The changing age pattern of mortality

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Motivation

Death risks in human populations display a specific age pattern:

- high but falling from birth,
- minimum for young teenagers
- increase to a plateau for young adults → traffic, other risky behaviour
- exponential increase beyond age 30

Life expectancies in Western countries during 20th century irregular, in particular for men

Life expectancies derived from period life tables

Difficult to interpret

Future?

Outline

Trends in life expectancy, median and modal age, compression

Life table construction (detailed)

Focus on d_x-column

Period vs cohort life tables – interpretation

Explain why period life tables may give distorted impression of reality

Context: Western countries, 20th (& 21st) century

Required reading: these notes and Chapter 5 on mortality in Population Handbook pp. 16-20

http://www.prb.org/Publications/Reports/2011/prb-population-handbook-2011.aspx

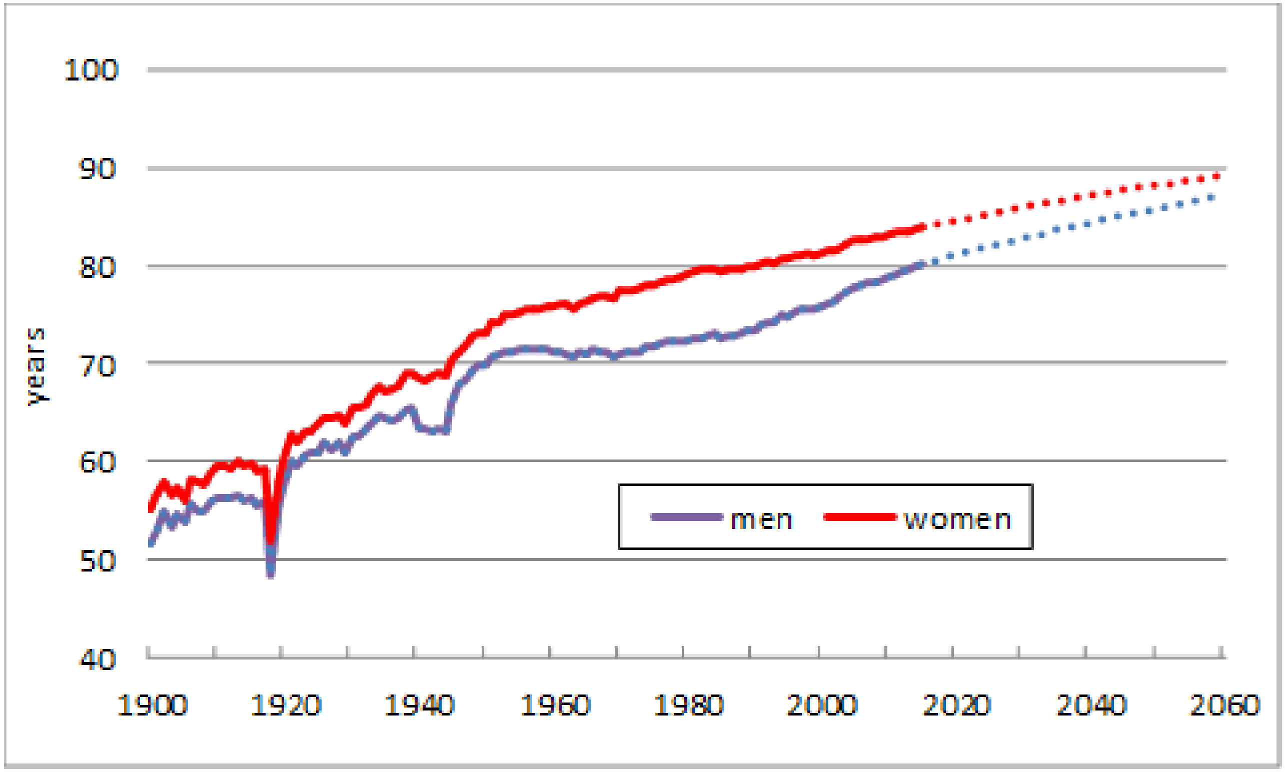
Main message

Period life tables may give a distorted picture of trends in age-specific mortality in times of changing mortality

Western countries: life expectancies increase faster than period life tables suggest

Norway: compression goes faster than period life tables suggest

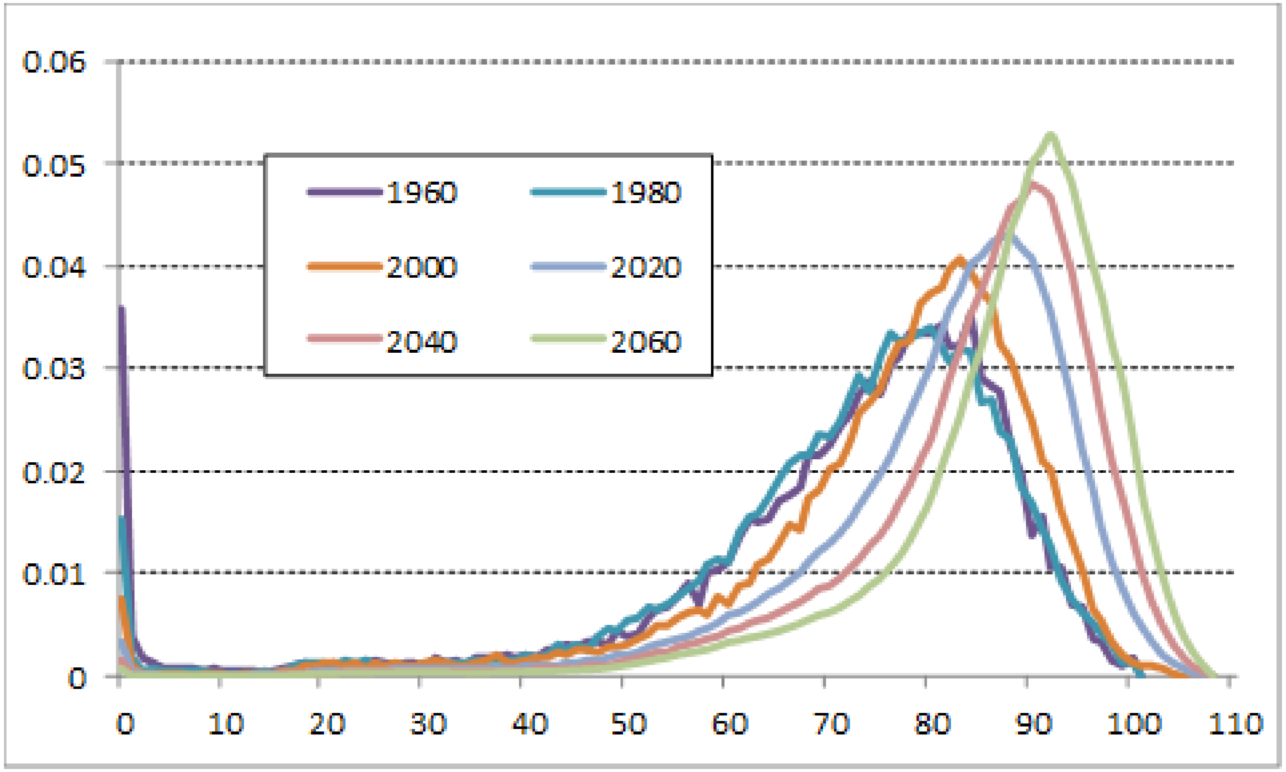
Life expectancy at birth, Norway
Empirical life tables 1900-2015, projected life tables 2016-2060 (source: StatNor)



Note

1. Irregular pattern (men 1950s, 1960s)
2. Convergence men-women

Age distribution of life table deaths; historical (1960, 1980, 2000) and projected (2020, 2040, 2060) values .
a. Men, Norway



Age distribution of life table deaths; historical (1960, 1980, 2000) and projected (2020, 2040, 2060) values
b. Women, Norway

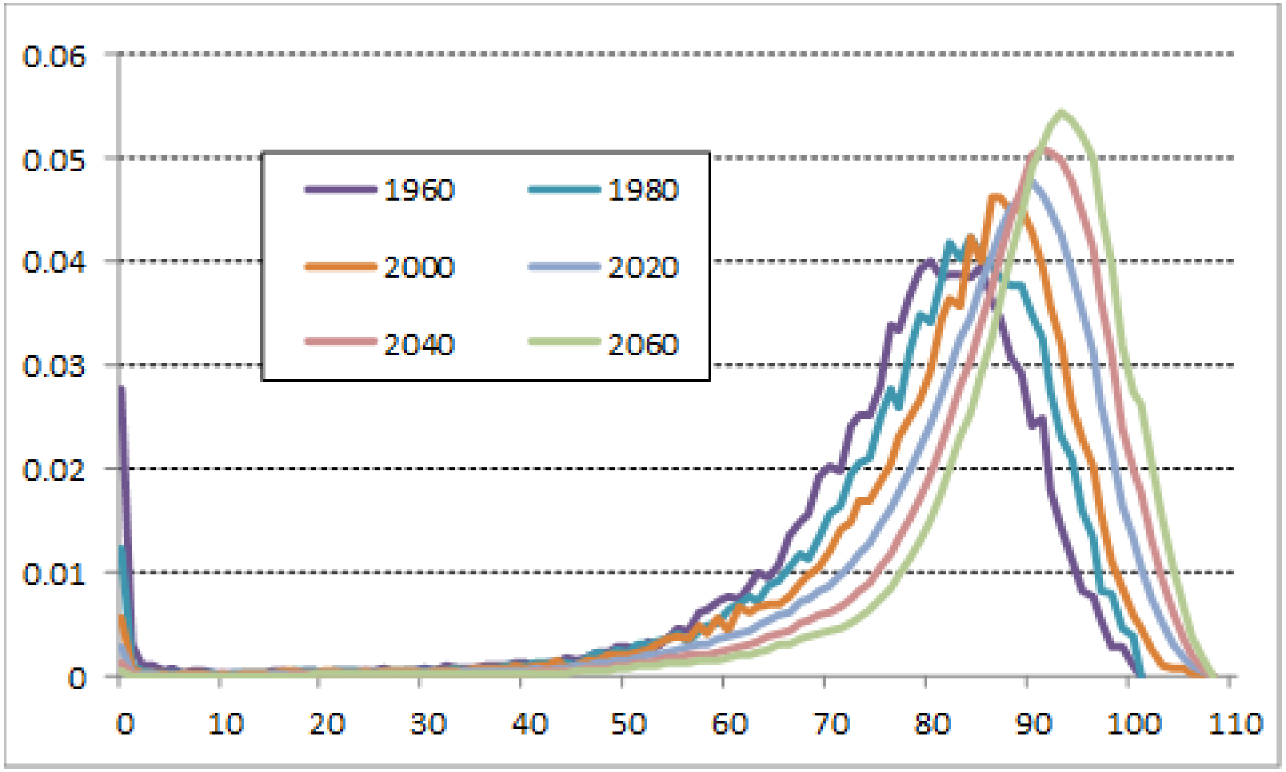
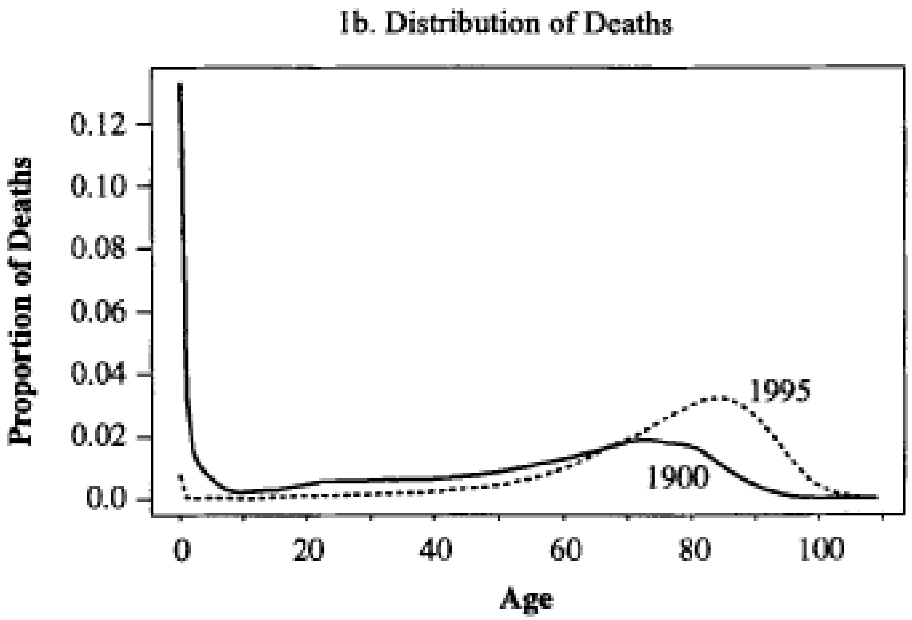


Fig. 6.2 Probability distribution of age at death in 1950 (solid) and 2000 (dashed) for Sweden, both sexes combined

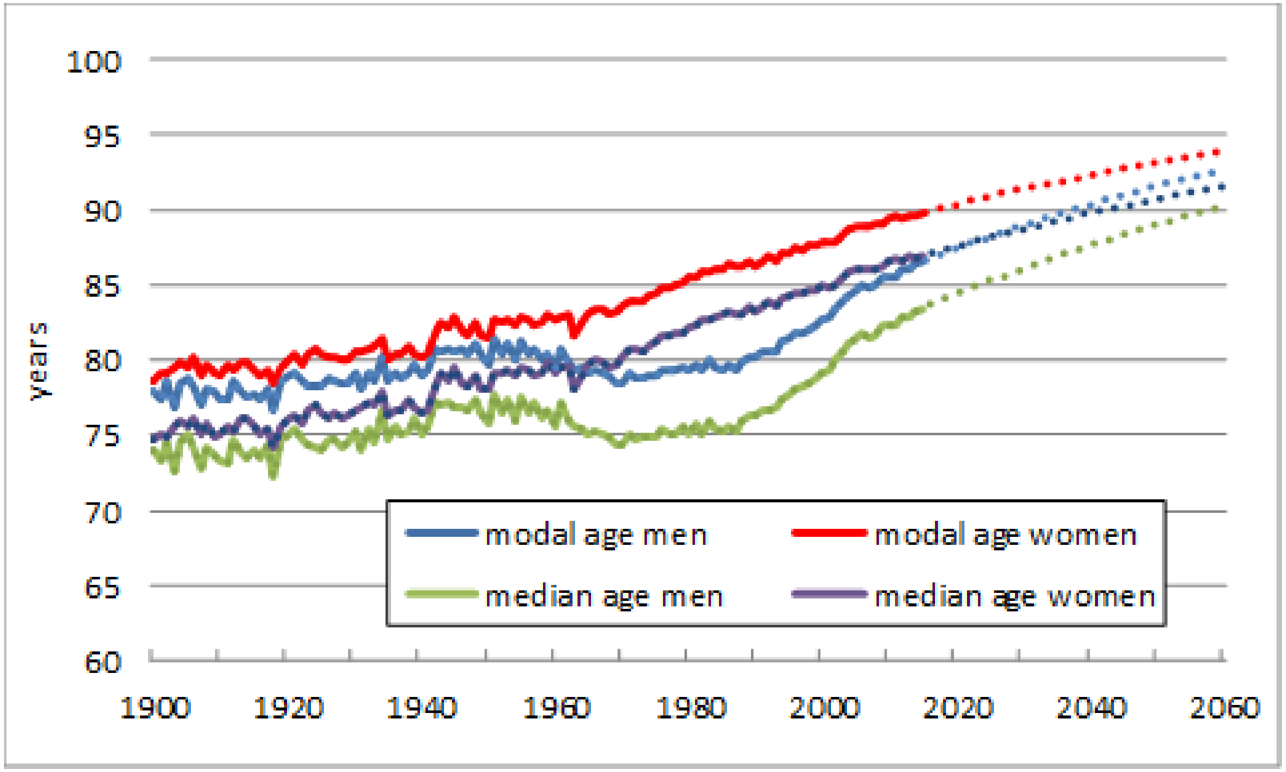
Source: S. Tuljapurkar, pp. 209-221 in J. Shoven (ed.) Demography and the Economy. Un Chicago Press 2010

Women, USA



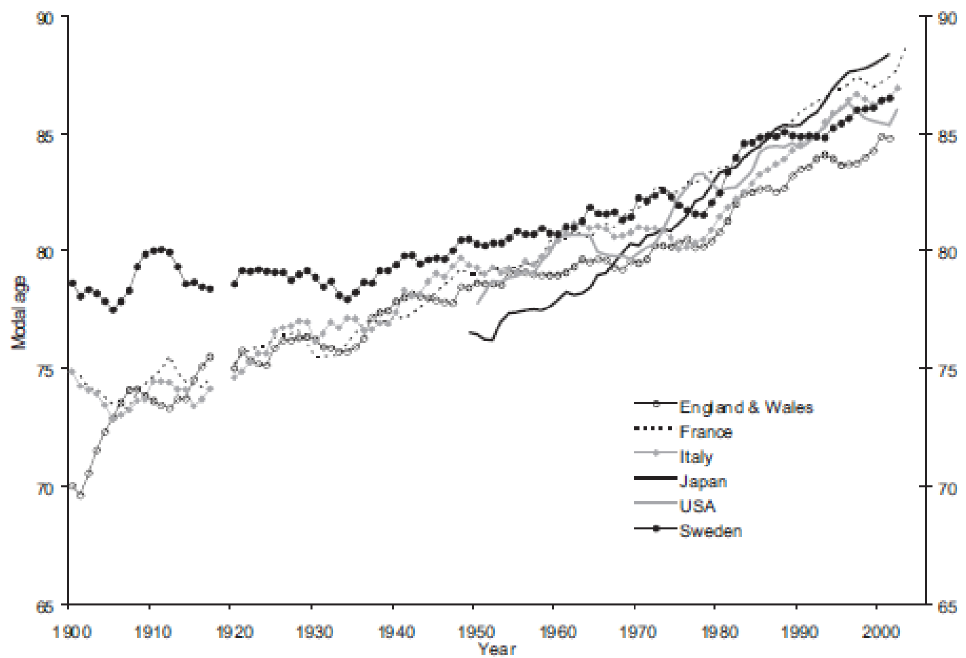
Source: J. Wilmoth & S. Horiuchi, Demography 36(1999), 475-495.

Modal age and median age at death, Norway
Empirical life tables 1900-2015, projected life tables 2016-2060



Modal age: age at which distribution reaches a top
Median age: age that divides distribution in two equal halves: 50% dies before median age, 50% dies after median age.

Figure 4a: **Five year moving average of the modal age at death for England and Wales, France, Italy, Japan, Sweden and the United States, for available years between 1900 and 2005**

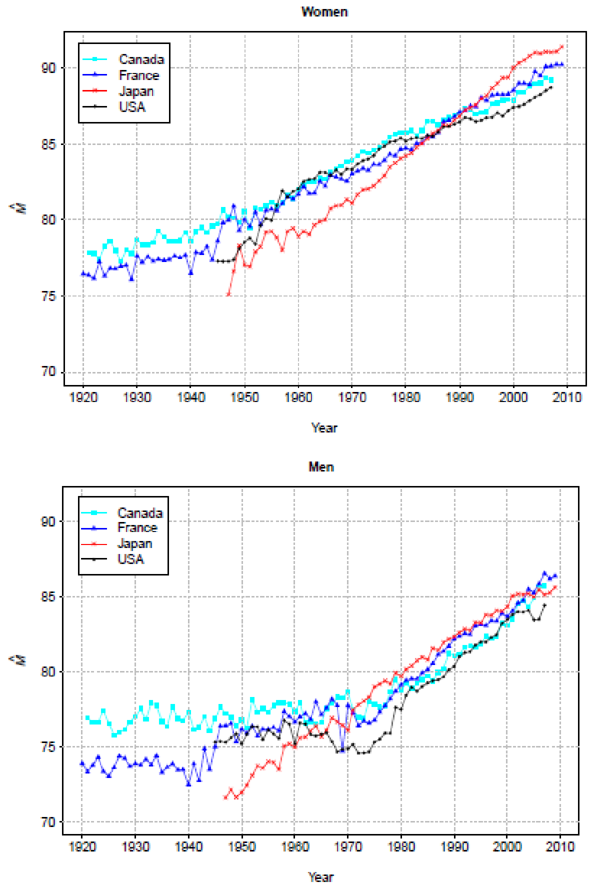


Source: Authors' calculations based on Human Mortality Database (2008). The years of the influenza epidemic 1918-1919 have been excluded.

Note: both sexes combined.

Source: V. Canudas-Romo, DemRes 19(2008), 1179-1204.

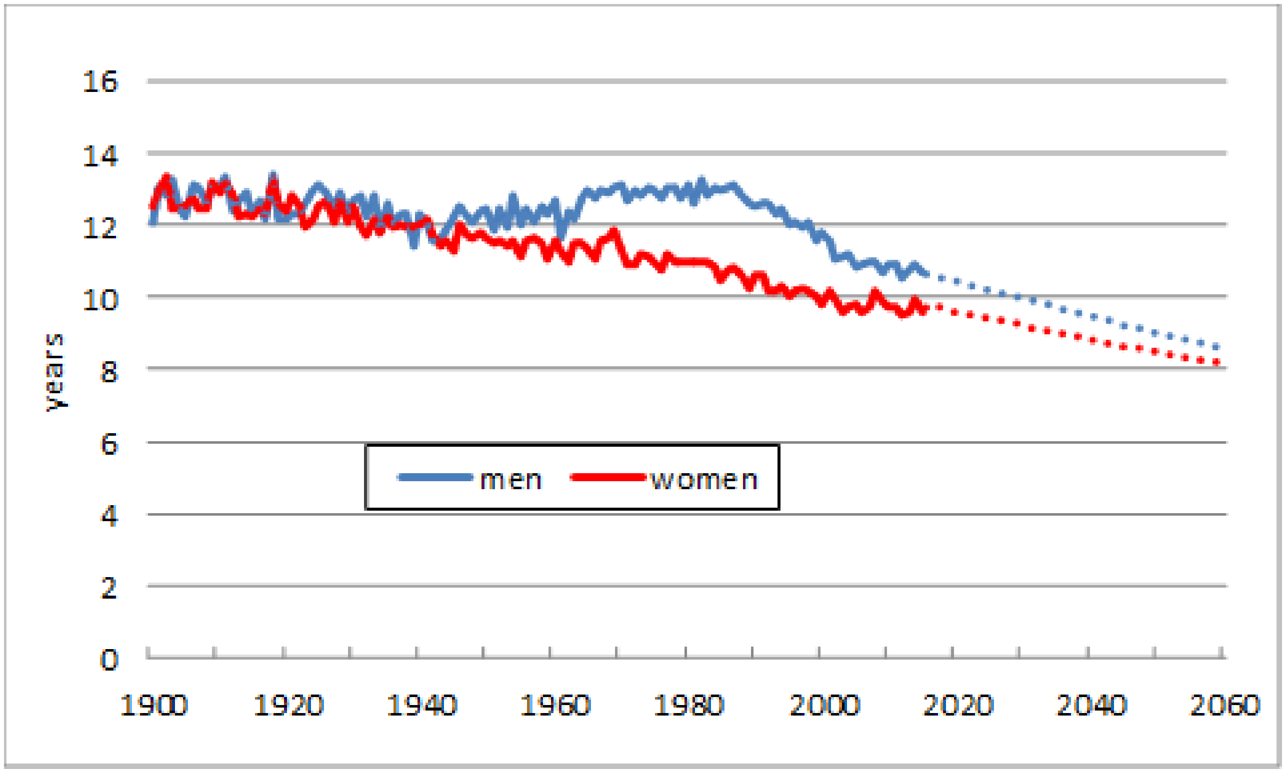
Figure 4: Estimated modal age at death based on smoothed density functions: Canada (1921–2007), France (1920–2009), Japan (1947–2009), and USA (1945–2007)



Source: N. Ouellette & R. Bourbeau, DemRes 25(2011), 595-628.

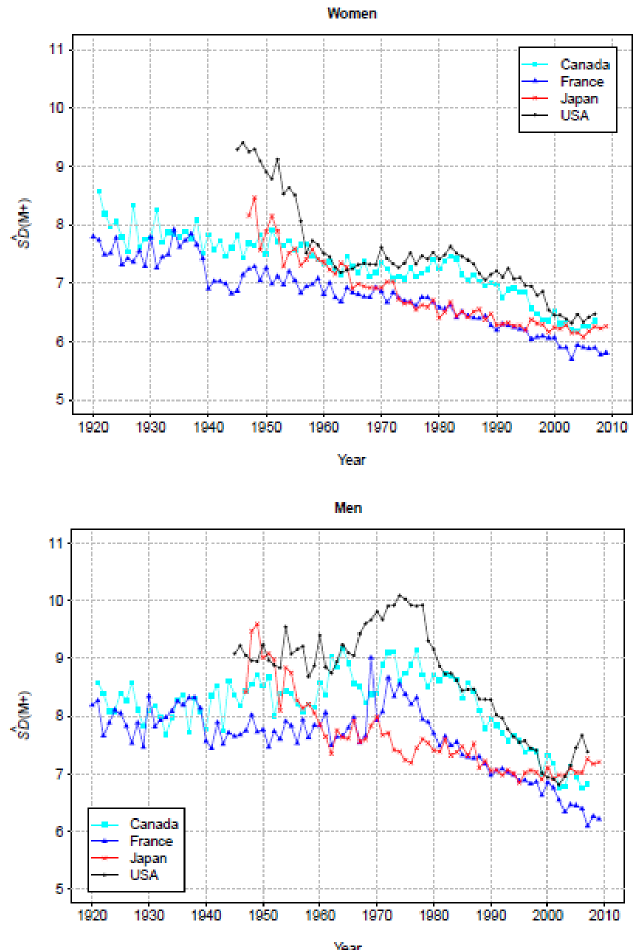
Standard deviation of age distribution of life table deaths for ages 30 and beyond; historical (1900-2015) and projected (2016-2060) values

Standard deviation ages > 30 reflects degree of compression



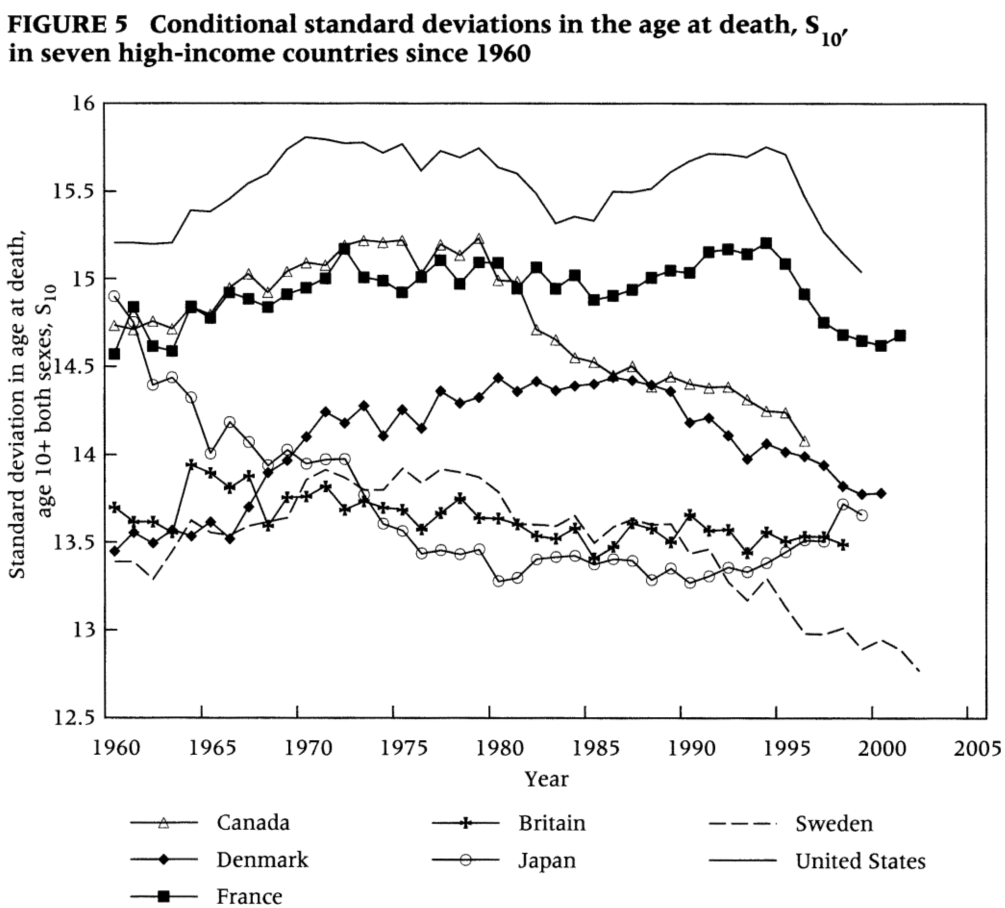
Note: stronger compression women (1900-2060), men (after 1990)

Figure 5: Estimated standard deviation of ages at death above the mode based on smoothed density functions: Canada (1921–2007), France (1920–2009), Japan (1947–2009), and USA (1945–2007)



Note: standard deviation above the mode

Source: N. Ouellette & R. Bourbeau, DemRes 25(2011), 595-628.

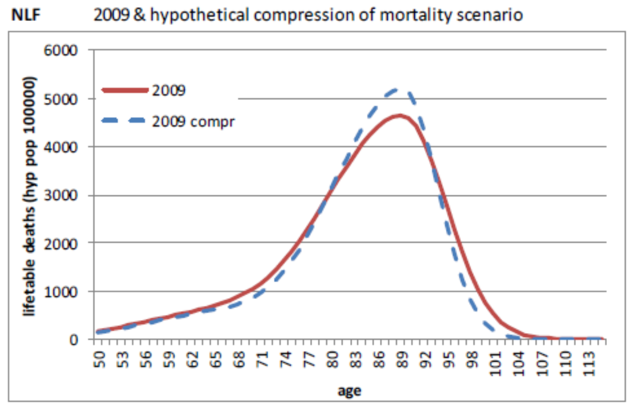


Note: short time period, both sexes combined. Standard deviation above age 10.
Source: R. Edwards & S. Tuljapurkar, PopDevRev 31(2005), 645-674.

Changes in age at death distribution

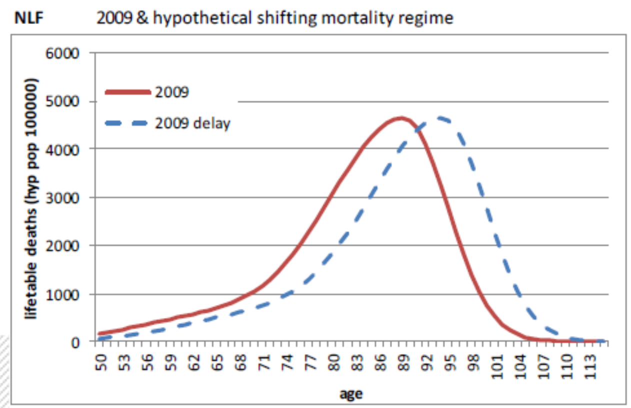
Compression of mortality scenario (Fries 1980)

- Rectangularization
- declining variability in the age of dying



Shifting mortality regime / **mortality delay** (e.g. Vaupel 2010)

- Increase in modal age at dying
- No changes in shape



Based on data for women, the Netherlands

Source: F. Janssen & J. de Beer (2016)

Construction of a life table

Required reading: Chapter 5 on mortality in Population Handbook pp. 16-20

http://www.prb.org/Publications/Reports/2011/prb-population-handbook-2011.aspx

A life table simulates a population's mortality experience during its lifetime

It does so by taking a set of empirical age-specific death rates and applying them, for subsequent ages from the youngest to the oldest, to a hypothetical population of 100,000 people born at the same time.

For each subsequent age in the life table, mortality inevitably thins the hypothetical population's ranks, until one reaches the highest age, and even the oldest people die.

How Life Tables Work						
Abridged Life Table for Males in Malaysia, 1995						
	1	2	3	4	5	6
				Persons living		
Age	Proportion dying in the age interval	Number living at beginning of age interval	Number dying during the age interval	in the age interval	in this and all subsequent intervals	Years of life remaining (life expectancy)
< 1	.01190	100,000	1,190	98,901	6,938,406	69.38
1-5	.00341	98,810	337	394,437	6,839,505	69.22
5-10	.00237	98,473	233	491,782	6,445,067	65.45
10-15	.00270	98,240	265	490,536	5,953,285	60.60
	- - - - -	- - - - - -	- - - - -	- - - - - -	- - - - - - -	- - - - -
65-70	.16050	70,833	11,368	325,743	928,004	13.10
70-75	.25762	59,464	15,319	259,024	602,260	10.13
75-80	.34357	44,145	15,167	182,808	343,237	7.78
80+	1.00000	28,978	28,978	160,428	160,428	5.54
Source: Department of Statistics, Malaysia, 1997						

Col. 1 $_nq_x$ probability of dying between ages *x* and *x*+*n* (empirical)

Col. 2 l_x number of persons alive at age *x* NB life table population l_0=100 000 chosen as a starting point («radix»)

Col. 3 $_nd_x$ number of deaths in life table population between ages *x* og *x*+*n*; col 3 = col 2 * col 1

Col. 4 $_nL_x$ years lived between ages *x* and *x*+*n*

Col. 5 years lived from age *x* and beyond

Col. 6 e_x remaining life expectancy at age *x*; col 6 = col 5/col 2

NB: *n* is width of age interval

Life table women Norway, 2007

	B	C	D	E	F	G	H	I
	pr.100000	pr.1						
	$_5M_x$	$_5M_x$	$_5q_x$	l_x	$_5d_x$	$_5L_x$	T_x	e_x
0-4 year	72	0.00072	0.003594	100000	359.3532	499101.6	8252829	82.5
5-9 year	8	0.00008	0.000400	99640.6	39.8483	498103.6	7753727	77.8
10-14 year	10	0.0001	0.000500	99600.8	49.7880	497879.5	7255624	72.8
15-19 year	18	0.00018	0.000900	99551.0	89.5556	497531.2	6757744	67.9
20-24 year	33	0.00033	0.001649	99461.5	163.9761	496897.3	6260213	62.9
25-29 year	35	0.00035	0.001748	99297.5	173.6187	496053.3	5763316	58.0
30-34 year	34	0.00034	0.001699	99123.9	168.3674	495198.4	5267262	53.1
35-39 year	64	0.00064	0.003195	98955.5	316.1517	493987.1	4772064	48.2
40-44 year	90	0.0009	0.004490	98639.3	442.8806	492089.5	4278077	43.4
45-49 year	154	0.00154	0.007670	98196.5	753.2129	489099.3	3785987	38.6
50-54 year	249	0.00249	0.012373	97443.2	1205.6632	484202.1	3296888	33.8
55-59 year	407	0.00407	0.020145	96237.6	1938.7085	476341.2	2812686	29.2
60-64 year	606	0.00606	0.029848	94298.9	2814.6145	464457.8	2336345	24.8
65-69 year	950	0.0095	0.046398	91484.3	4244.6910	446809.6	1871887	20.5
70-74 year	1607	0.01607	0.077247	87239.6	6738.9617	419350.4	1425078	16.3
75-79 year	2933	0.02933	0.136631	80500.6	10998.9186	375005.7	1005727	12.5
80-84 year	5635	0.05635	0.246960	69501.7	17164.1075	304598.2	630721	9.1
85-89 year	10795	0.10795	0.425042	52337.6	22245.6621	206073.8	326123	6.2
90-94 year	22468	0.22468	0.719344	30091.9	21646.4516	96343.47	120049	4.0
95-99 year	35373	0.35373	0.938612	8445.5	7927.0182	22409.8	23706	2.8
100 year and over			1	518.5	518.4507	1296.127	1296	2.5
				sum				

Input to life table:
Column B: mortality rates for women 2007, per 100000

computed
Column C: mortality rates for women 2007, per 1
Column D: probability of dying between ages x and x+5
Column E: number alive at age x in hypothetical population
Column F: numbers dying in age interval (x,x+5) in hypothetical population
Column G: years lived by hypothetical population in age interval (x,x+5)
Column H: years lived by hypothetical population from age x and beyond
Column I: remaining life expectancy at age x

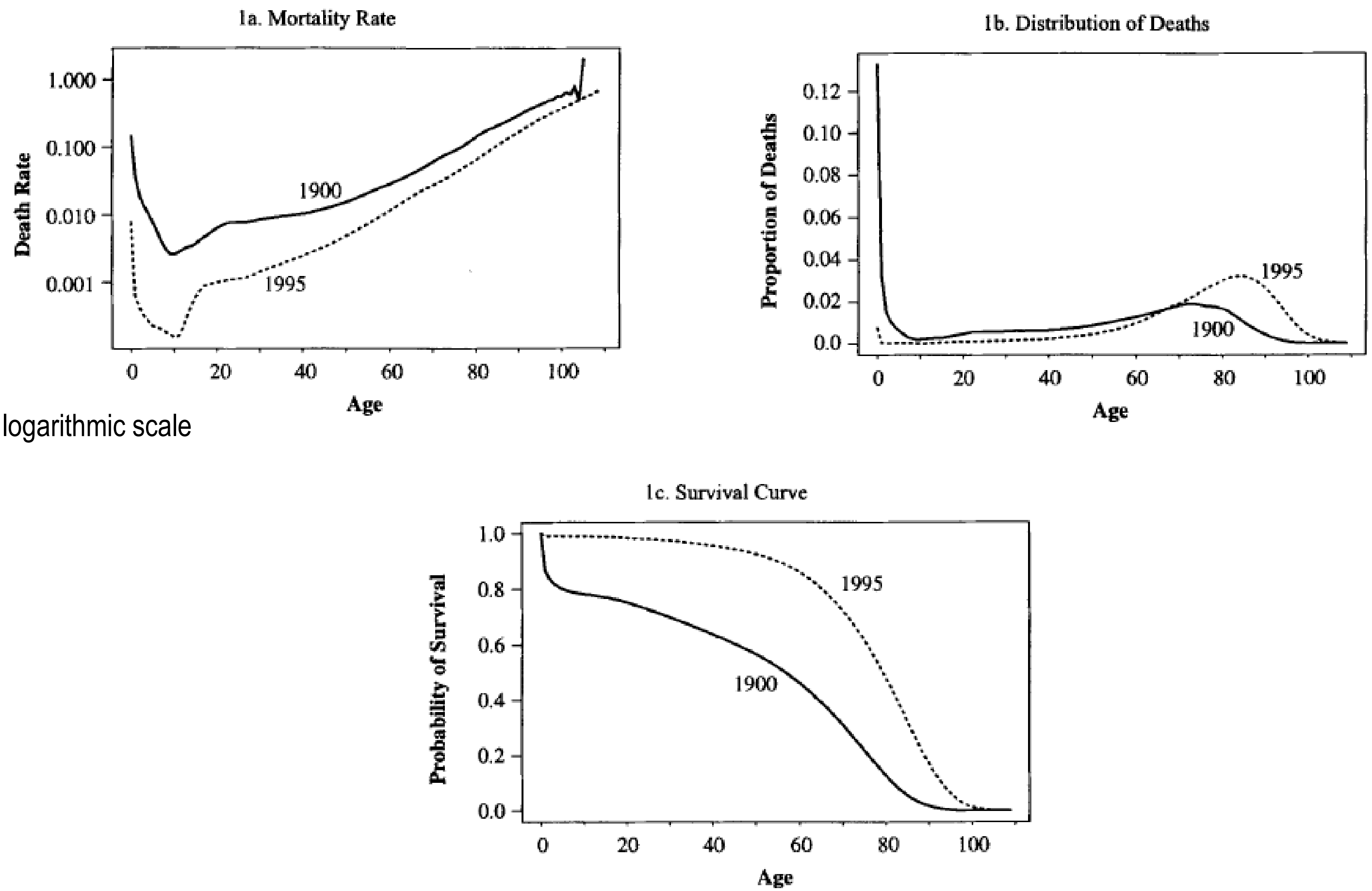
Death rate M = Number of deaths/Exposure time (which is number of person-years lived in the relevant period) – death rates differ strongly across ages

Approximation:
Exposure time between 0 and t = 0.5* (Population at 0 + Population at t) * t, which is called linear hypothesis (deaths spread evenly across the period).

Death probability $q = M/(1+0.5M)$ or, if the length of age interval is $t \neq 1$, $q = Mt/(1+0.5Mt)$ Here: $t = 5$

$_5L_x$ is exposure time from age x to age x+5.

FIGURE 1. COMPARISON OF THREE LIFE TABLE FUNCTIONS, U.S. WOMEN, 1900 AND 1995



Note logarithmic scale

Source: J. Wilmoth & S. Horiuchi, Demography 36(1999), 475-495.

Types of life tables

- Based on five-year age intervals (abridged life table) or one-year intervals (unabridged life table)

- Based on age specific death rates from one calendar year (or short period, for example five years) or death rates for a birth cohort → period life table vs. cohort life table

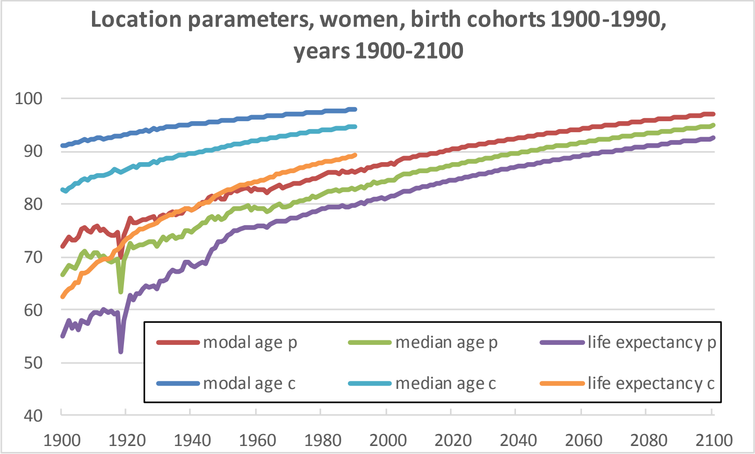
Period life table: death rates refer to mortality experience during only one calendar year, for persons born in many different birth years

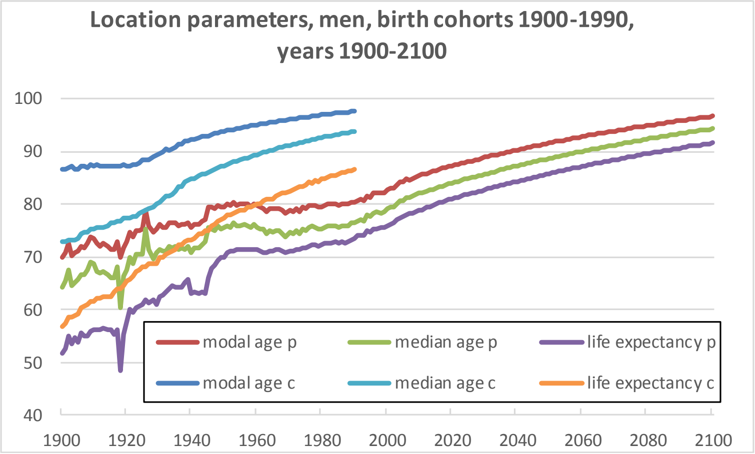
In reality, people do not behave that way: they are born in only one year, and they live their lives during many calendar years

Cohort life table: age specific death rates for persons born one particular year as they age (many different calendar years)

Cohort life tables may lead to different conclusions (about cohort life expectancy, cohort compression etc.) than period life tables (period life expectancy, period compression etc.) in times of changing mortality

Norway, empirical and projected data

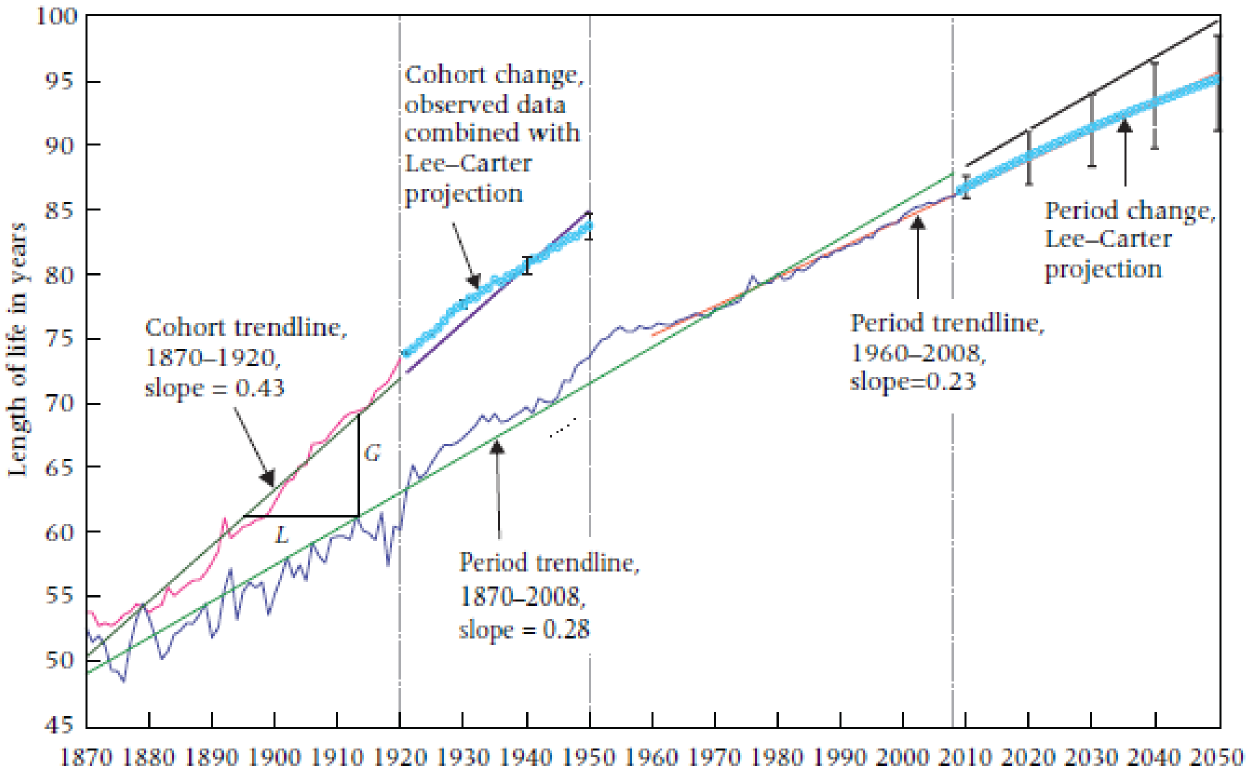




Cohort life expectancy of men increases faster than their period life expectancy

Best practice life expectancy = world record l.e.

FIGURE 1 Trends in best-practice period and cohort life expectancies since 1870, females



Note: cohort life expectancy increases by appr. 4 years per decade since 1870, much faster than period l.e. (2.5 yrs/decade)

Source: V. Shkolnikov et al., PopDevRev 37(2011), 419-434.

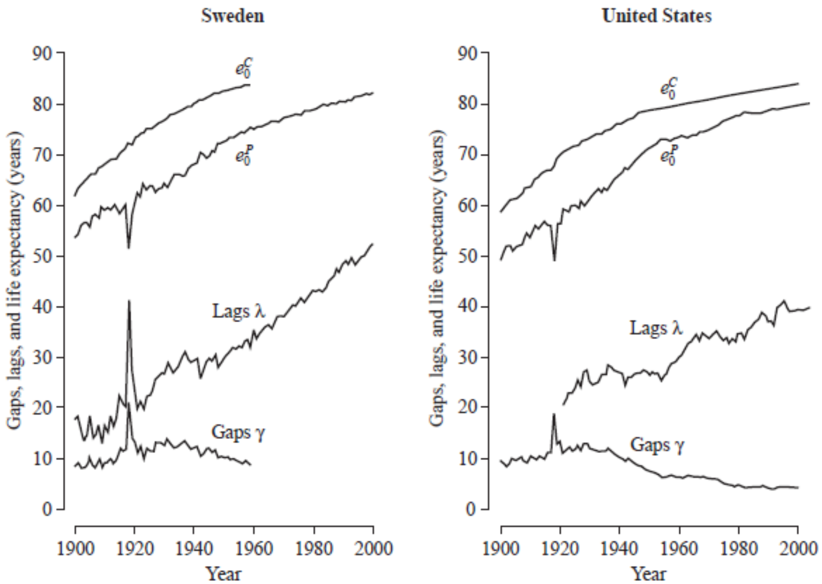


Figure 2 Observed and forecast cohort and period life expectancy of females at birth in Sweden and the USA and accompanying gaps and lags

Sources: US Social Security Administration available at Berkeley Mortality Database (www.demog.berkeley.edu/~bmd); Human Mortality Database (www.mortality.org); Statistics Sweden. Early Swedish lags are based on nineteenth-century e_0^C (not shown).

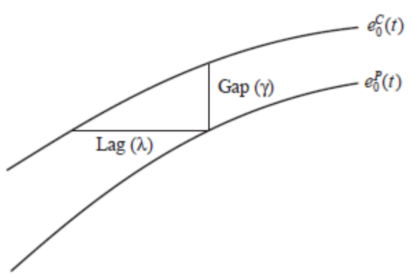
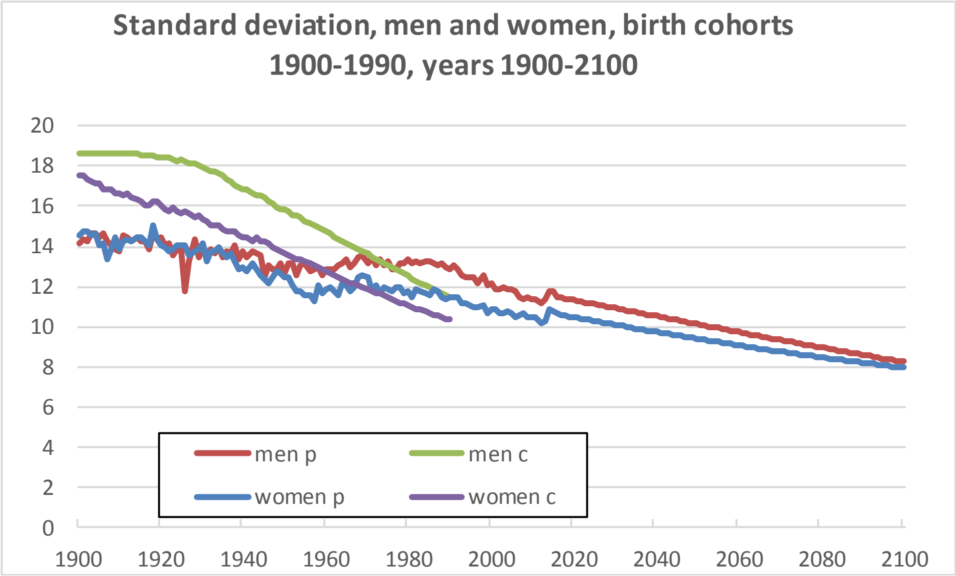


Figure 1 Sketch of gap (γ) and lag (λ) between cohort and period life expectancy when mortality and entropy are decreasing with time

Source: J. Goldstein & K. Wachter, PopStudies 60(2006), 257-269.



Cohort standard deviation falls more than twice as fast as period standard deviation

Try to avoid projections of age specific mortality

Problem: we need 100 years of data for one cohort

One way of avoiding that is to inspect “partial” life expectancy (also called “truncated l.e.)

Number of years lived up to a certain age (f. ex. 50, 60, 70, 80 …).

Area under survival curve between ages x = 0 and age x = 50 (or 60, 70, …)

When there is no mortality, the partial life expectancy up to age 50 ($e_{0|50}$) is 50 years.

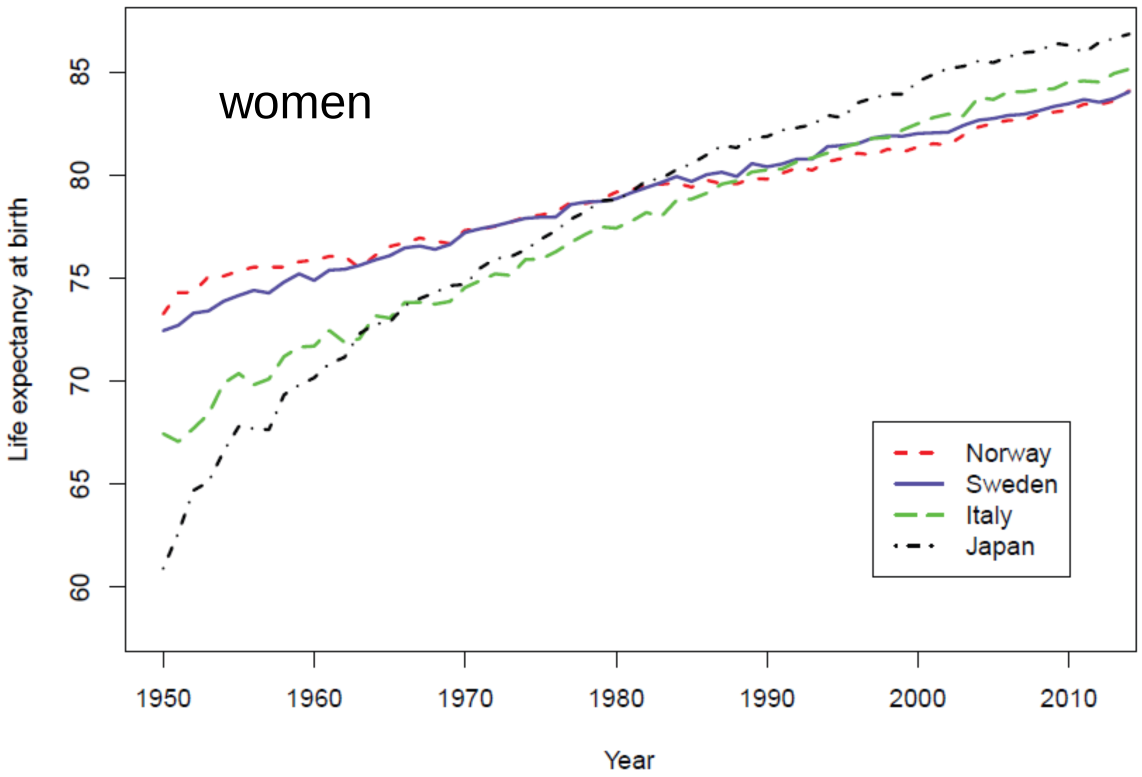
No lives go lost

With actual mortality, $e_{0|50}$ is (slightly) lower than 50.

Difference between 50 and $e_{0|50}$ is expected number of years lost up to age 50.

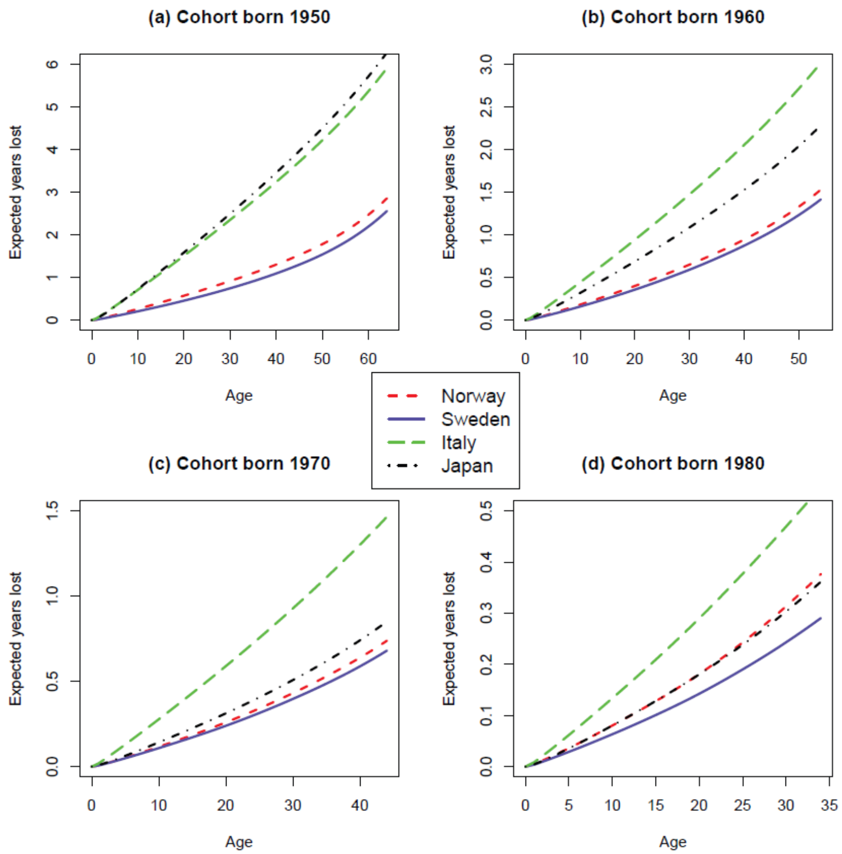
YL(50) = 50 - $e_{0|50}$, or, for a general age *a*: YL(*a*) = *a* - $e_{0|a}$

Advantage: we need data for only 50 (or *a*) years to compute YL(50) (or YL(*a*)) for cohorts

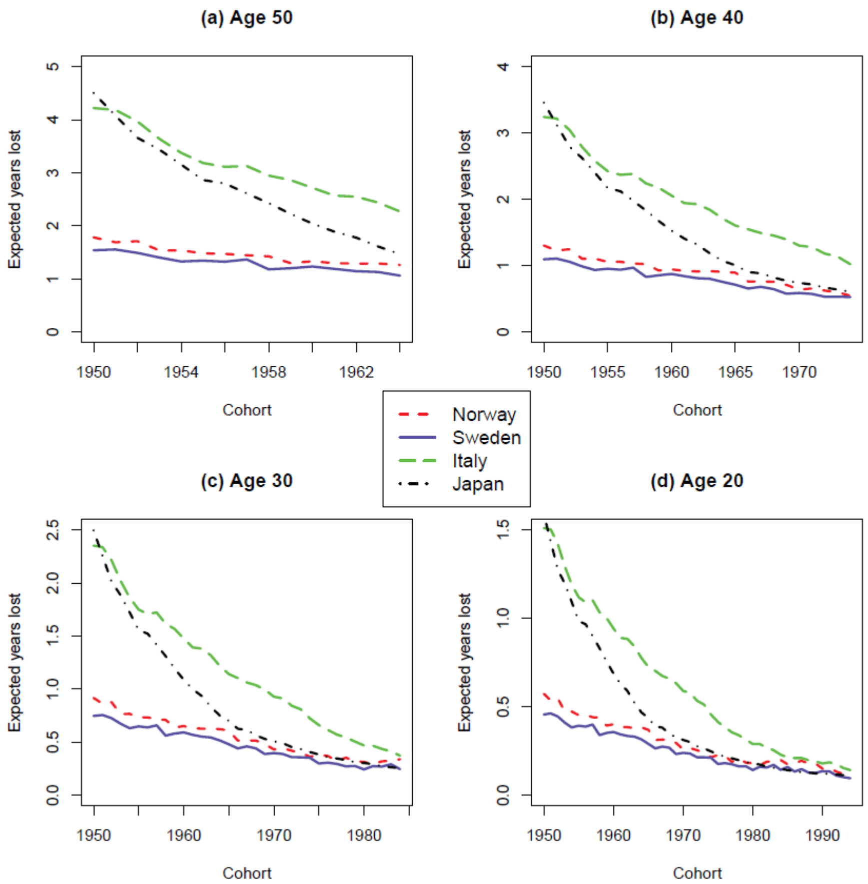


Period data suggest that since 1980-1990, women in Italy and Japan live longer than women in Norway and Sweden

Expected number of years lost, birth cohorts 1950, 1960, 1970, 1980 Women in Norway, Sweden, Italy, Japan (note: different scales)



Expected number of years lost, up to age 50, 40, 30, 20
Women in Norway, Sweden, Italy, Japan (note: different scales)



Cohort data show that Italian women born in 1950 or later have lost more years of life than Norwegian or Swedish women did. Likewise for Japanese women born 1950-1965

The cohort results provide no indication that Italian and Japanese women may expect to live longer than Norwegian and Swedish women.

Large differences in longevity seen for period data seem to be an artefact due to the distortion that period life tables imply in times of changing mortality

Conclusion: period life tables may give a distorted picture of trends in age-specific mortality in times of changing mortality

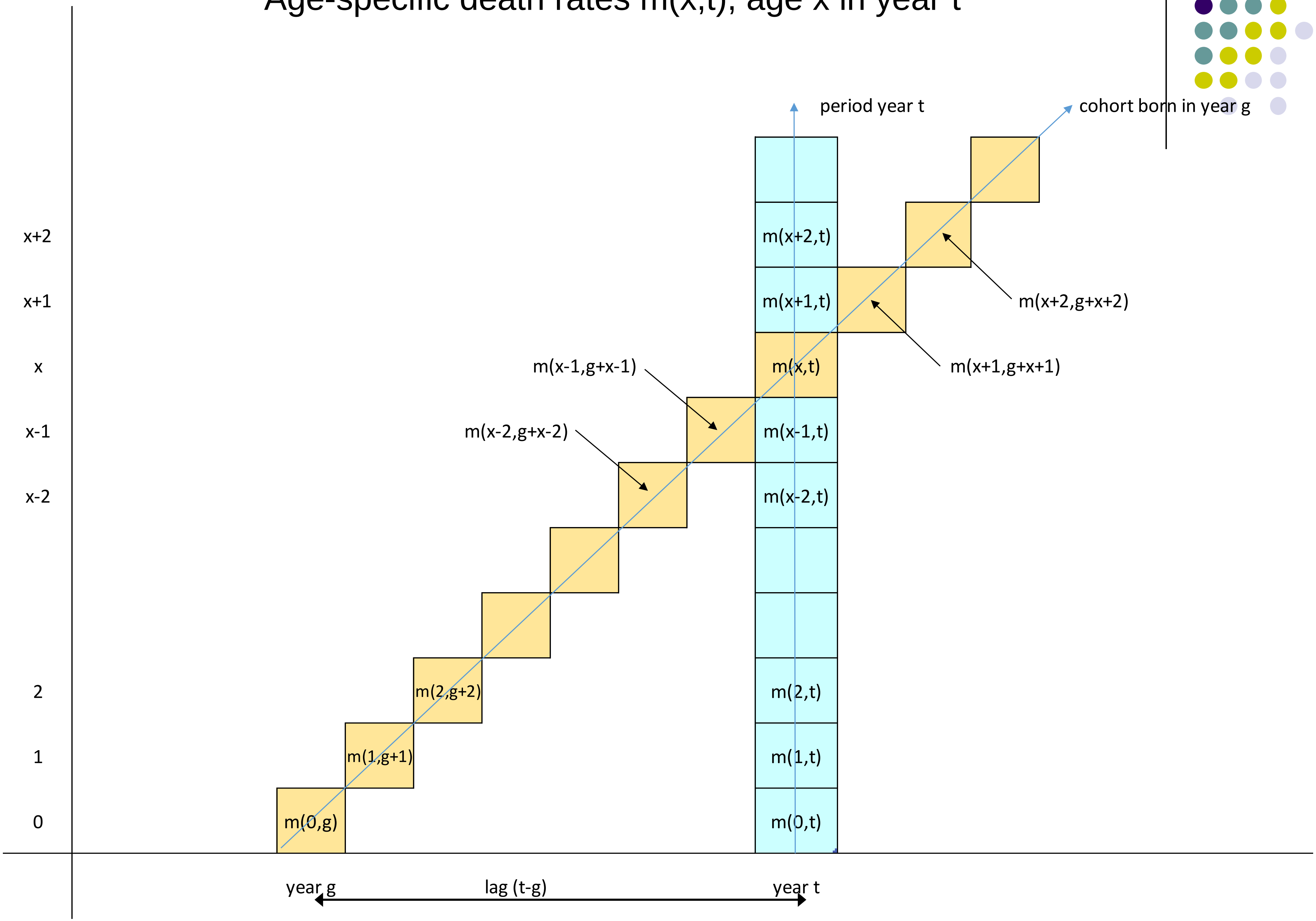
Western countries: life expectancies increase faster than period life tables suggest

Norway: compression goes faster than period life tables suggest

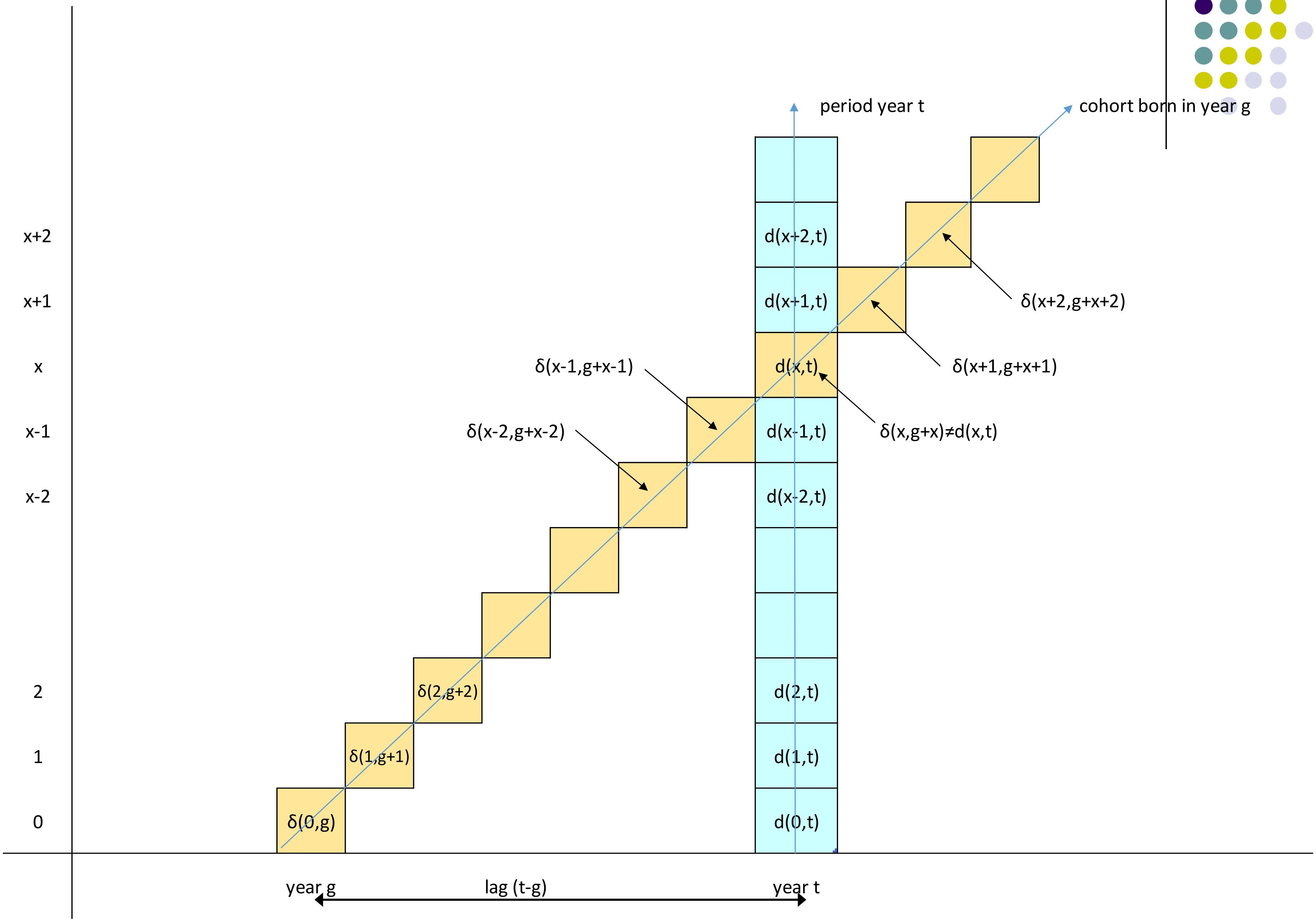
Why?

When mortality changes over time: d_x-column in period life tables (and hence period life expectancy) may be very different from d_x-column in cohort life tables (cohort l.e.)

Age-specific death rates m(x,t), age x in year t



Age at death distributions: d(x,t) for periods - δ(x,g+x) for cohorts



Thus it is the *changing age pattern* of mortality (d_x-column for period life tables, δ_x-column for cohort life tables) which causes the differences

Example: Denmark (Lindahl-Jacobsen et al. PNAS 113(15) April 12, 2016)

period life expectancies of men and women stagnated between 1970 and 1990

Caused by different age patterns of mortality in cohorts born 1915-1945, compared to earlier and later cohorts.

Stagnation disappears when Danish women born 1945-1945 are assumed to have the same survival probabilities as Swedish or Norwegian women born those years. See green curves.

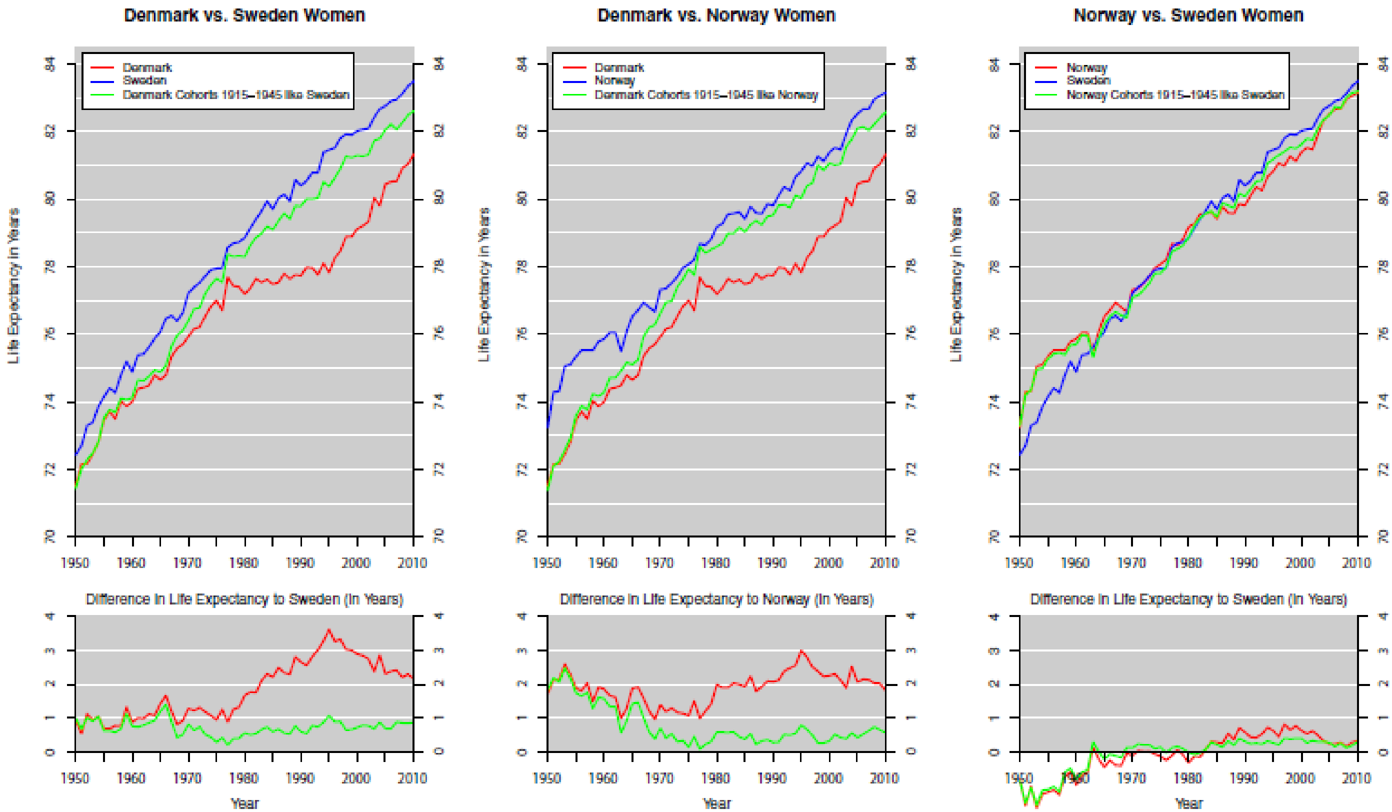
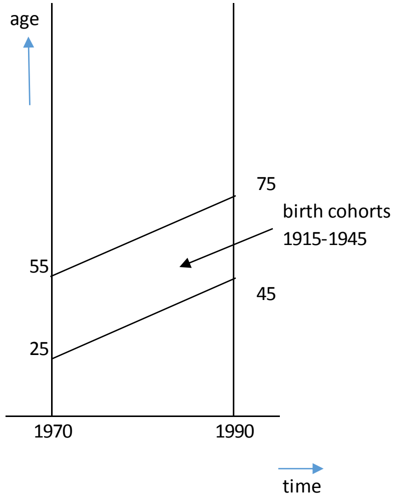


Fig. 1. Trends and differences in life expectancy for Danish, Norwegian, and Swedish women since 1950 and hypothetic life expectancy of Danish and Norwegian women when assuming survival probabilities of Danish and Norwegian women born 1915–1945 equal those of Swedish women born 1915–1945.

Many women born 1915-1945 were smokers. By 2000, they were aged 55-85, and many of them had died. These cohorts had little effect on period life expectancy from then on, which increased again.

Earlier cohorts had not started smoking as much as 1915-1945 cohorts.

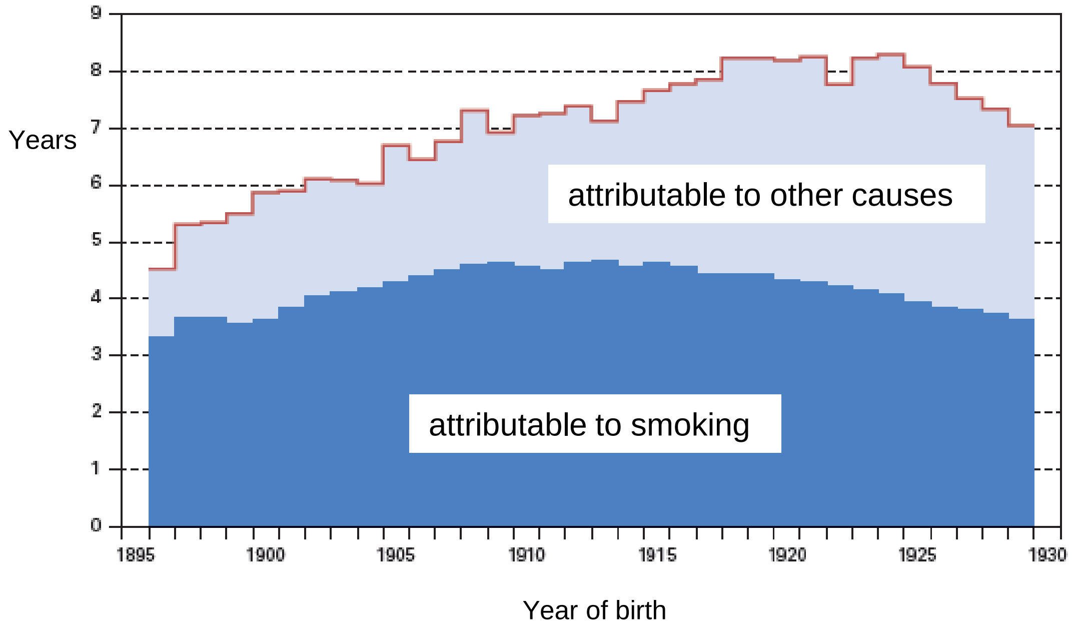
Later cohorts reduced smoking progressively.



Additional evidence: excess mortality of Dutch men born 1895-1930

(Janssen & Van Poppel Demos 32(6)2016; Biomed Research International 2015)

Difference in life expectancy between women and men (women minus men, red line) and part of difference attributable to smoking, birth cohorts 1895-1930, the Netherlands



Excess mortality of men for a large part caused by smoking: at least 50%, up to 70% in cohorts 1895-1906

Men started smoking after WWI. Those born 1890-1925 started smoking at young ages.

Women started smoking much later – later cohorts, and at later ages.

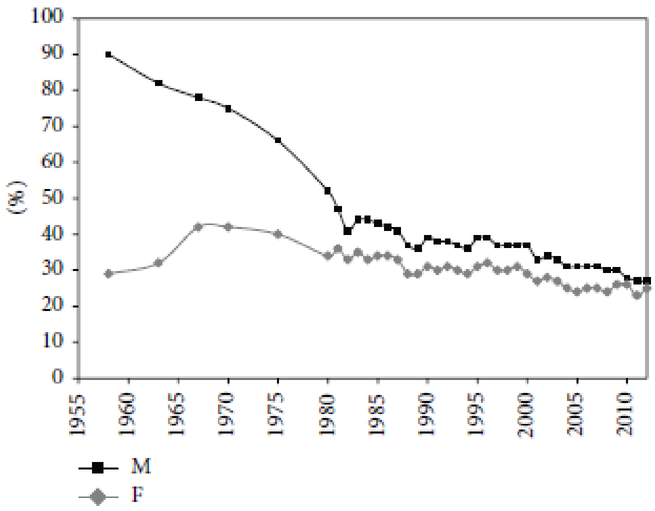
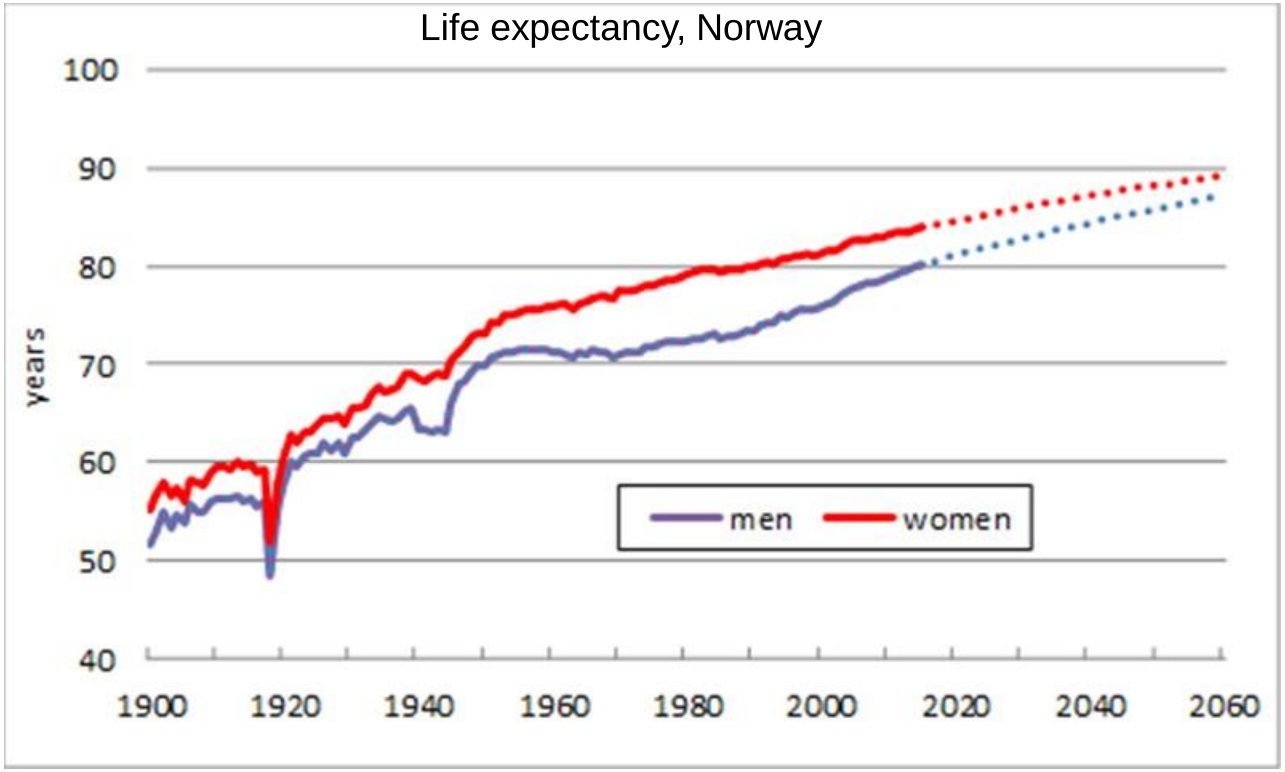


FIGURE 1: Smoking prevalence (15+) by sex, Netherlands, 1958–2012. Source data: Stivoro (2013) [24]; M = males; F = females.

Hypothesis: similar effects for Norwegian men during 1950s and 1960s
Cohorts born 1900-1920 unhealthy life style: smoking, inactivity, eating habits
→ cancer, cardiovascular diseases, respiratory diseases

Cohort effect to be confirmed empirically



Main message

Period life tables may give a distorted picture of trends in age-specific mortality in times of changing mortality

→ Inspect cohort patterns (provided data available)

Western countries: life expectancies increase faster than period life tables suggest

Norway: compression goes faster than period life tables suggest