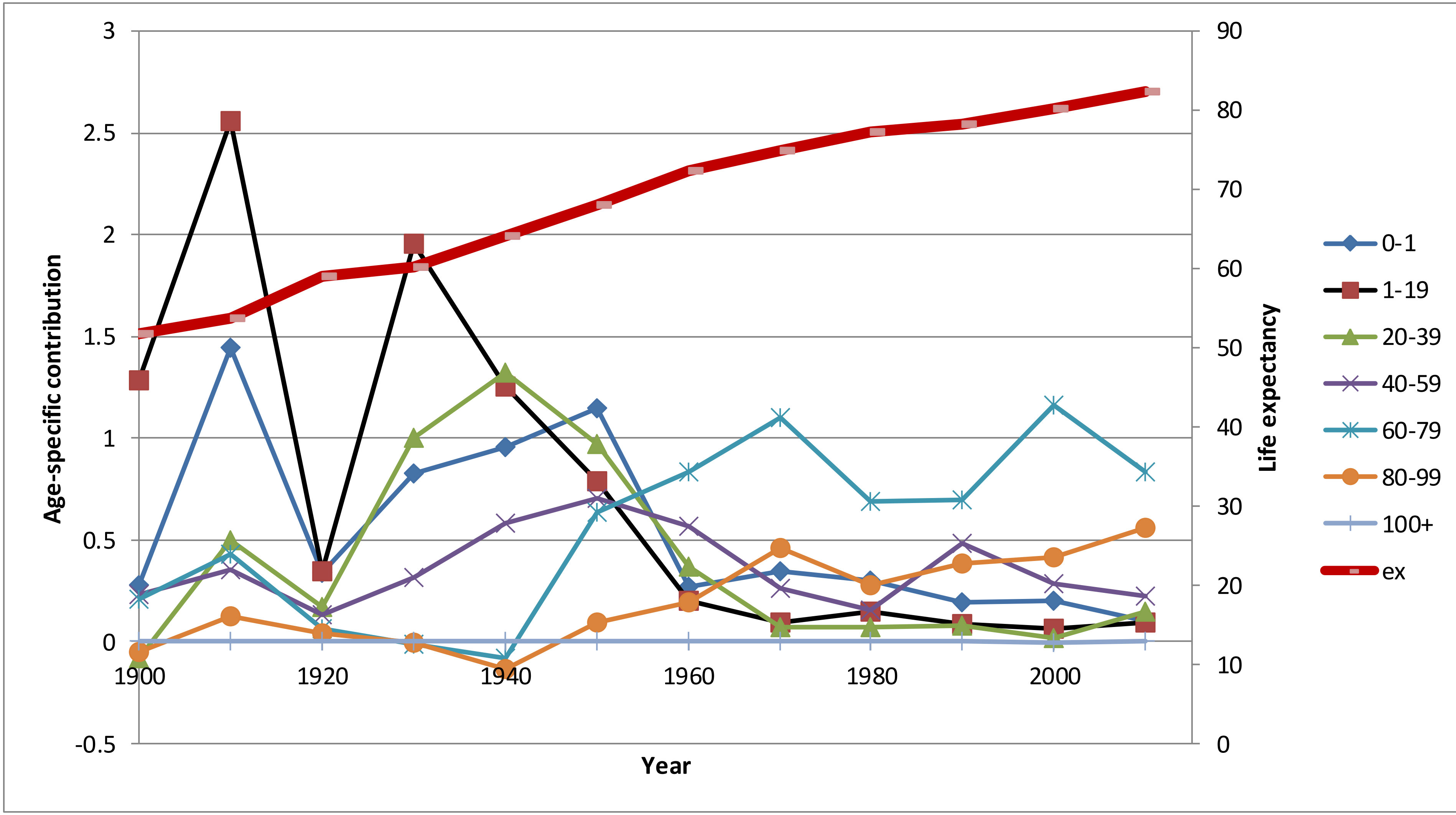
Country	Year	Total on top
Norway	1870-1871, 1873-1881, 1883-1885, 1886,1897, 1900-1903,1905,1908, 1911, 1920,1938,1945, 1947-1948, 1951,1953, 1956,1957,1959,1960, 1965-1970	39
Switzerland	1872,1887,1888,1890,18911894,1895,1898, 1907, 1909,1916,1923, 1942, 1943,1971,1973	16
Iceland	1889,1892,1893,1896,18991906,1912,1913,1917,19191946,1949,1950,1952,19541955,1958,1961-1964, 1975-1981,1983	32
Denmark	1904,1910,1914,1915,1918	5
Australia	1921,1922,1924,1925	4
New Zealand	1926-1937,1939-1941,1944	16
Japan	1982,1984-2015	27
Hong Kong	2016, 2017	2

Period and cohort life time by age group

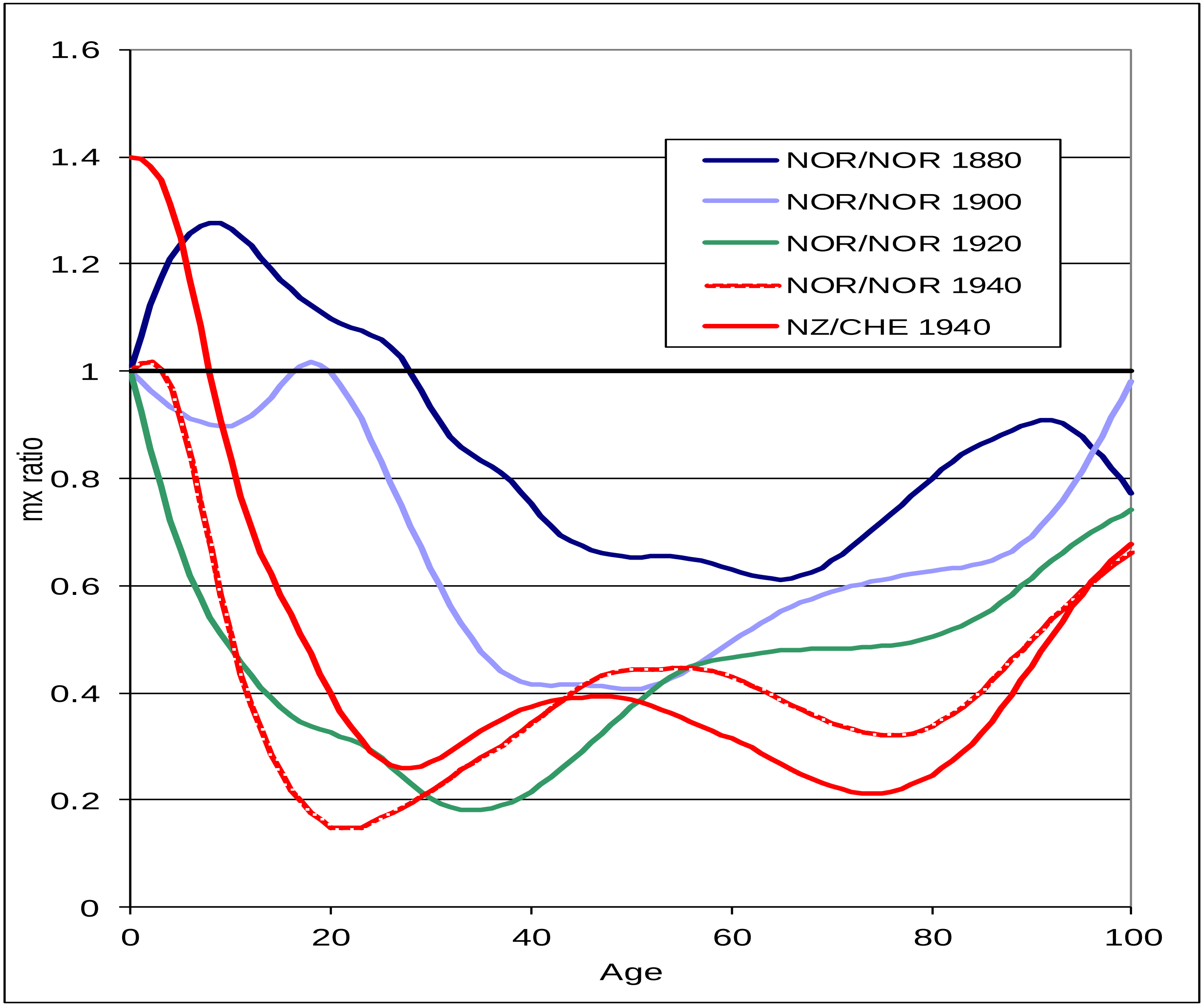




Decomposition of life expectancy increase by age group



Death rate ratio cohort/period



Debates

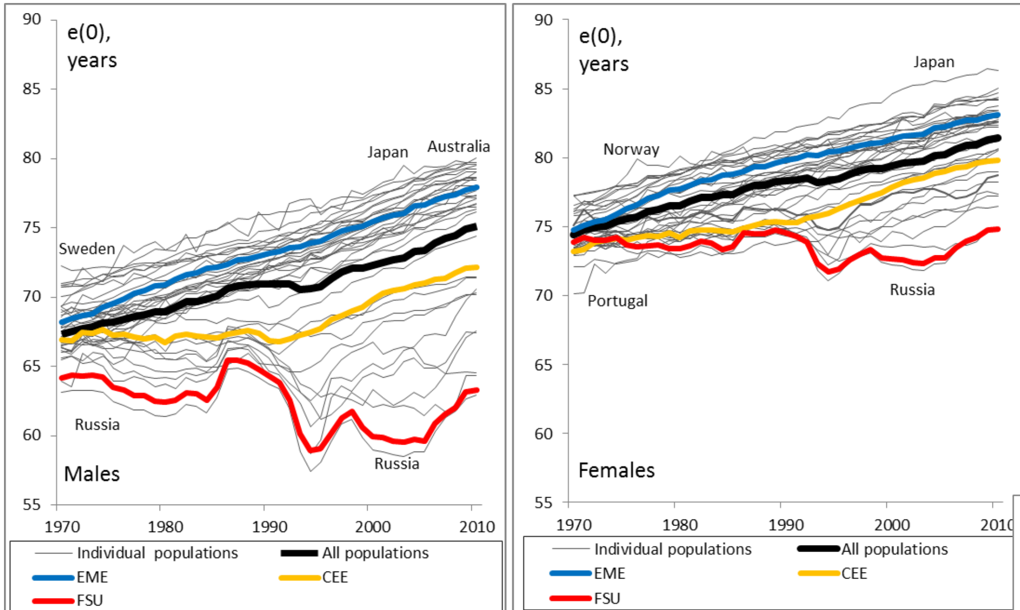
Zeno's New Paradox: The Immortality (**Jay Olshansky**, 2012):
'If survival to age X is possible, and there are no biological or other reasons why survival to age X plus 1 day is not possible, then all we must do is reduce the risk of death to rates that match or exceed the passage of clock time, and we will become immortal.'
The essential error in the Paradox of Immortality is the belief that because there are no genetic programs for aging and death, that evolution does not measure time and therefore, we can forever add one more day of life… Evolution does in fact measure time; it measures 'essential lifespan', the longevity window of survival time needed to achieve Darwinian fitness.

Jim Vaupel (2012)
We do not assume that the future will repeat the past: we recognize that the ways death rates will be reduced in the future will be different from the past…

Olshansky's and Carnes' essay is not only factually inaccurate, it is deliberately misleading. We are astonished it passed scientific and editorial review.

Mortality divergence and steep progress at old ages

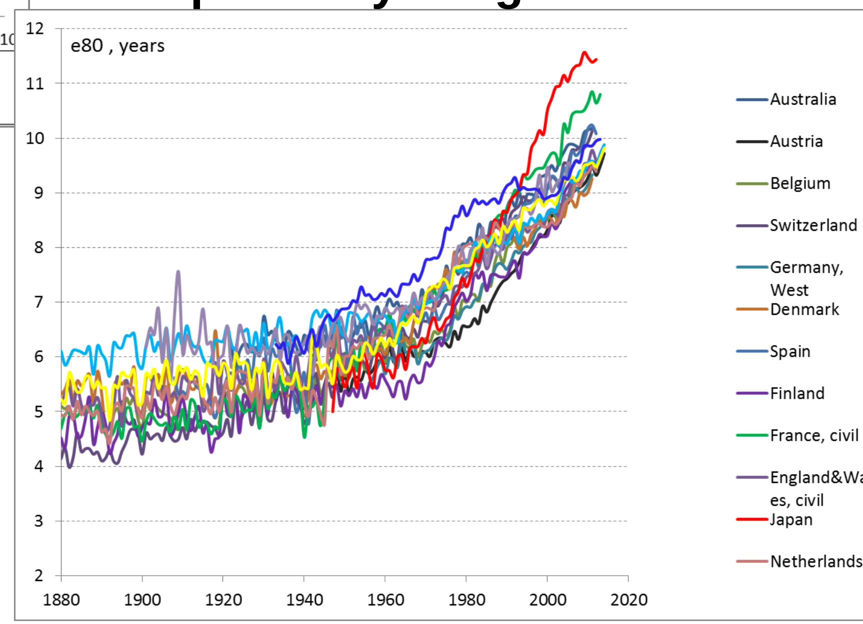
Life expectancy divergence after 1970



Source: Timonin et al, 2015; Barbieri et al. 2015

Life expectancy divergence:
- unexpected health crisis in communist and post-communist countries of the former USSR and CEE;
- unexpected further progress in the established market economies (EME)

Life expectancy at age 80 since 1880

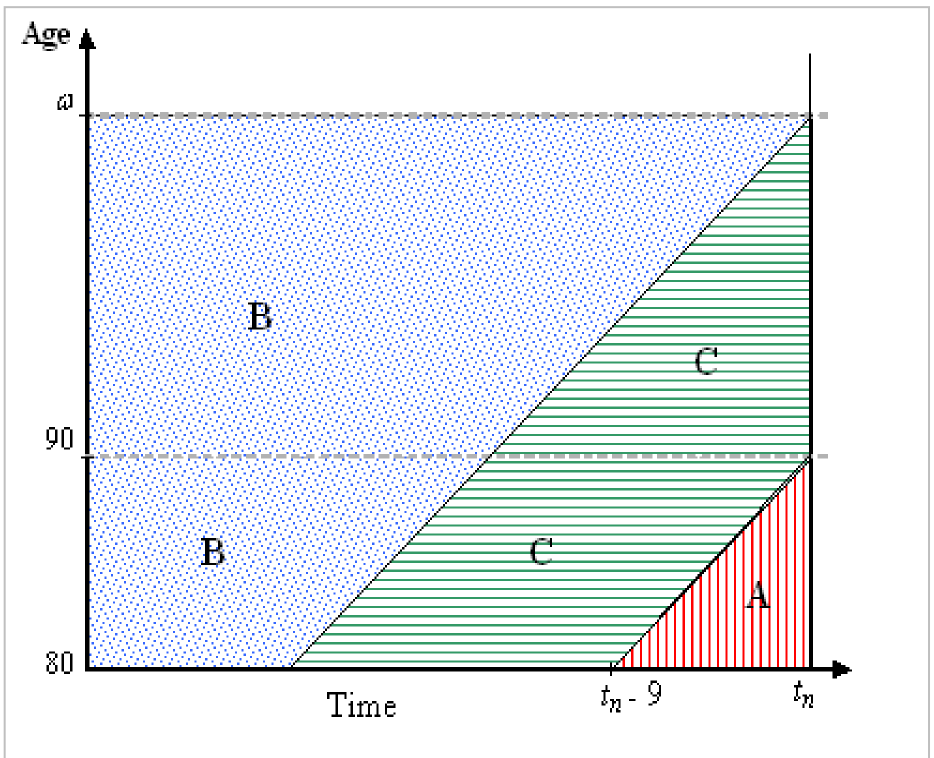


Source: Built on HMD data

Success in fight with CVD and other “degenerative” diseases led to spread of mortality reduction toward very old ages.

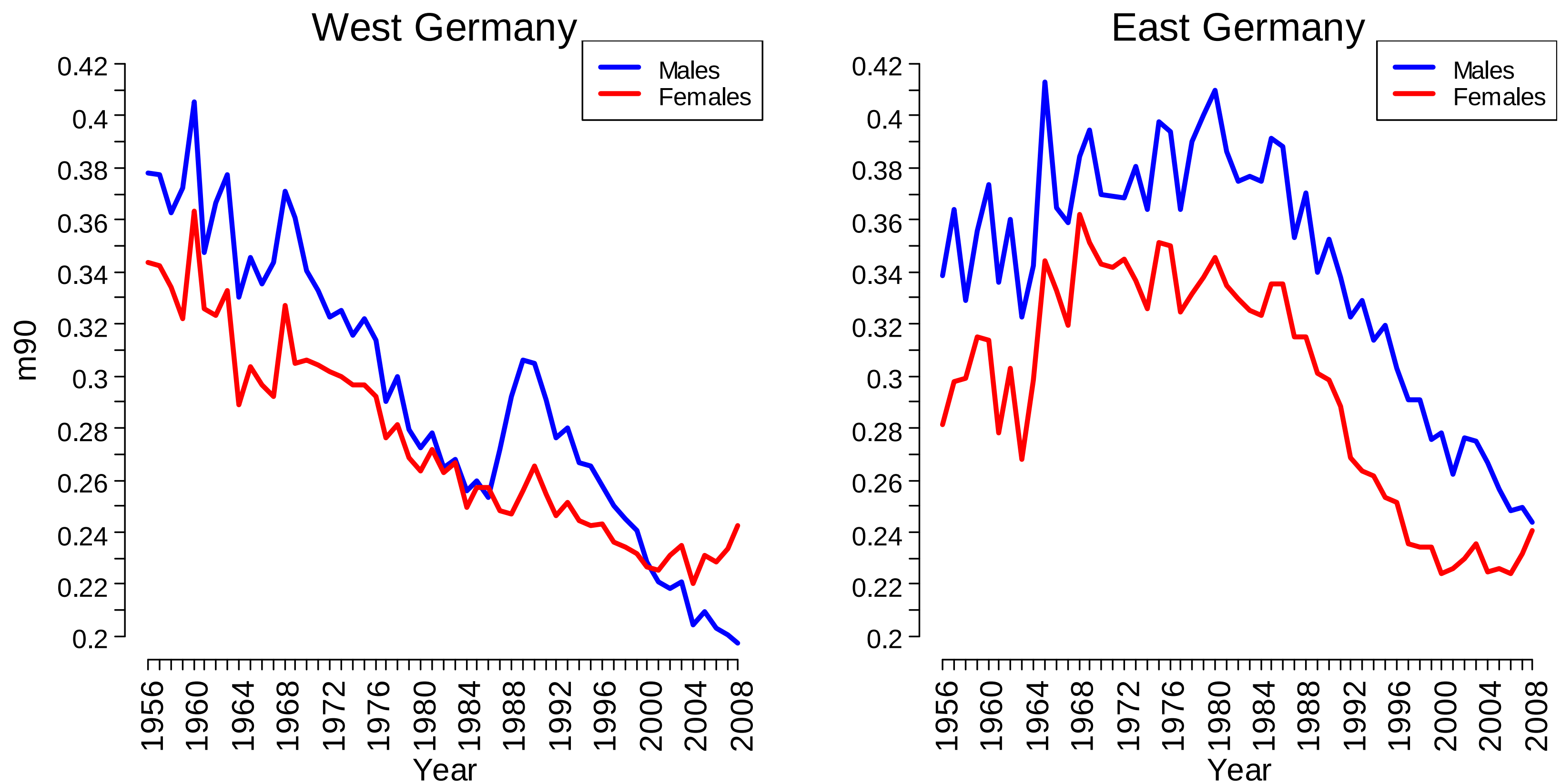
Mortality estimates at old ages

- Internationally comparable high quality demographic data on old-age populations remain insufficient.
- The HMD is the only major demographic database which provides such data. Population estimates for ages 80+ in the HMD are recalculated using extinct/almost extinct cohort and survival ratio methods.



A-official population estimates;
ω -age of extinction (about 103-105)
B-extinct cohort method;
t_n-beginning of the last available year
C-survival ratio+extinct cohort methods

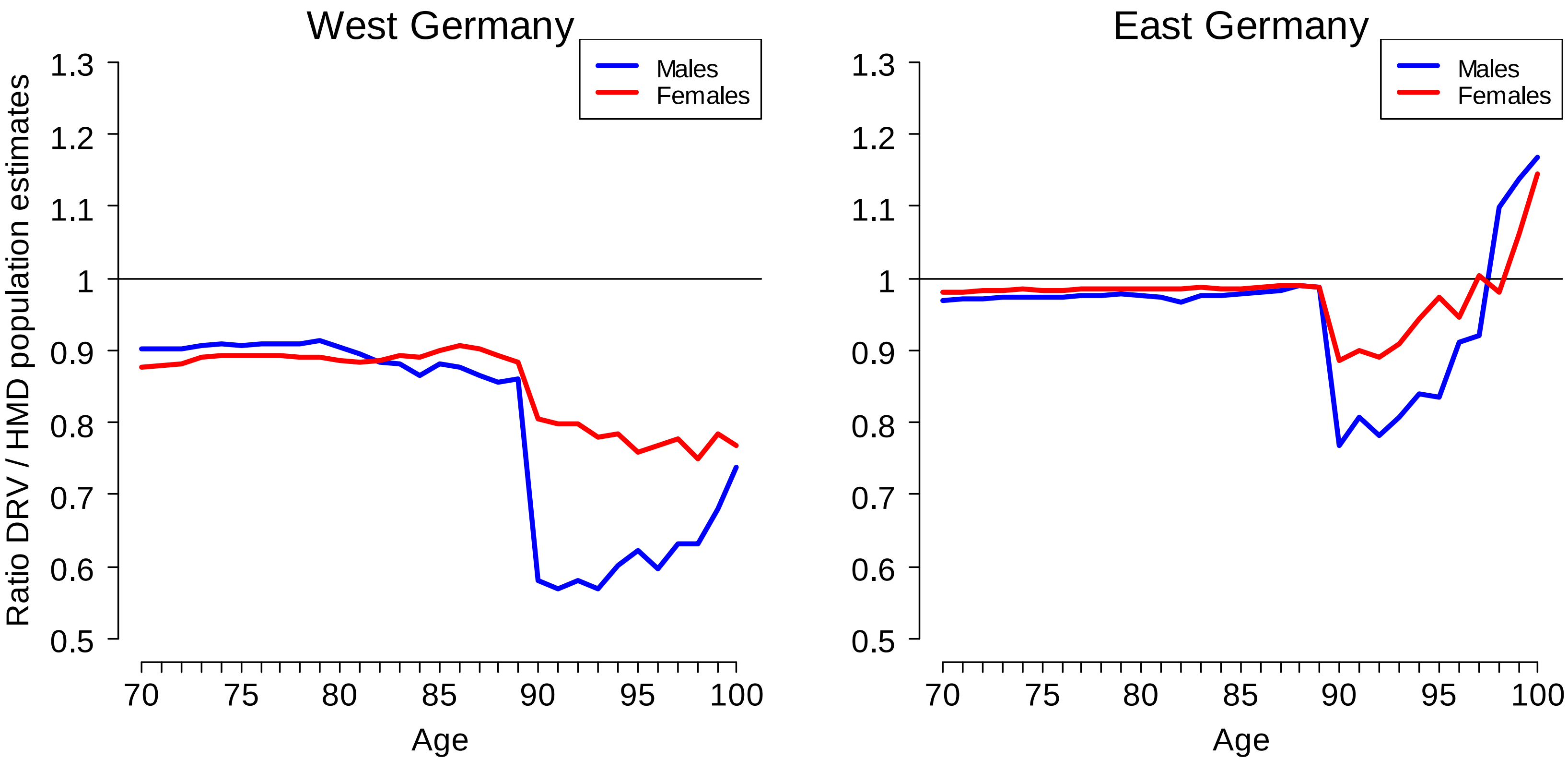
Germany: old ages



Trends in death rates at age 90+, calculated from the official population estimates, for the West and East Germany, males and females, 1956-2008.

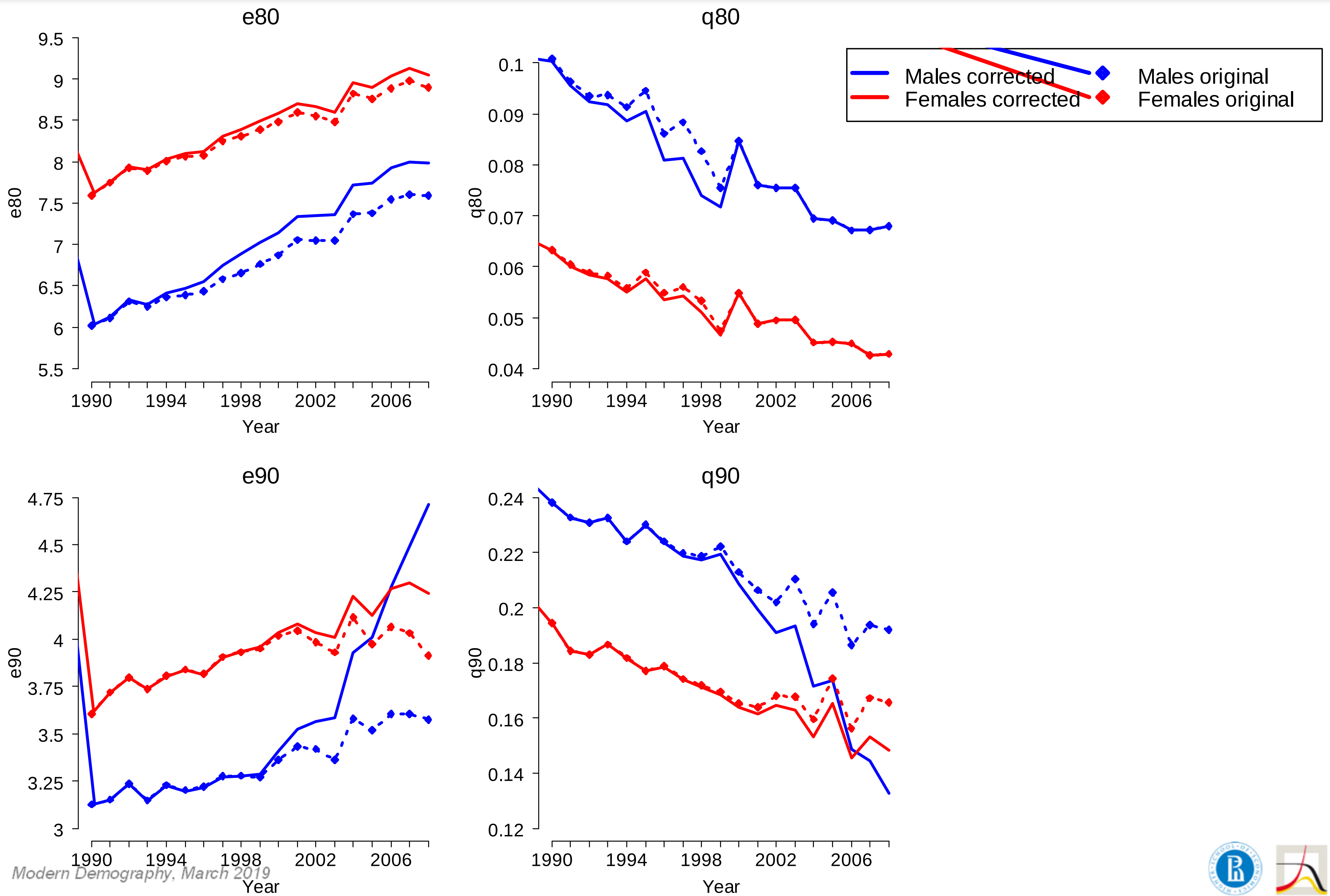
Germany: old ages (cont.)

To correct population estimates for West Germans at older ages in 2010, the HMD team used data by the *Deutscher Rentenversicherung Bund* (DRV), the German Pension Scheme.

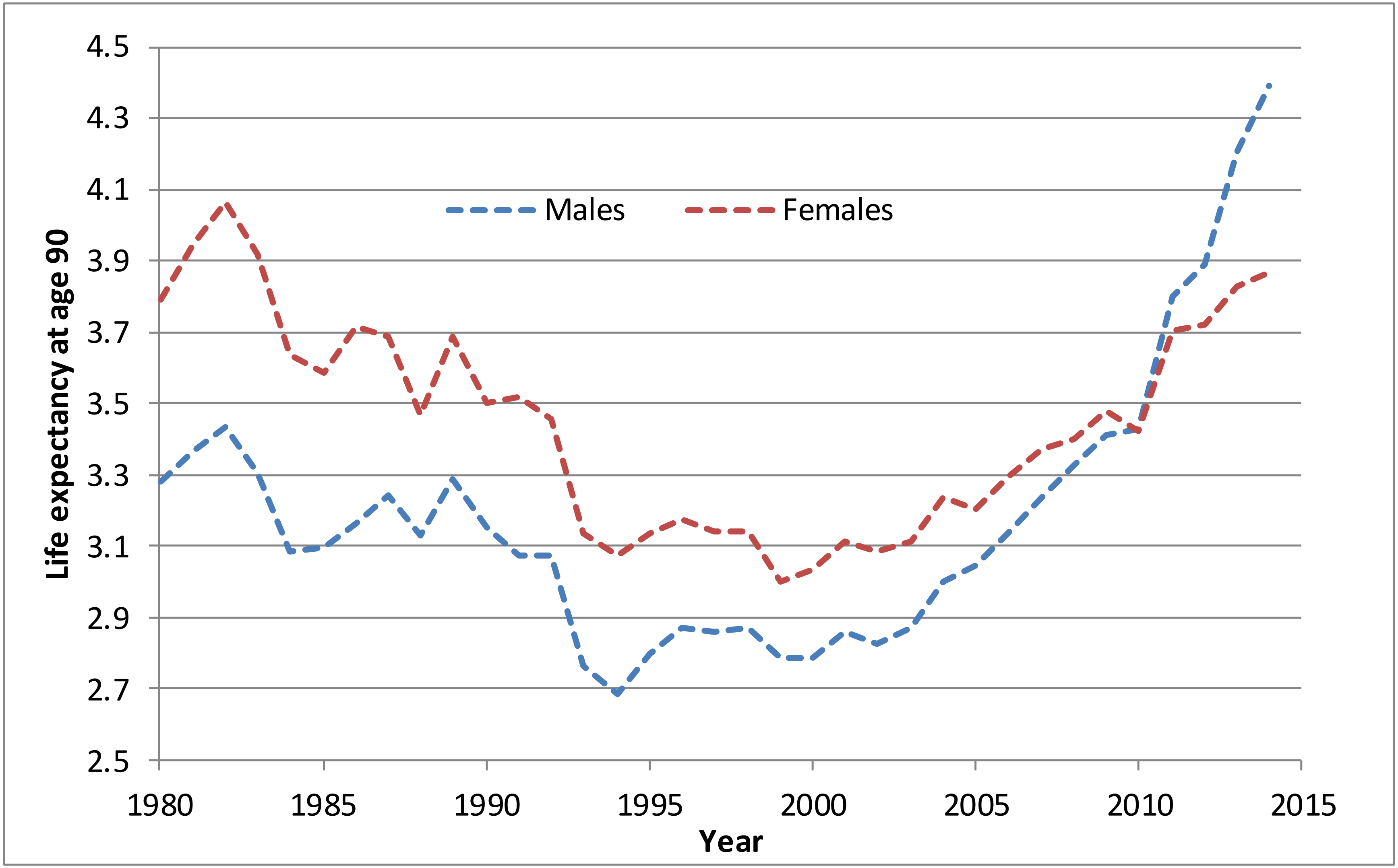


Ratio of DRV records by age based on own pensions to estimates based on official data, West and East Germany, 2009.

Life expectancy and probability of death for the corrected and the original data, West Germany, 1990-2008



Human Mortality Database, Russia: update 2015



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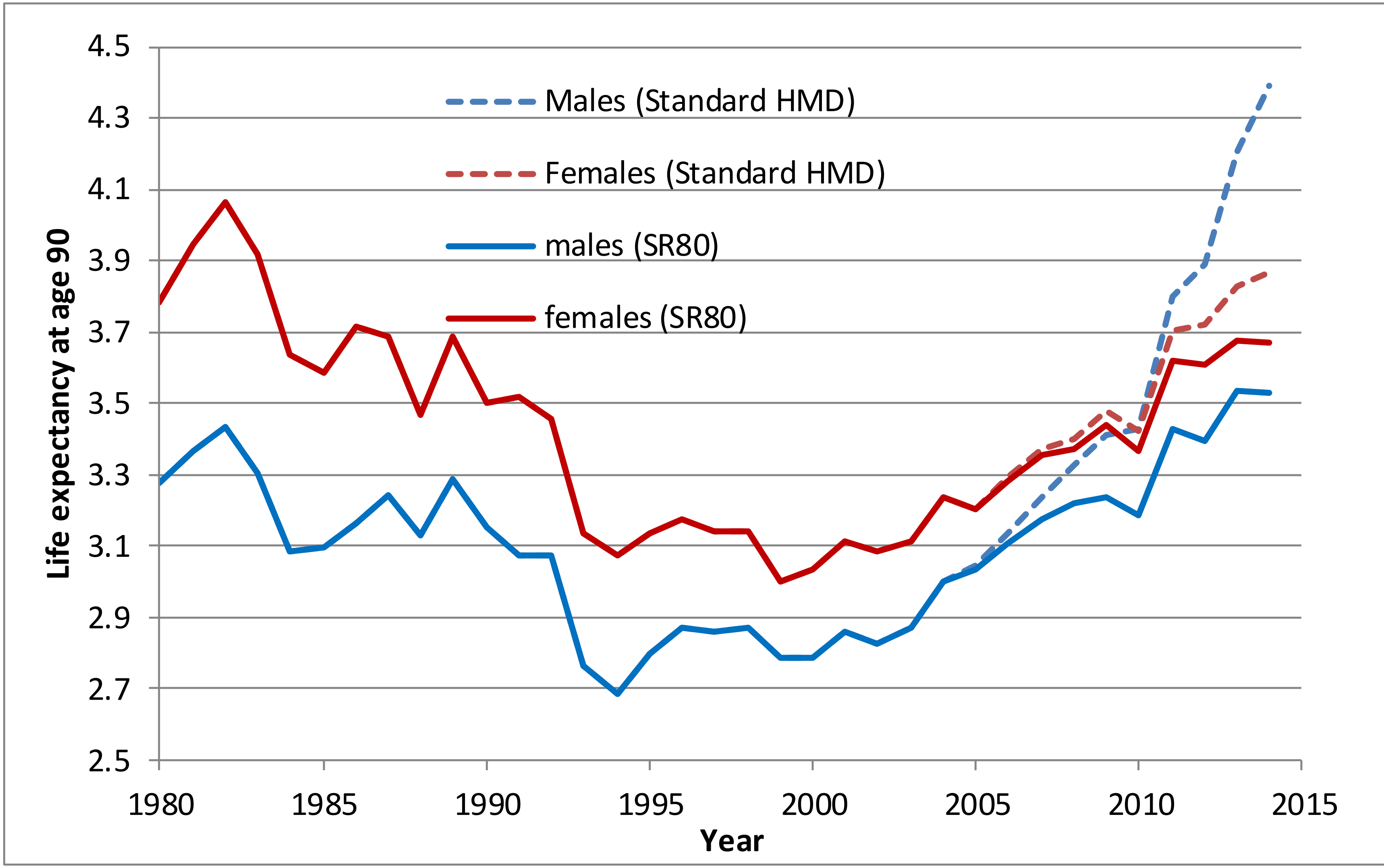
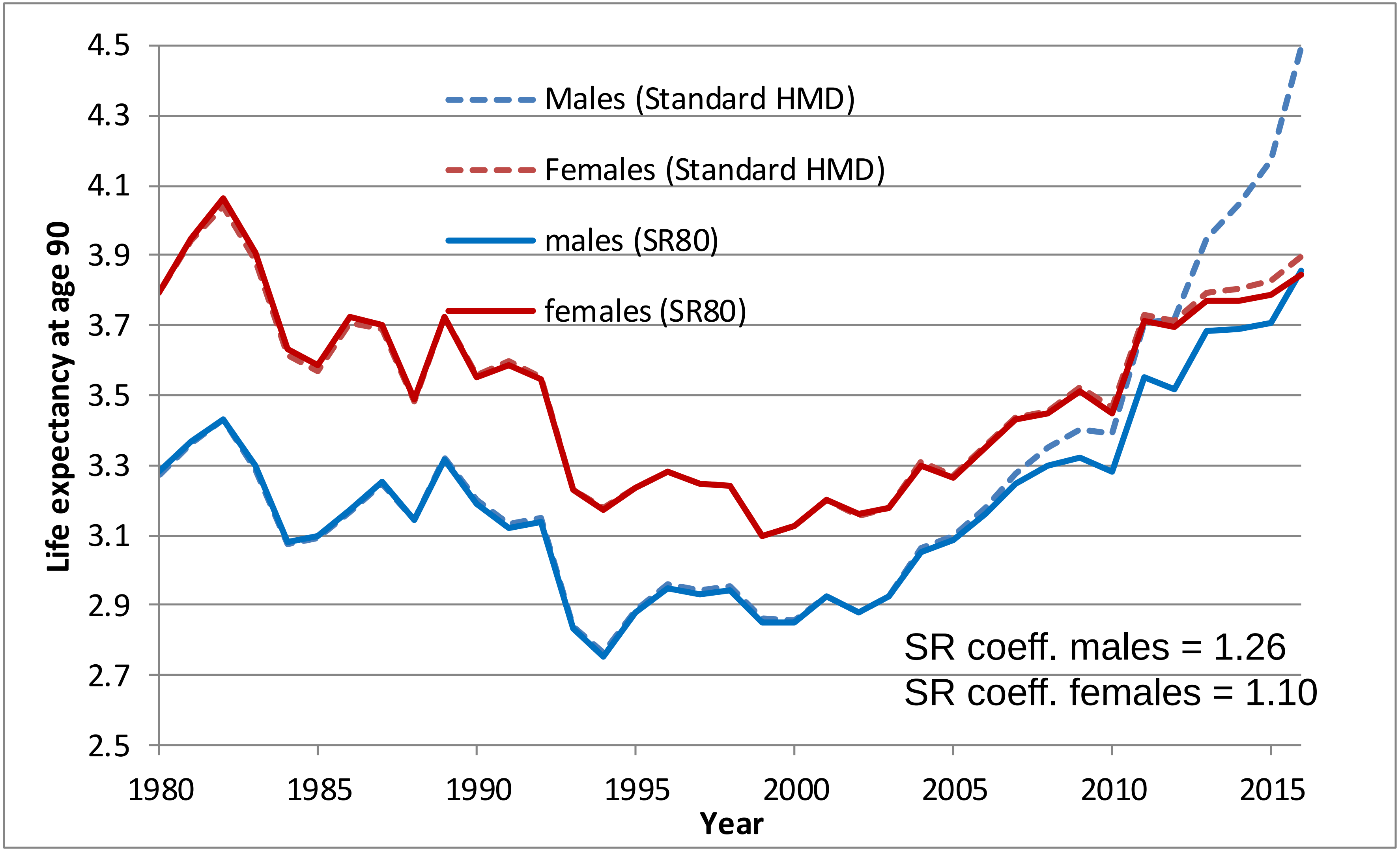
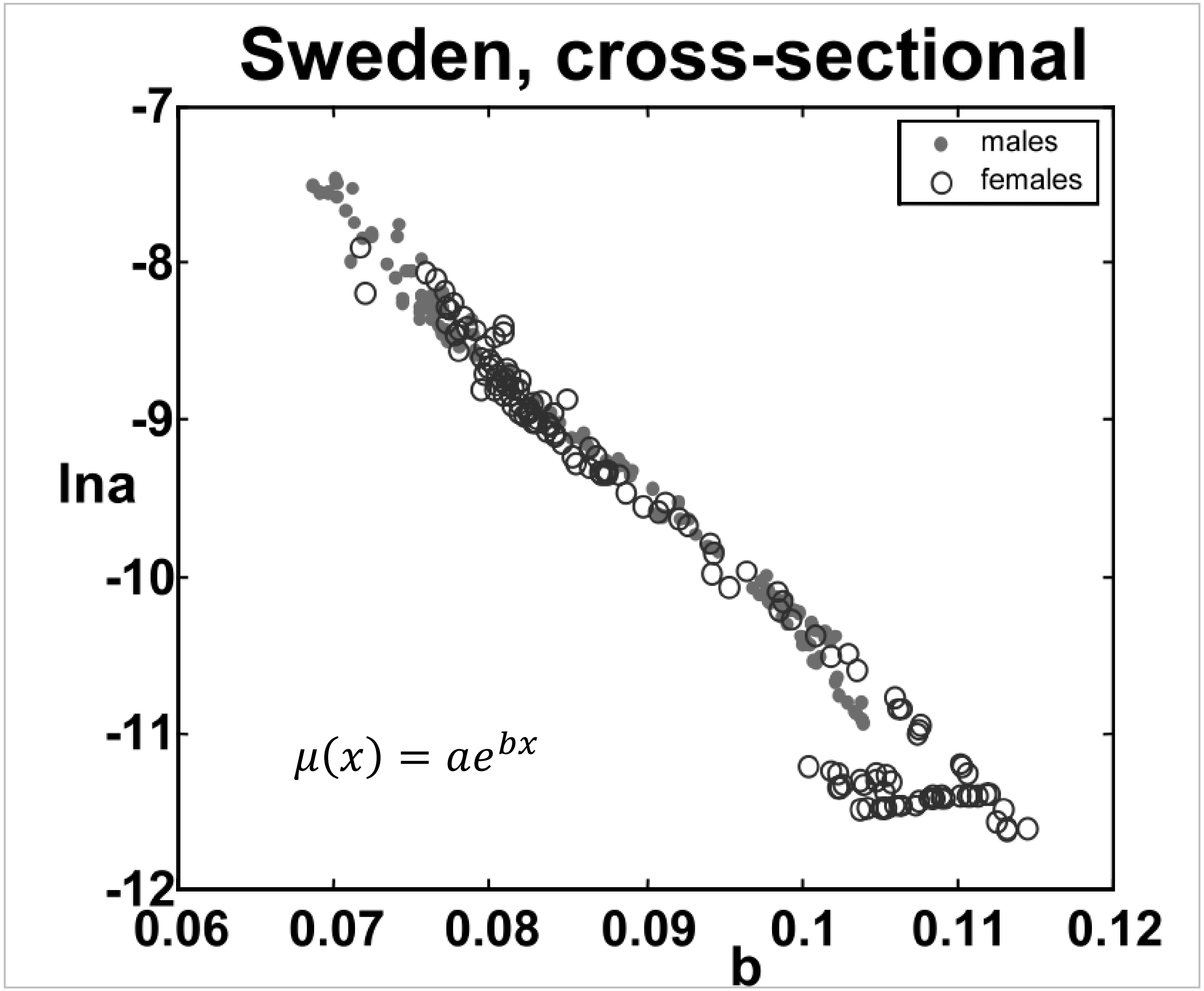


Human Mortality Database, Russia: update 2017



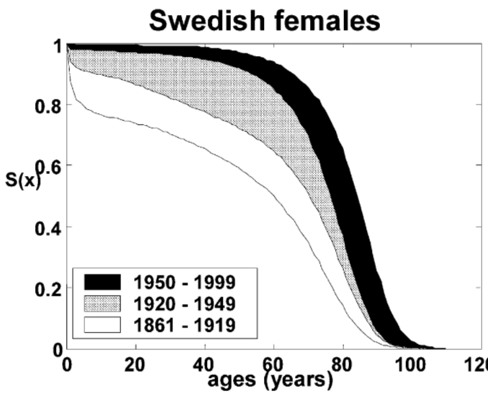
Old-age mortality

The S-M correlation

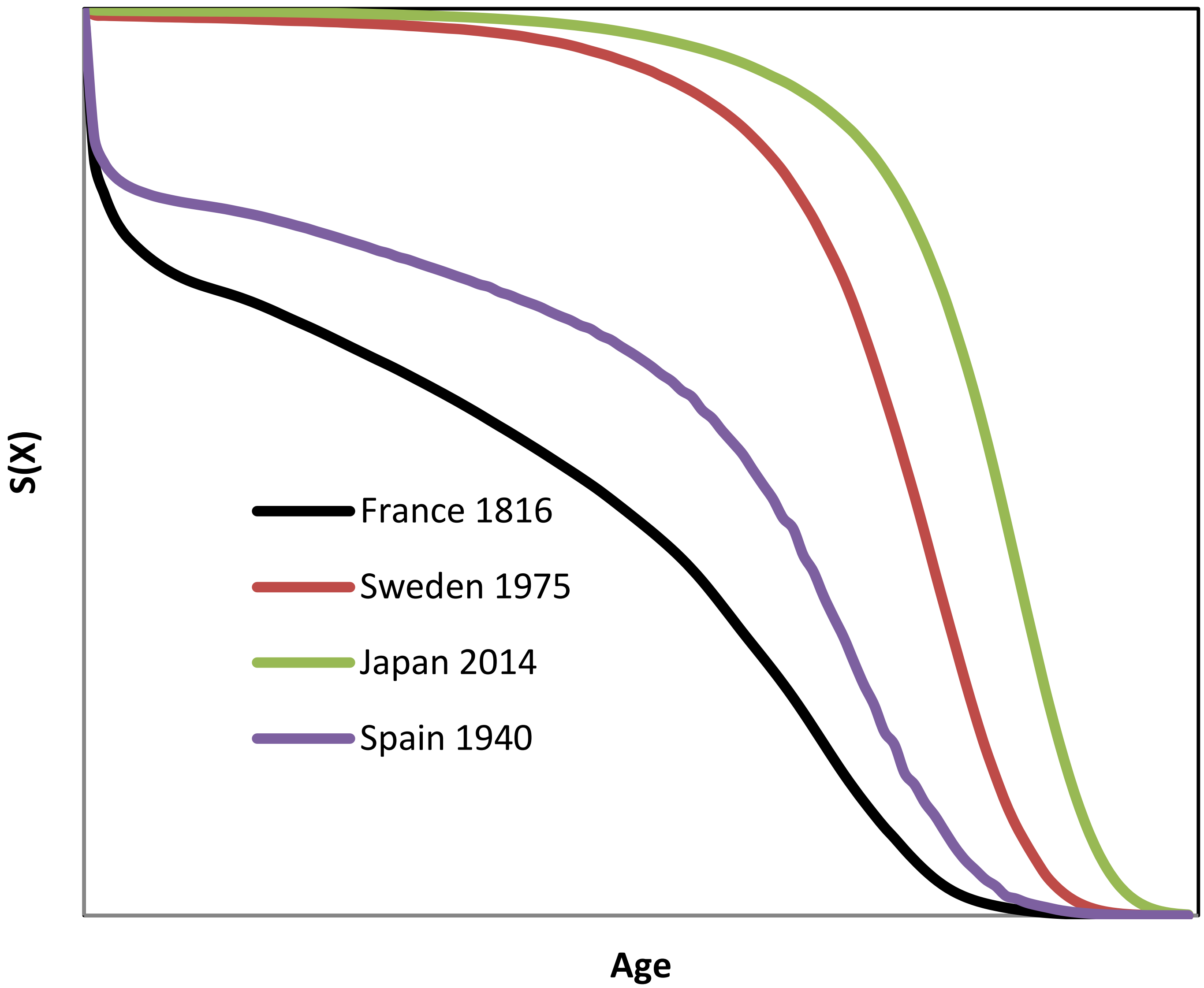


The patterns of SM correlation obtained for period mortality data for Swedish males (filled circles) and females (empty circles) from 1861 to 1999.

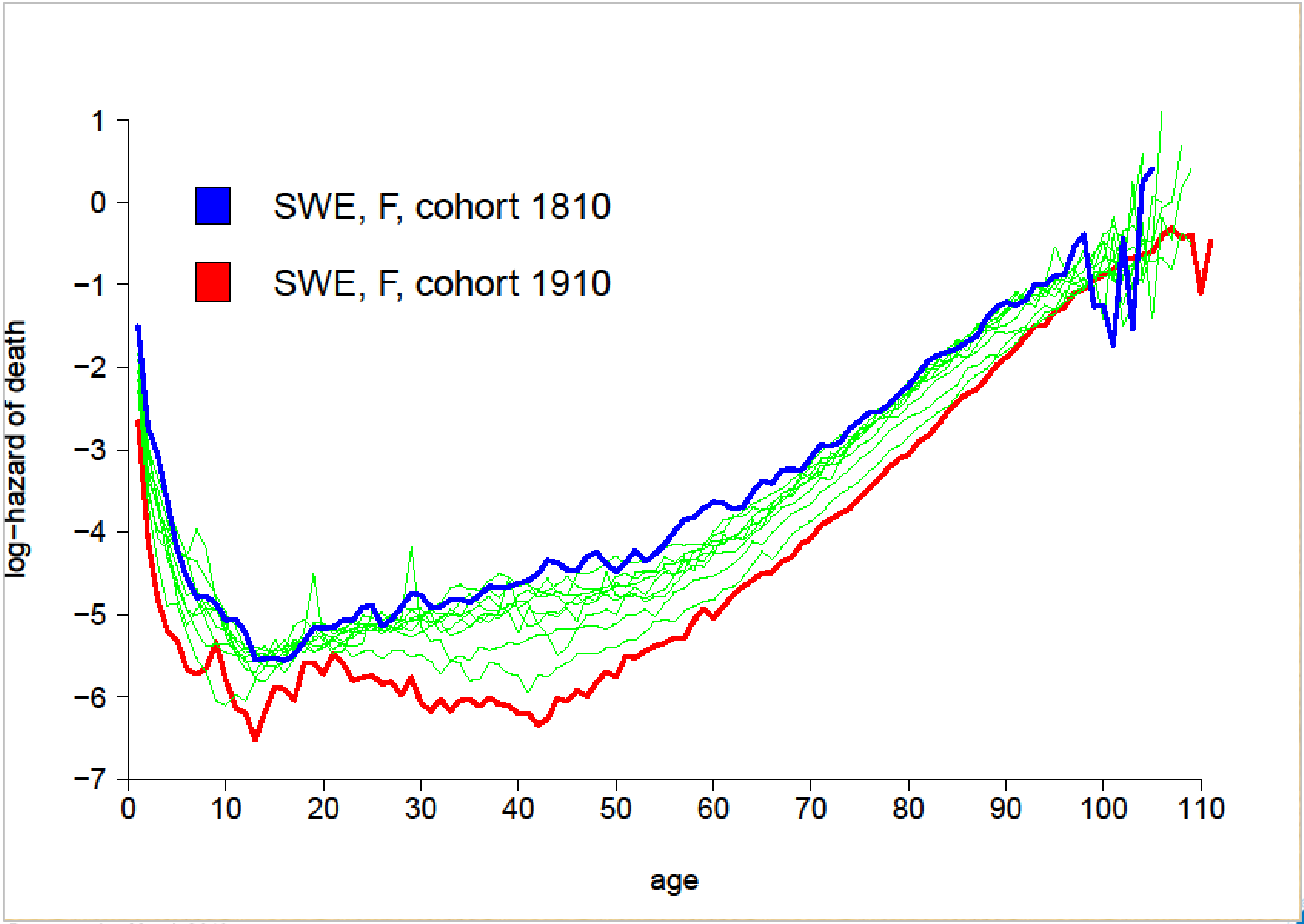
Source: Yashin et al. 2002



Evolution of mortality



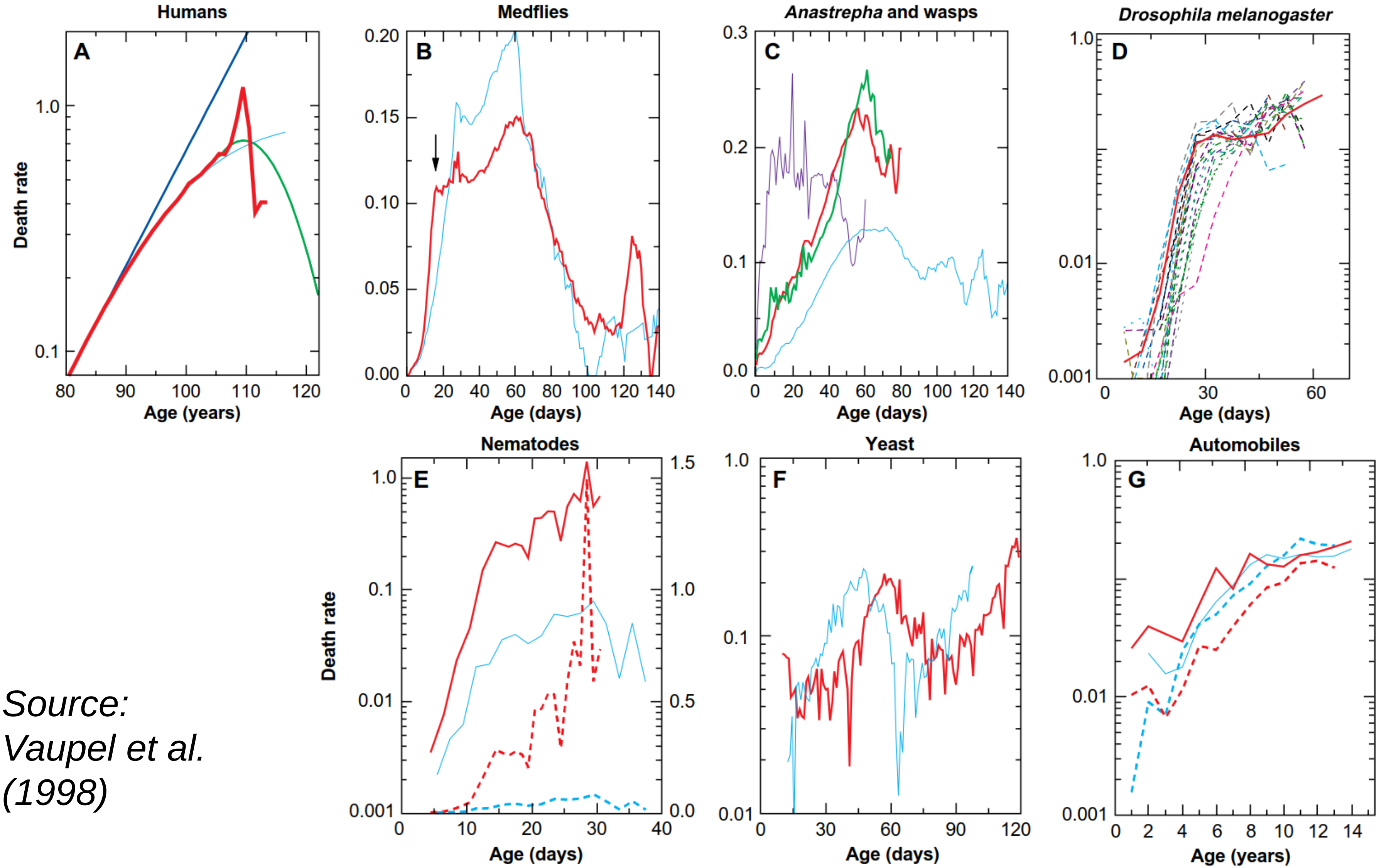
Human mortality plateau: individual cohorts



Mortality plateau origins

- Evolutionary theories: reflect optimal life-course strategy of certain organisms (Wachter 1997)
- Unobserved heterogeneity/selection: individuals exposed to increasing risks of dying, but as weaker die out over time, overall mortality is pushed down to level off at the oldest ages (Vaupel and Yashin 1985, Vaupel et al. 1998)
- Mathematical considerations: plateau is a property of quasi-stationary distributions (Steinsaltz and Evans 2004)

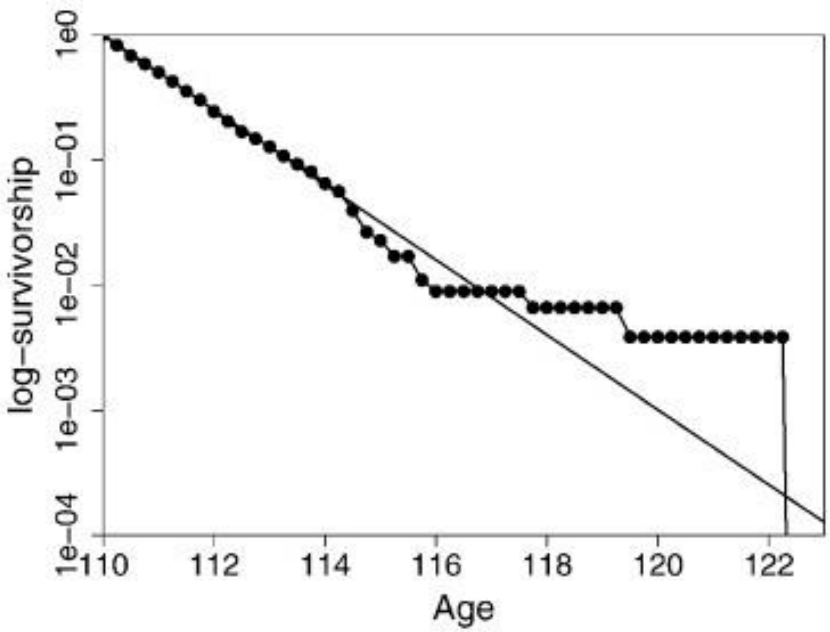
Mortality plateau: examples



Source: Vaupel et al. (1998)

Human mortality plateau: summary

- Individual lifetimes follow a Gompertz curve, modulated by random susceptibility to death (frailty) that is gamma-distributed (Vaupel et al. 1979)
- Mortality deceleration detected in numerous human populations
- Flat mortality observed for supercentenarians (Gampe 2010): plateau at ~0.7 corresponding to 50% chance of dying



Mortality plateau: Italy

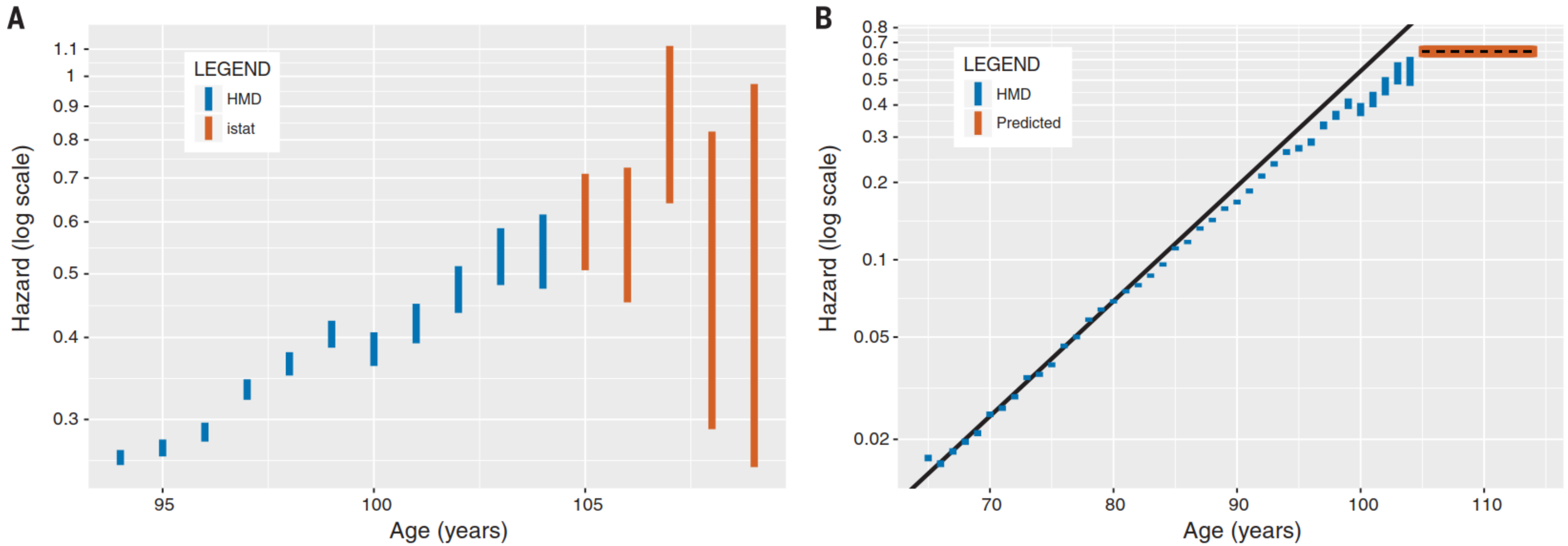


Fig. 1. Yearly hazards on a logarithmic scale for the cohort of Italian women born in 1904. Confidence intervals were derived from Human Mortality Database (HMD) data for ages up to 105 and from ISTAT data beyond age 105. (**A**) Closeup with 95% confidence intervals based solely on single-cohort data. (**B**) Broad view with estimated plateau beyond age 105 (black dashed line) and 95% confidence bands (orange) predicted from the model parameters based on the full ISTAT database, along with a straight-line prediction (black) from fitting a Gompertz model to ages 65 to 80.

Source: Barbi et al. (2018)

Kannisto or Gompertz?

Source: Gavrilova & Gavrilov 2014

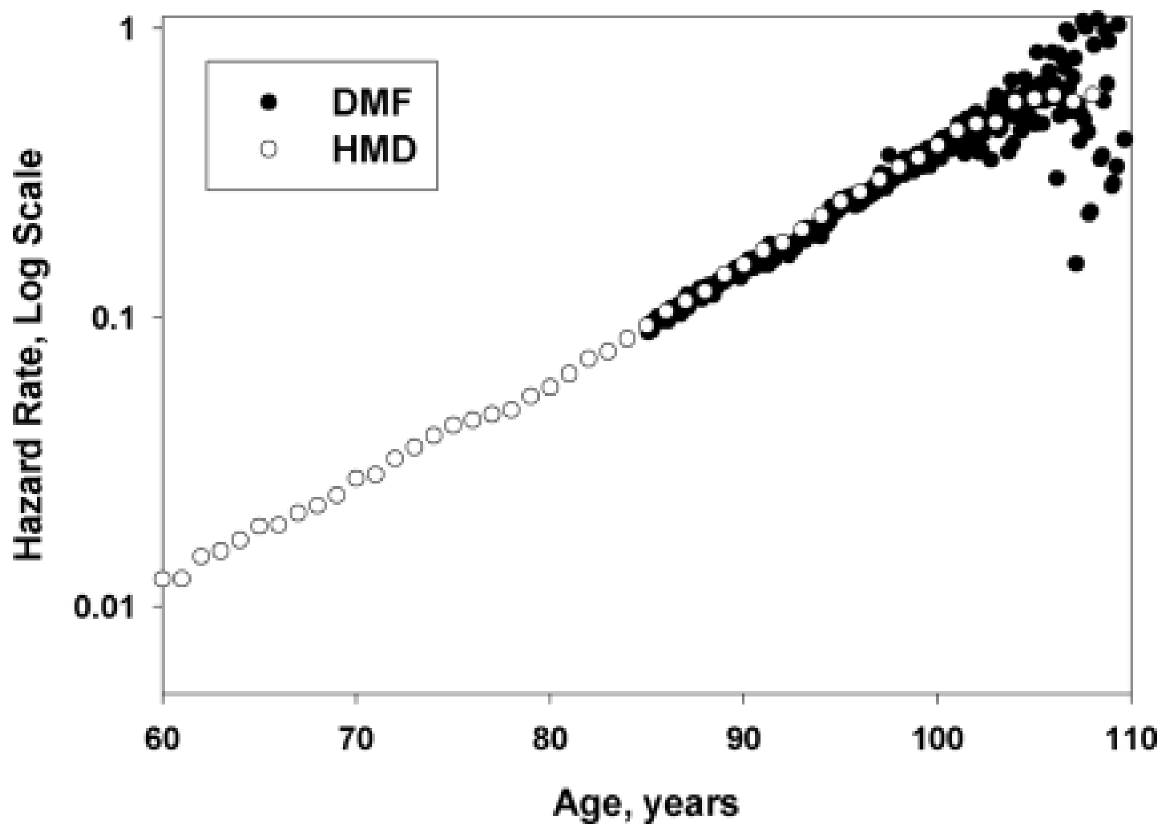


Figure 2. Comparison of Social Security Administration Death Master File and Human Mortality Database mortality data for 1898 birth cohort of U.S. women. Note that these two different datasets produce very similar mortality estimates and mortality trajectories in overlapping age interval.

Quality of mortality estimates at advanced ages

Source: Gavrilov & Gavrilova (2019)

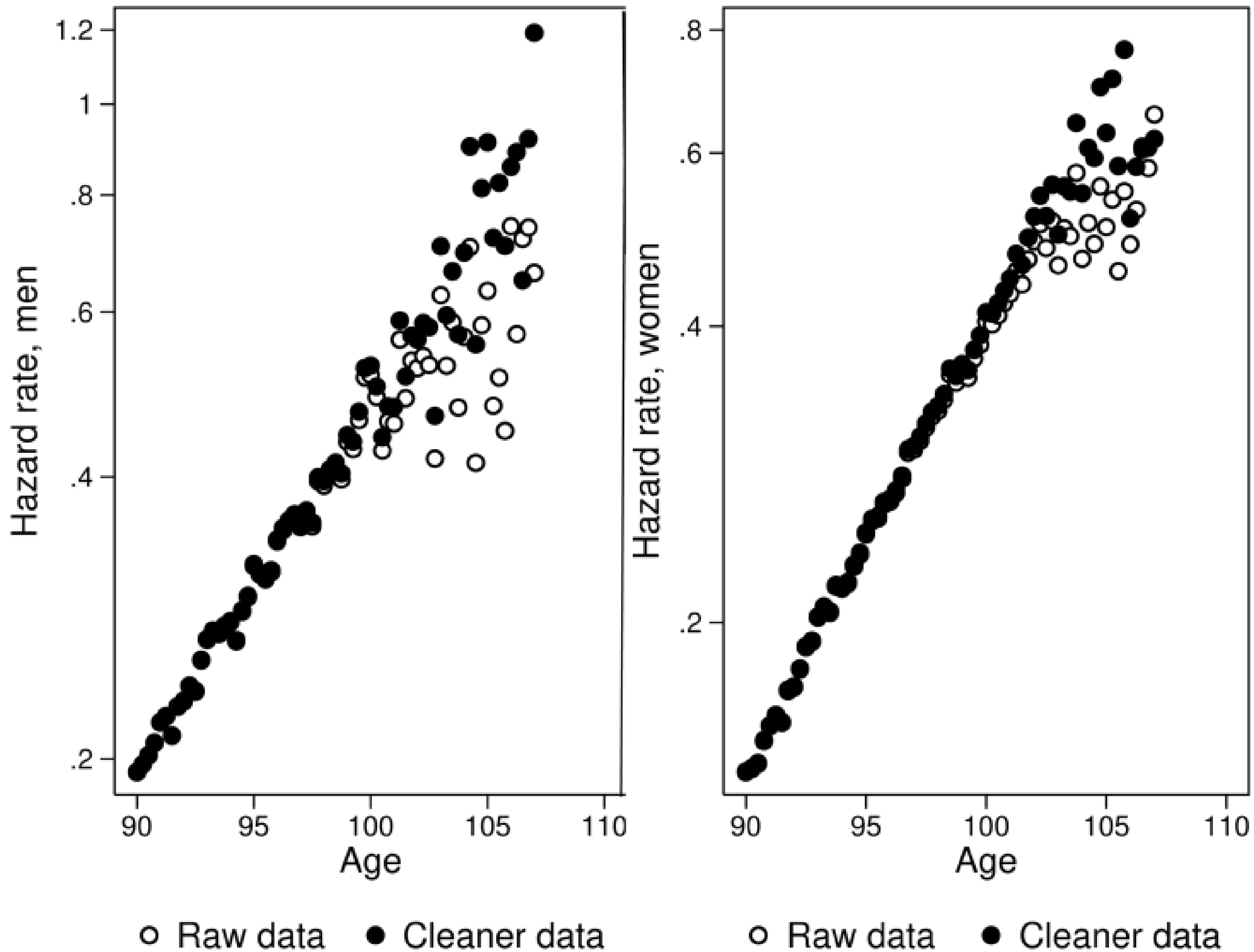
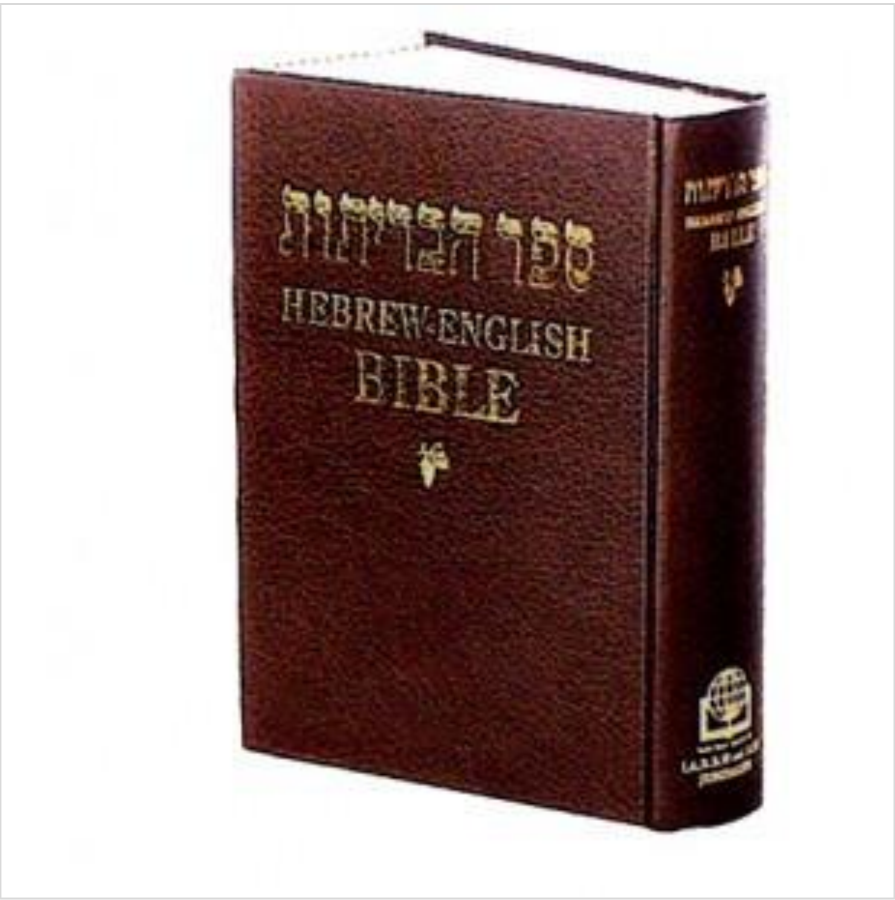


Fig 1. Data cleaning increases late-life mortality estimates. Mortality of U.S. men (on the left) and women (on the right) born in 1900 as a function of age, by the degree of data quality (S1 Data).

Supercentenarians

First list of supercentenarians

Hebrew Bible



Total number of supercentenarians: 40

Name	Age
Methuselah	969
Jared	962
Noah	950
Eve	940
Adam	930
Seth	912
Kenan	910
Enos	905
Mahalalel	895
Lamech	777
Shem	600
Eber	464
…….	……….

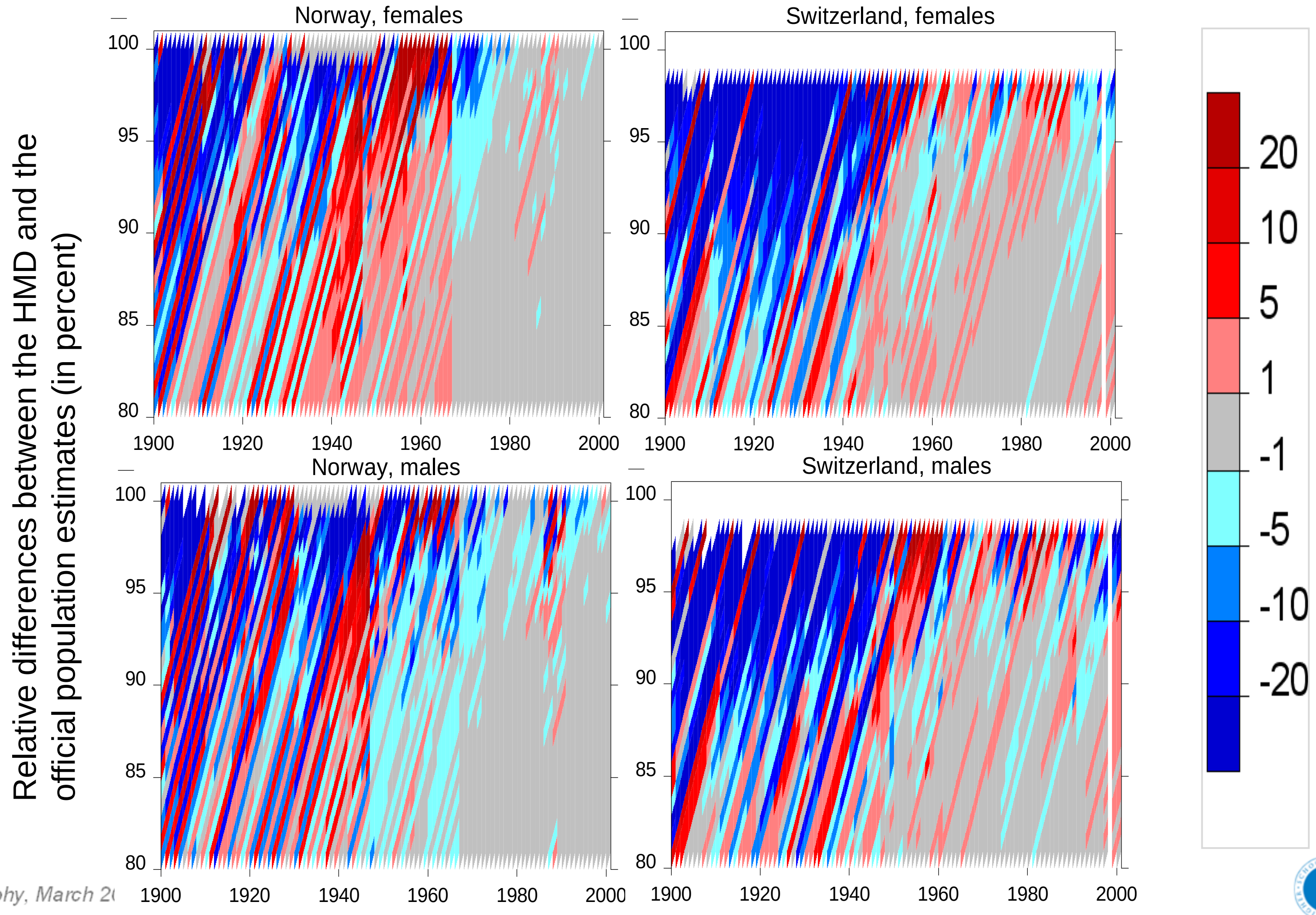
Source: https://en.wikipedia.org/wiki/Longevity_myths

Existing data sources on extreme human longevity

- National-level data assembled by national statistical agencies that include information on deaths and population exposures for ages 105+
  - Data published by national and international statistical authorities (Eurostat, WHO).
  - Human Mortality Database (HMD), Kannisto-Thatcher Database
- Special lists and data collections that contain information on cases of extreme longevity. The cases included in these lists may be detected, collected, and validated using a variety of approaches not always comparable to each other.
  - Gerontology Research Group's (GRG) Supercentenarian List

Official statistical data

Routine population statistics at very high ages is often problematic, the proportion of erroneous cases increases sharply with age.



Official statistical data. Emerging migrants.

Sweden 2014:

Age group	Males	Females	Males foreign born (%)	Females foreign born (%)
90-94	23,648	52,869	0.00	0.00
95-99	3,941	12,585	0.05	0.02
100-104	309	1,558	0.97	0.19
105+	12	74	33.3	5.4

A steep increase in the proportion of foreign-born individuals in the population denominator that does not match with a similar increase in the death numerator is a signal of problematic population estimates, and of a numerator-denominator bias at extreme ages. In light of this new problem, Statistics Sweden has decided to use an aggregated open age interval 100+ instead of showing individual ages above 100.

Lists of supercentenarians

GRG list is the best example. It includes all supercentenarians around the world who "are known" (to the GRG), and whose ages have been "proven."

Disadvantages:

- not representative for any country;
- identification procedures may identify people reaching record ages with higher likelihood than those at very high but not the highest ages -> *age ascertainment bias*;
- procedures used to validate the ages of the individuals included in the list are not standardized and are inconsistent across places and time.

=> Although the GRG List documents all known records of longevity, it cannot be used to derive statistical evidence on trajectories of mortality and survival at extreme ages.

IDL

A desire to learn more about the patterns of human mortality at extreme ages was the main motivation for the establishment of the International Database on Longevity (IDL) by an international collaborative research group

Aim:
to provide highly reliable data on mortality among semi- and supercentenarians Free of the age ascertainment bias.

Priorities:
1) to ensure that all individuals included are real (true) cases of extreme longevity;
2) to ensure that there is no dependency between the probability of being included and age.

The IDL does not include exhaustive sets of validated supercentenarians and semi-supercentenarians for any country. Nevertheless, IDL guarantees that all records in the database are of individuals who really survived to age 105 or higher and that their age is measured with high precision.

IDL data processing

Data collection and processing in the IDL

Initial list of potential cases of people aged 105+ (semi-supercentenarians –SSC) or aged 110+ (supercentenarians – SC): typically from population statistics

↓

Validation: exhaustive or sample

The validation process is subject to a number of restrictions, and the technical implementation of this process differs by country.

Typically involves early-life documents such as baptism certificates or old census records.

↓

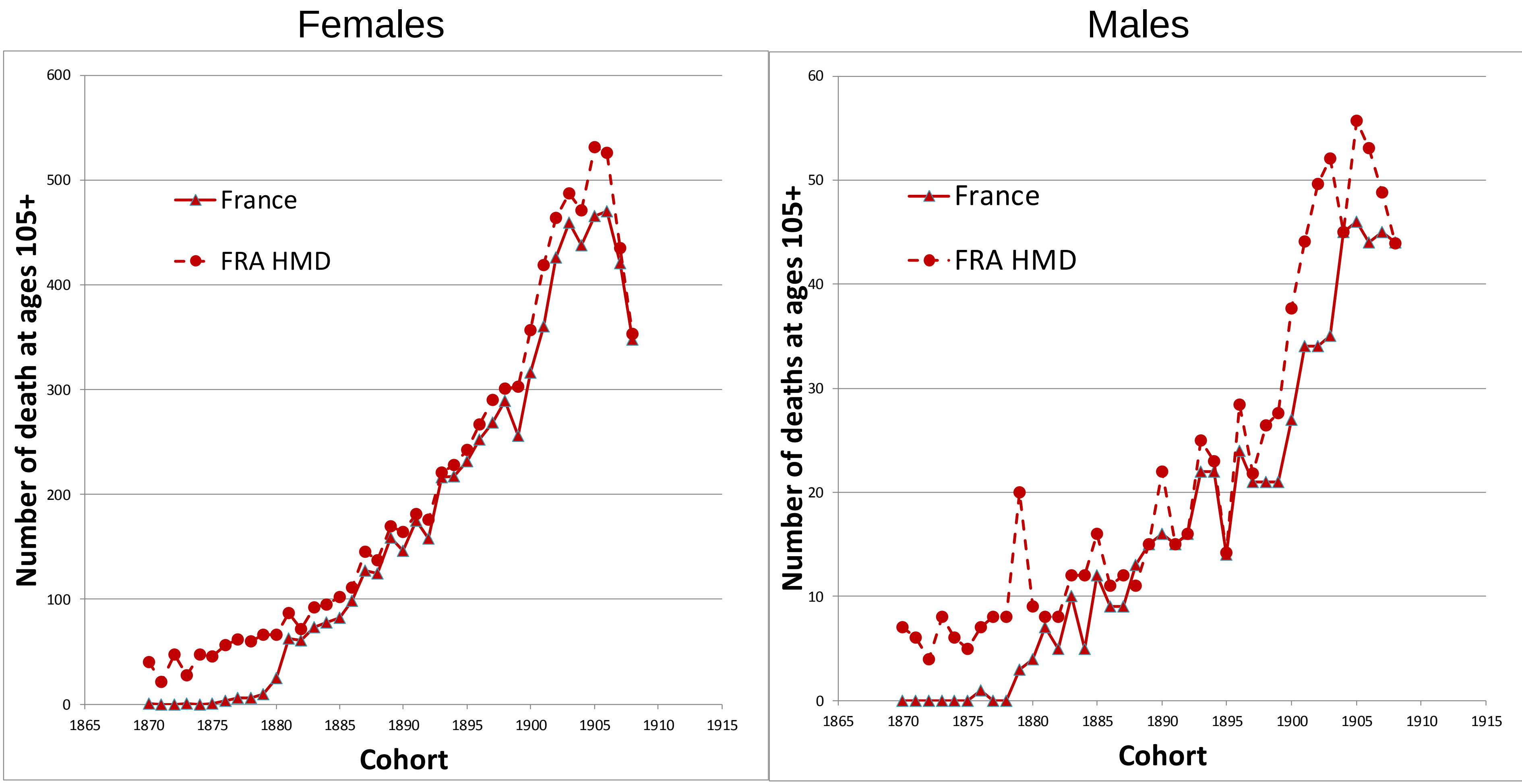
Final lists of SSC and SC

Validation

- All of the cases included in the IDL have been validated.
- The validation procedures vary across countries, but tend to be consistent within each country.
- Using early life documents, e.g. original birth certificate or baptism record combined with old entries in local registers or national censuses that corroborate the individual’s age at various points in her/his life course
- Supercentenarians: all cases were validated using the exhaustive validation approach.
- Semi-supercentenarians: sample validation method was applied when using the exhaustive validation approach was unaffordable. Random subsamples of individuals was created using equal numbers of individual records from each single-year age from 105 to 109.

IDL vs. HMD

Deaths at ages 105+ by birth cohort in France recorded in the HMD and in the IDL



Lists of validated cases may be somewhat biased compared to records on the general population due to the exclusion of two types of cases: 1) those with an incorrect age (age overstatement), and 2) those that could not be validated (for example, people born outside France).

Use of the IDL data

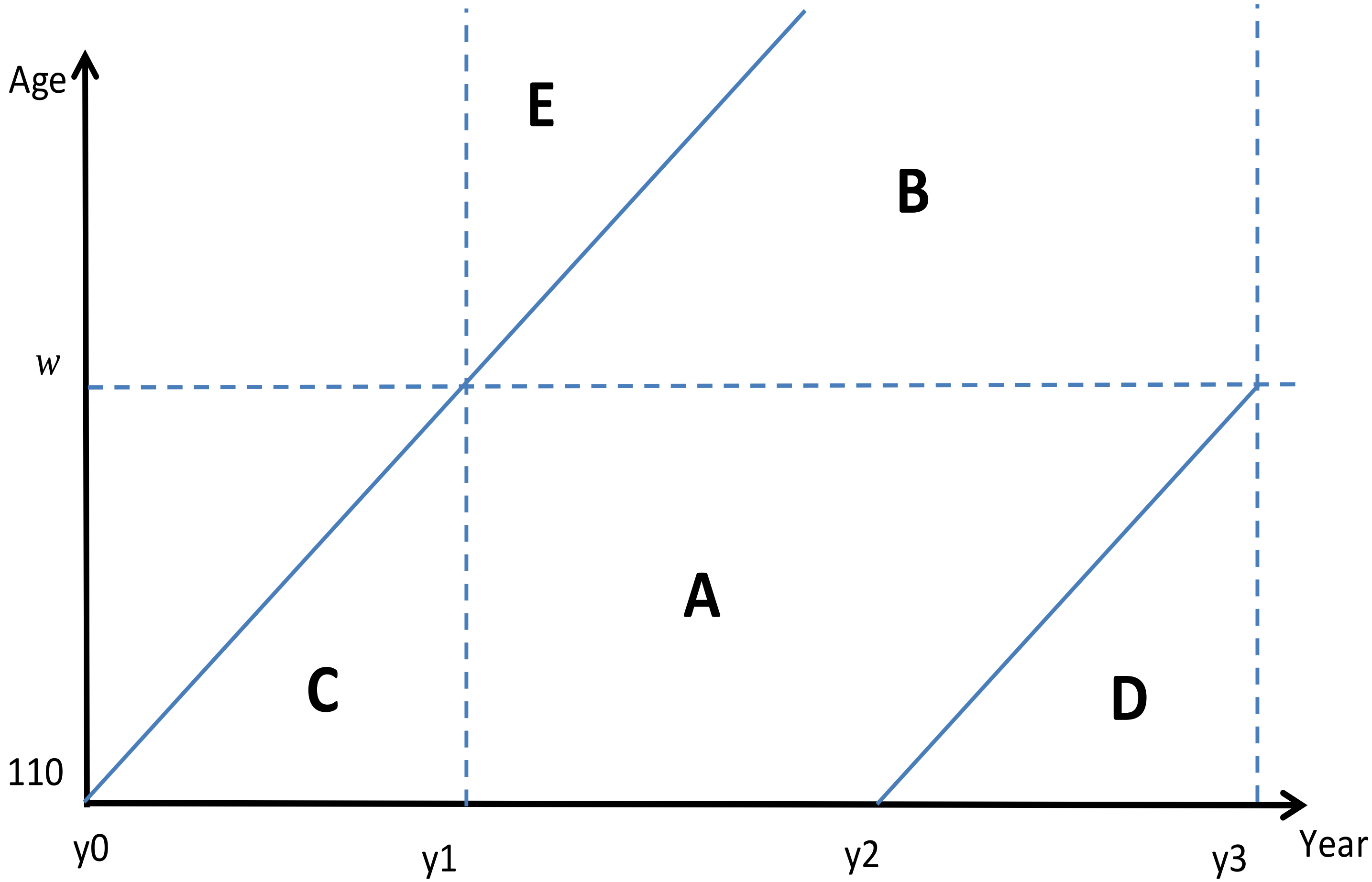
Peculiarities of the IDL data

The IDL is the only the database that provides validated individual-level data on semi- and supercentenarians *free from age ascertainment bias*.

Any analysis of the IDL data should, take into account the data collection and data validation processes:

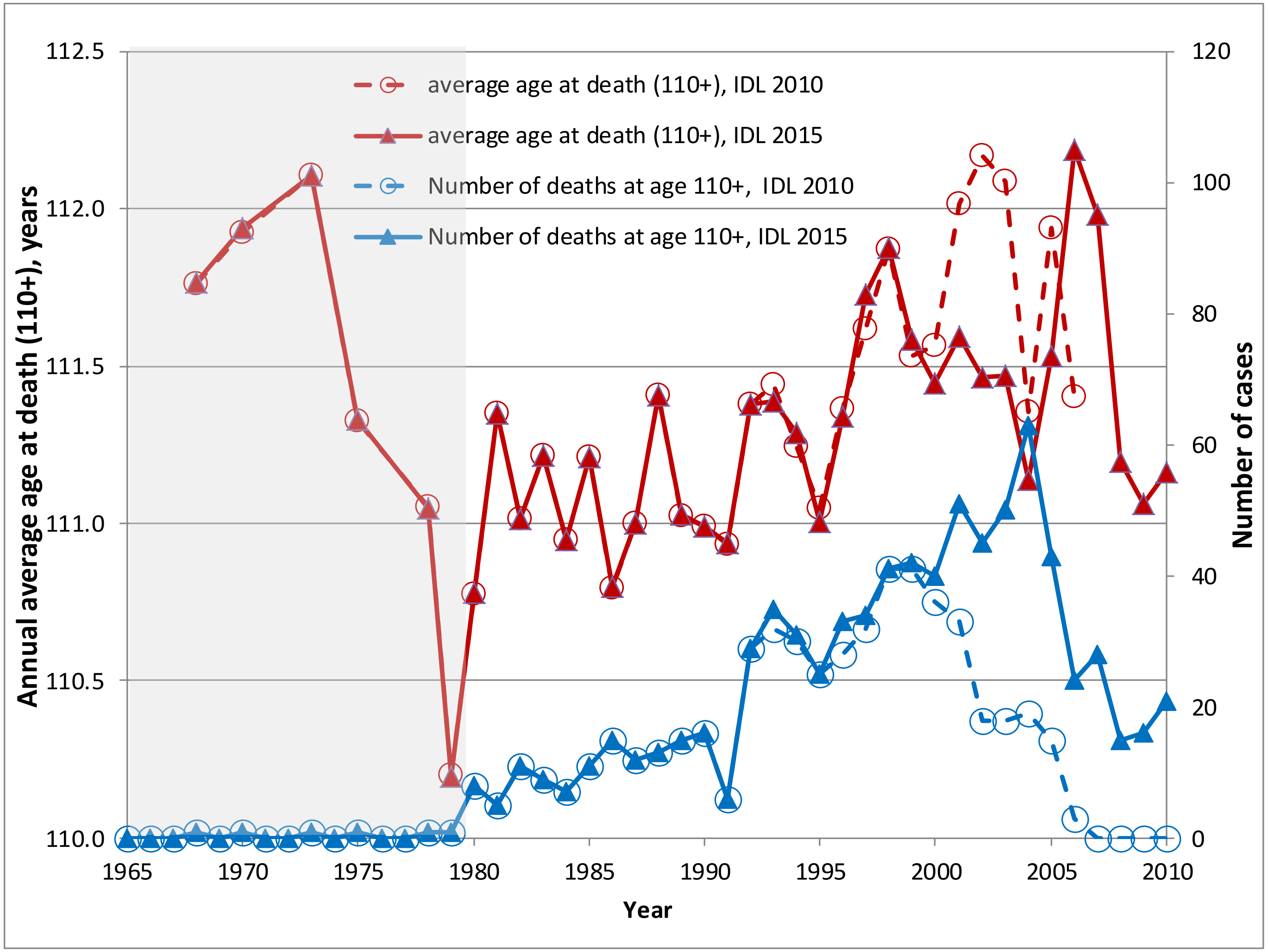
1) The IDL is a collection of validated *individual* cases. The cases that have been validated might be more or less selective with respect to place and year of birth.
2) The IDL provides *individual trajectories*.
3) All country samples are relatively small, with a high degree of *stochastic variation*.
4) Data for the early years might be of lower quality with respect to the age ascertainment bias.
5) Data for the most recent years of observation could be incomplete.
6) It is important to take into account possible cohort effects due to the uneven sizes of cohorts under consideration. These sizes vary significantly.
7) The validation process differs between different countries.

Sampling frames



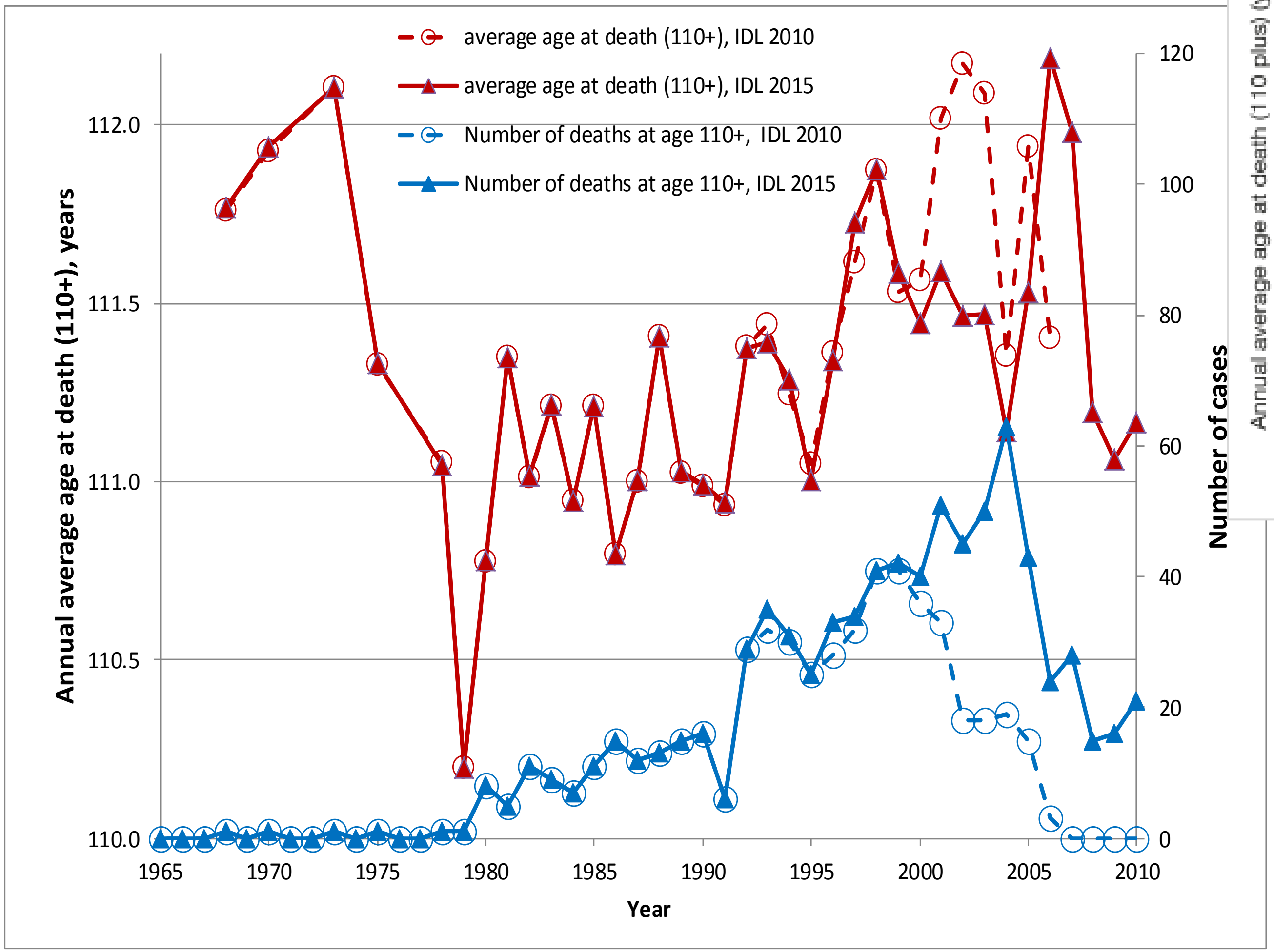
Lexis diagram for data collection: area A+B+C – cohort approach; A+B+D+E – period data; *w* is the age of extinction, y0 and y2 denote the year of birth of the first and the last available cohorts, and y1 and y3 are the first and the last years available through the period observation.

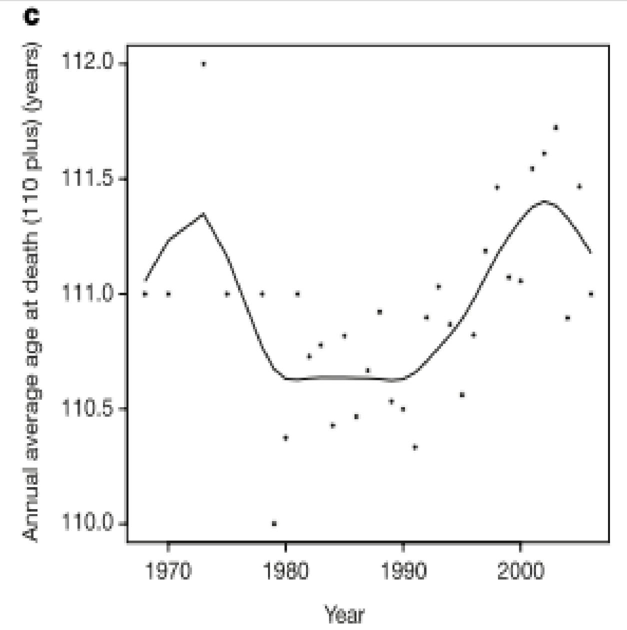
Time frame



Average age at death of individuals who died at ages 110+ (red lines), and the number of supercentenarians (blue lines) according to the IDL-2010 (dashed lines with open circles) and the IDL-2015 (solid lines with triangles).

Example of incorrect use of the IDL data: average age at death

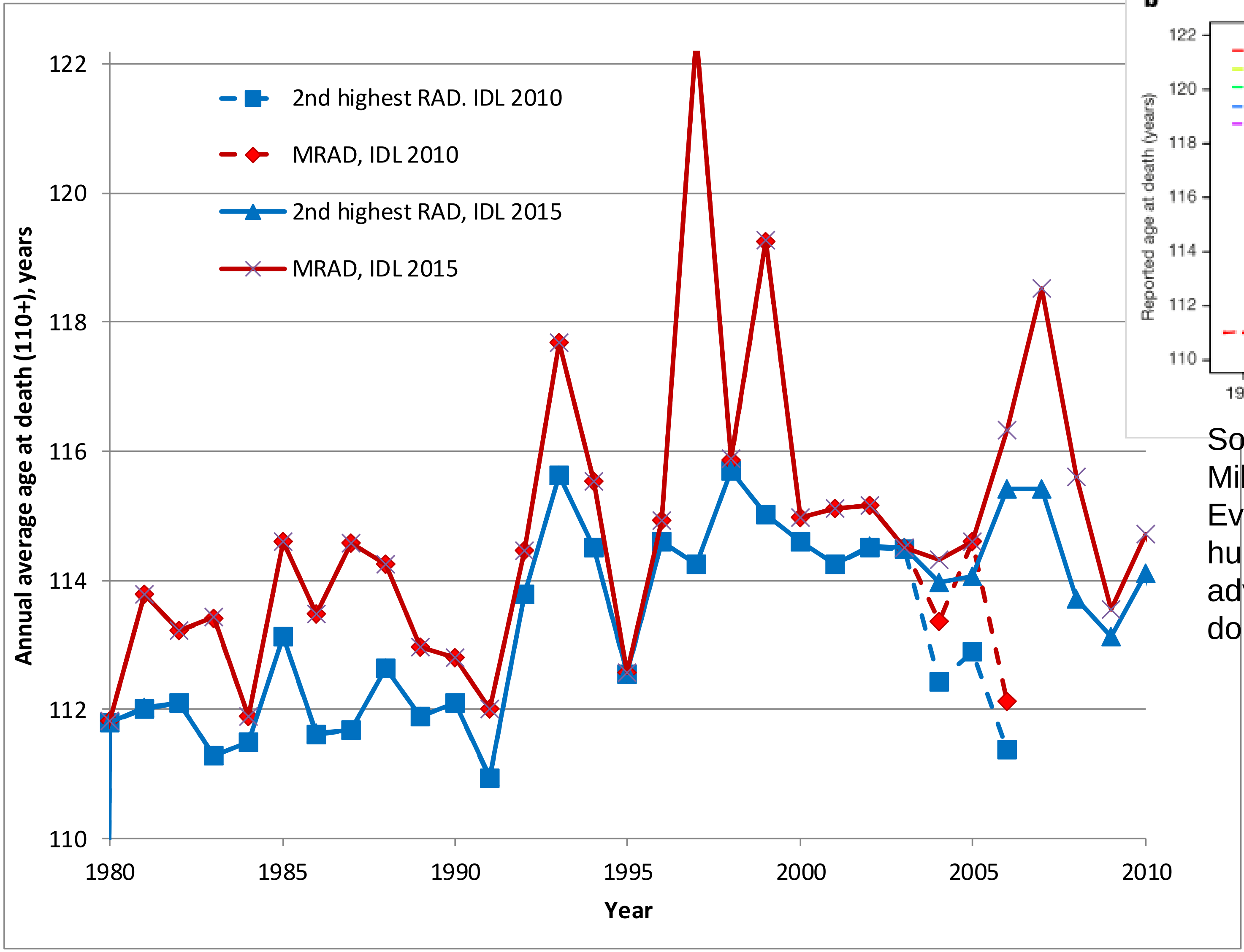


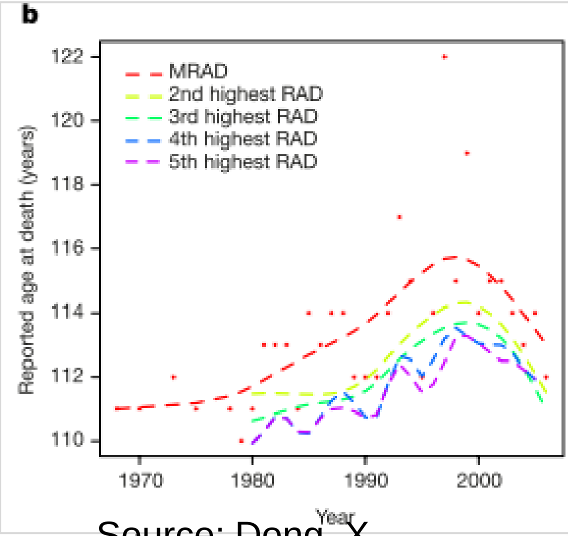


Source: Dong, X., Milholland, B., Vijg, J., 2016. Evidence for a limit to human lifespan. Nature advance online publication. doi:10.1038/nature19793

Data: France + Japan + UK + US

Example of incorrect use of the IDL data: maximum reported age at death (MRAD)





Source: Dong, X., Milholland, B., Vijg, J., 2016. Evidence for a limit to human lifespan. Nature advance online publication. doi:10.1038/nature19793

Data: France + Japan + UK + US

Data available today

IDL data, 2018 data set, 110+

Country	Data frame	Period	Cohorts	Dead	Alive	Year alive	Total SC
Austria	period, left truncation, right censoring	2005-2012	1895-1902	6	0	n/a	6
Belgium	period, left truncation, right censoring	1990-2015	1878-1904	21	2	2015	23
Canada (Quebec)	period, left and right truncation	1962-2009	1852-1898	11	n/a	n/a	11
Denmark	period, left truncation, right censoring	1996-2014	1884-1903	3	1	2014	4
England and Wales	period, left and right truncation	1968-2014	1856-1904	159	n/a	n/a	159
Finland	period, left truncation, right censoring	1989-2006	1878-1896	5	1	2008	6
France	cohort, left and right truncation	1966-2015	1875-1905	188	n/a	n/a	188
Germany	period, left truncation, right censoring	1994-2005	1883-1894	16	1	2005	17
Italy	period, left truncation, right censoring	1973-2016	1863-1906	143	18	2016	161
Japan	period, interval censoring (annual list of alive)	1968-2005	1846-1895	83	120	1968-2005	203
Norway	period, left and right truncation	1987-2004	1875-1893	9	n/a	n/a	9
Spain	period, left and right truncation	1989-2016	1878-1906	60	n/a	n/a	60
Sweden	period, left truncation, right censoring	1986-2003	1874-1892	10	2	2008	12
Switzerland	period, left and right truncation	1993-2000	1881-1890	4	n/a	n/a	4
USA	period, left and right truncation	1980-2010	1867-1899	504	n/a	n/a	504
Total				**1,222**	**145**		**1,367**

Note: Australia & Netherlands are excluded because of age ascertainment bias (information collected from news media), Switzerland can be used for analysis but should be excluded from the public (online) version of the IDL

IDL data, 2018 data set, 105-109

Country	Data frame	Period	Cohorts	Dead	Alive	Year alive	Validation	Total
Austria	period, left truncation, right censoring	2003-2014	1893-1909	261	44	2014	Exhaustive	305
Belgium	period, left truncation, right censoring	1977-2015	1870-1910	782	61	2015	Exhaustive	843
Canada (Quebec)	period, left and right truncation	1985-2009	1877-1904	321	n/a	n/a	Exhaustive	321
Denmark	period, left truncation, right censoring	1970-2014	1863-1909	447	33	2015	Exhaustive	480
England and Wales	period, left and right truncation	2000-2014	1890-1909	1,054	n/a	n/a	Sample	1,054
France	cohort, left and right truncation	-	1870-1909	7,468	n/a	n/a	Sample	7,468
Germany	period, left truncation, right censoring	1989-2005	1881-1898	928	25	2005	Exhaustive	953
Italy	period, left truncation, right censoring	2009-2015	1899-1910	2,336	1,198	2016	Exhaustive	3,534
Japan	period, interval censoring (annual list of alive)	1995-2005	1886-1895	28	2,832	1854-1898	Exhaustive	2,860
Norway	period, left and right truncation	1986-2006	1877-1899	220	n/a	n/a	Exhaustive	220
Switzerland	period, left and right truncation	1971-2005	1864-1900	236	n/a	n/a	Exhaustive	236
USA	period, left and right truncation, sample	1979-2009	1871-1899	338	n/a	n/a	Exhaustive	338
Total				**14,419**	**4,193**			**18,612**

Note: Switzerland can be used for analysis but should be excluded from the public (online) version of the IDL

Possible updates in near future

Country	Deaths 110+	Alive 110+	Deaths 105-109	Alive 105-109
Austria	6	-	261	44
Belgium	21+	2+	782+	61+
Canada	11+	-	321+	-
Denmark	3+	1+	447+	33+
E&W	159+	-	1,054+	-
Finland	5	1	-	-
France	188+	-	7,468+	-
Germany	16	1	928	25
Italy	143+	18+	2,336+	1,198+
Japan	83	120	28	2832
Norway	9	-	220	-
Spain	60+	-	-	-
Sweden	10	2	-	-
Switzerland	4	-	236	-
USA	504+	-	338 (sample)+	-
Total	***1,222+***	***145+***	***14,419+***	***4193+***

Mortality plateau

Jeanne Calment

The oldest human whose age was well-documented

Jeanne Calment

1875--1997

122 years and 164 days

Became the oldest person ever in 1990

The oldest man whose age was well-documented

Jiroemon Kimura

1897--2013

116 years and 54 days

Became the oldest
men ever in 2012

The second oldest man whose age was well-documented

Christian
Mortensen

1882--1998

115 years and 252 days

Became the oldest
men ever in 1998

Three kinds of probabilities

- Probability of an observed maximum age within a specific cohort
- Retrospective probability that current records might have been broken until today
- Probability that record will be broken within the limited time (e.g. 15 years) in future

Cohort-specific probability

N	Name	Age at death	Year of birth	Year of death	P in %	P in years
1	Jeanne Calment	122.4	1875	1997	0.1	1 in 1100 yrs
2	Sarah Knauss	119.3	1880	1999	3.5	1 in 29 yrs
3	Lucy Hannah	117.7	1875	1993	5.3	1 in 19 yrs
1	Jiroemon Kimura	116.1	1897	2013	26.8	1 in 4 yrs
2	Christian Mortensen	115.7	1882	1998	8.7	1 in 11 yrs
3	Emiliano Mercado del Toro	115.4	1891	2007	16.1	1 in 6 yrs

Source: Oulette & Wilmoth (2014)

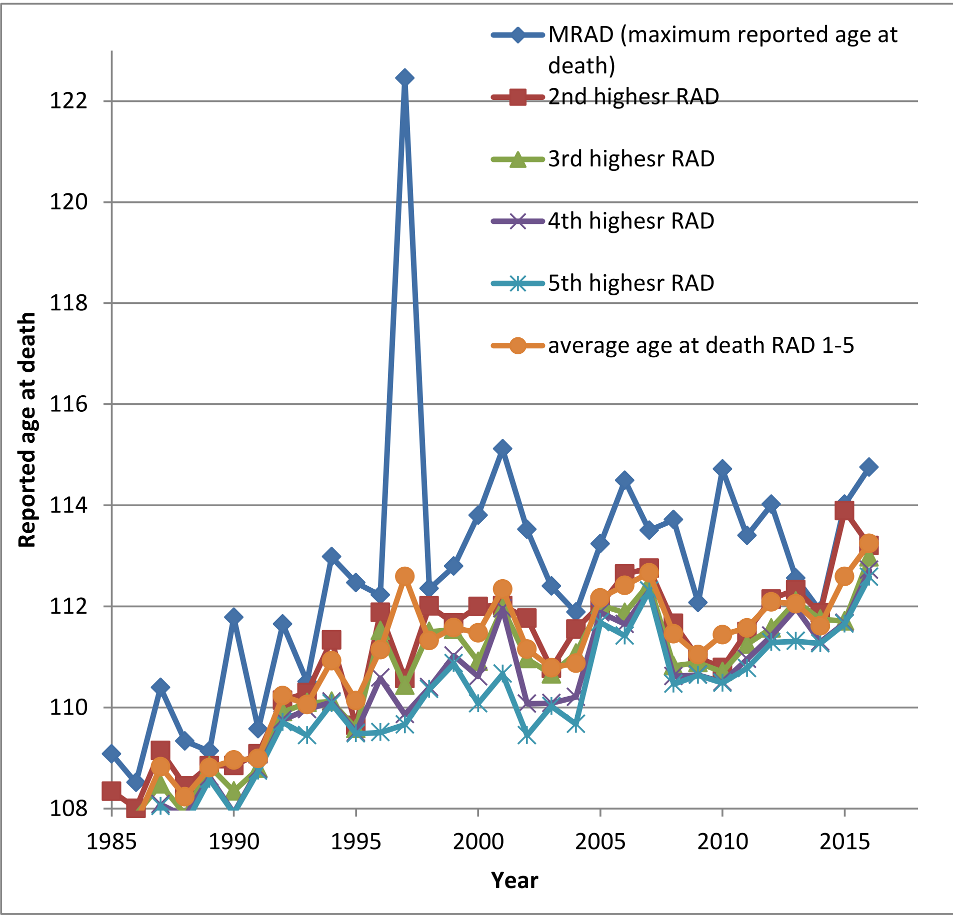
Probability of breaking record

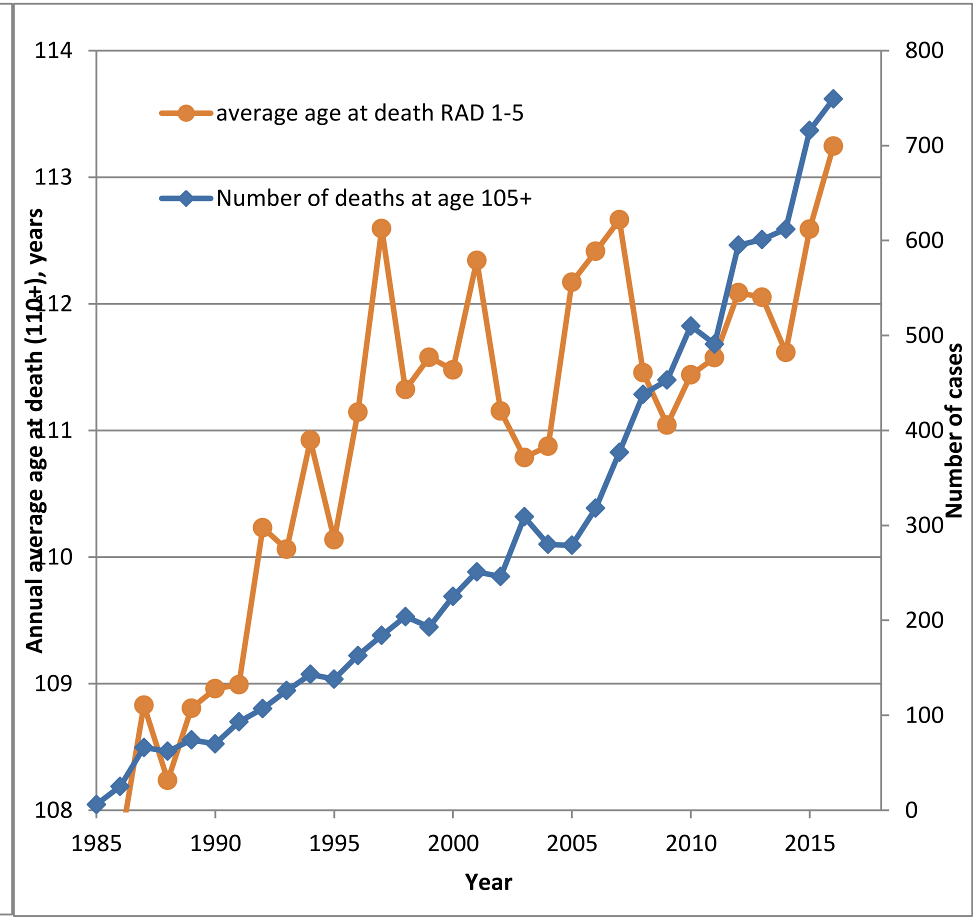
Name	Retrospective*	In 15 years**	In 30 years**
Jeanne Calment	3.9	5.5	13.8
	(2.5;6.6)	(3.4;9.5)	(8.7;23.3)
Christian Mortensen	85.3	99.0	100.0
	(72.3;95.3)	(95.6;99.9)	(100;100)

*Retrospective probabilities are from death until 31 December 2012
** Future (conditional) probabilities are for periods beginning 1 January 2013

Source: Oulette & Wilmoth (2014)

France, maximum reported age at death





Wide Field Planetary Camera 1 | Wide Field Planetary Camera 2

https://blogs.voanews.com/science-world/2016/04/22/

https://www.theverge.com/2015/7/14/8958079/nasa-new-horizons-pluto-color-image
https://www.tumblr.com/search/nasa%20jokes