Actuaries

Risk is Opportunity.℠

Are We Approaching the Upper Bounds of Human Life Span?

Jack C. Yue
National Chengchi University
2016/05/19

SOCIETY OF ACTUARIES

Summary

Actuaries
Risk is Opportunity.℠

Motivation

↓

Proposed Approach

↓

Simulation Study

↓

Applications

↓

Discussions

Actuaries
Risk is Opportunity.℠

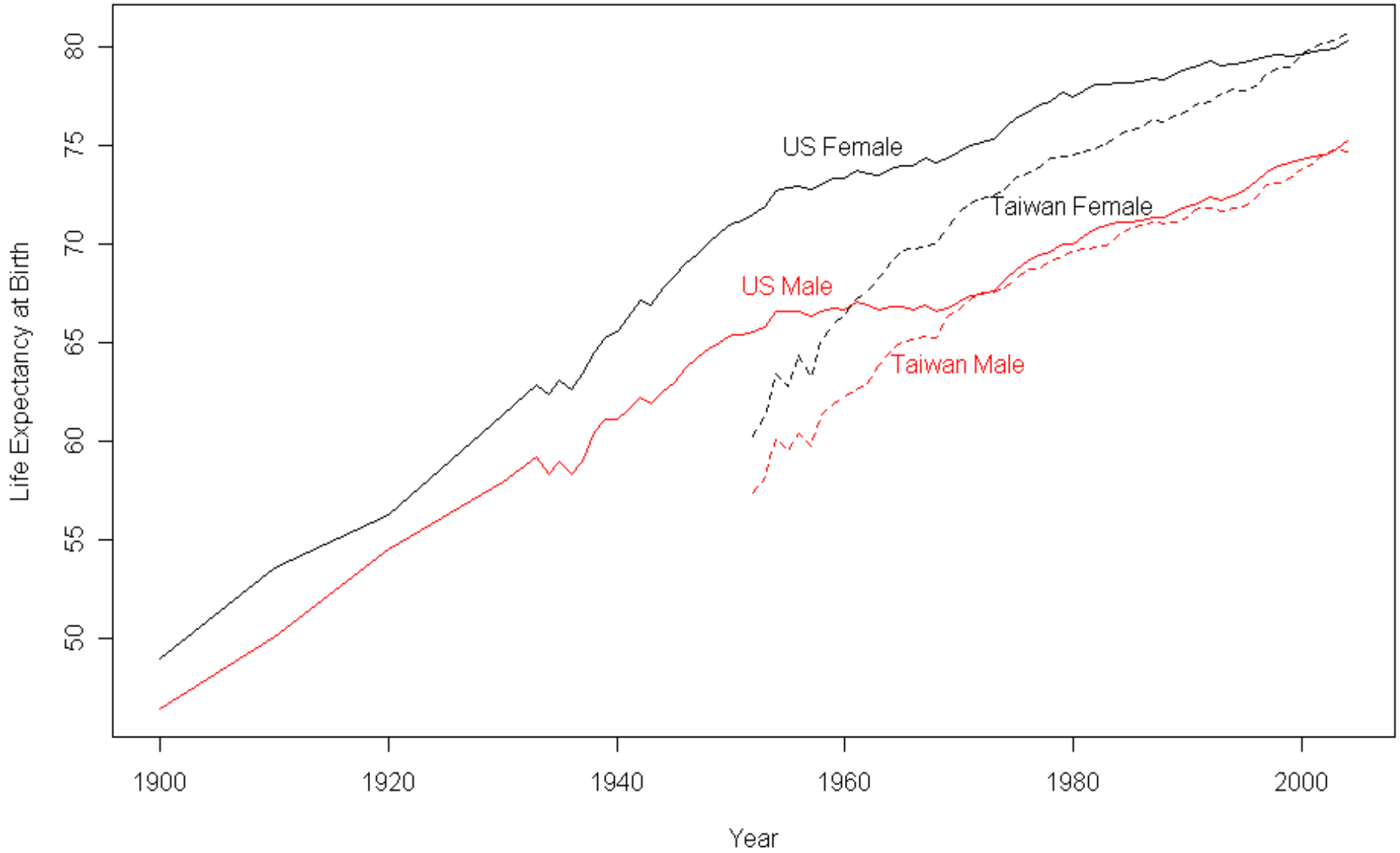
Prolonging Life Expectancy

- The average life-span has being experienced a significant increase since turning to the 20th century.

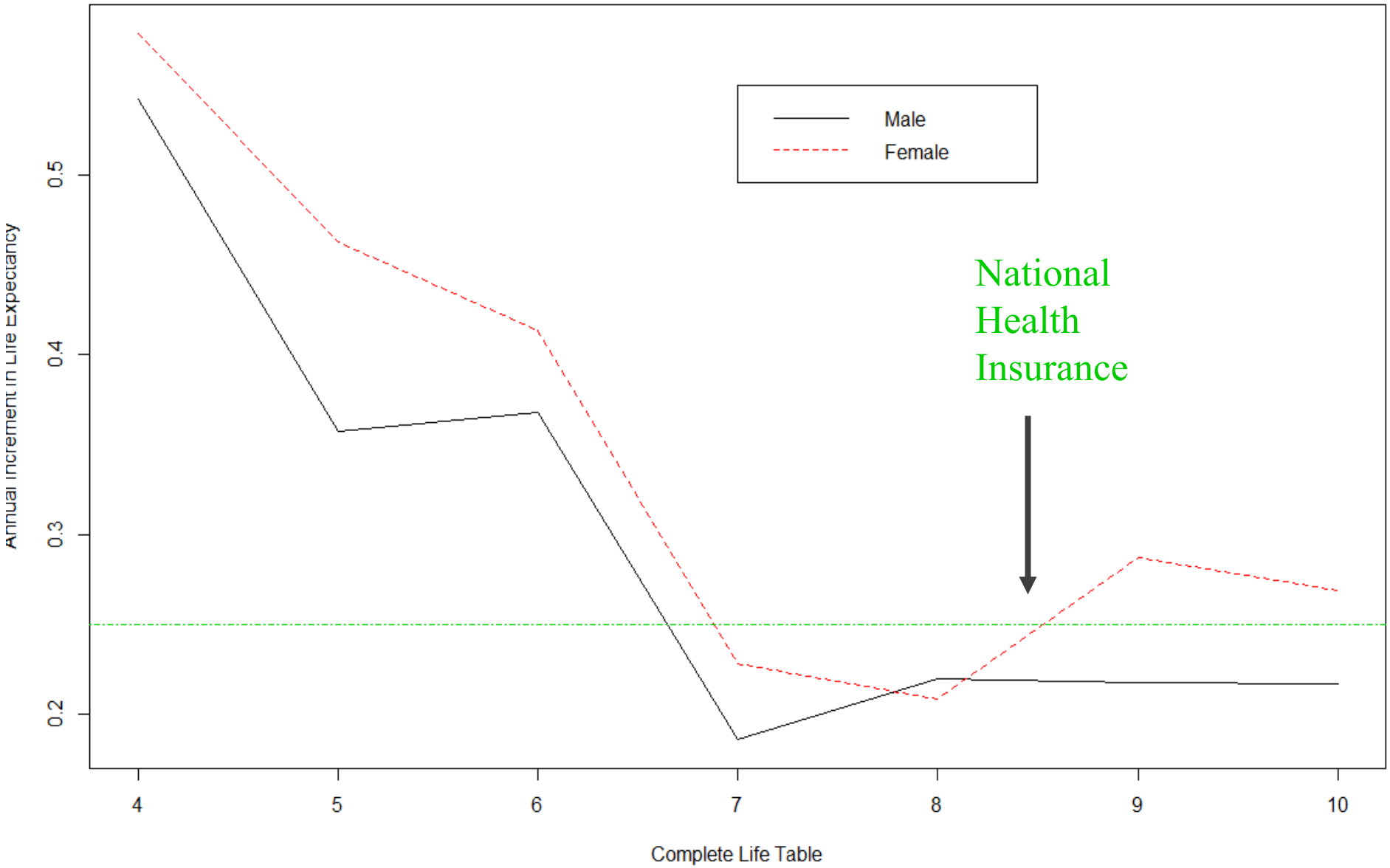
→For example, the life expectancies of U.S. male and female were at the upper 40's in 1900's and reached upper 70's in 2000's.

→The life expectancies of Taiwan male and female have similar increasing trend.

The Life Expectancy of U.S. and Taiwan



Increments of Life Expectancy (Taiwan Complete Life)

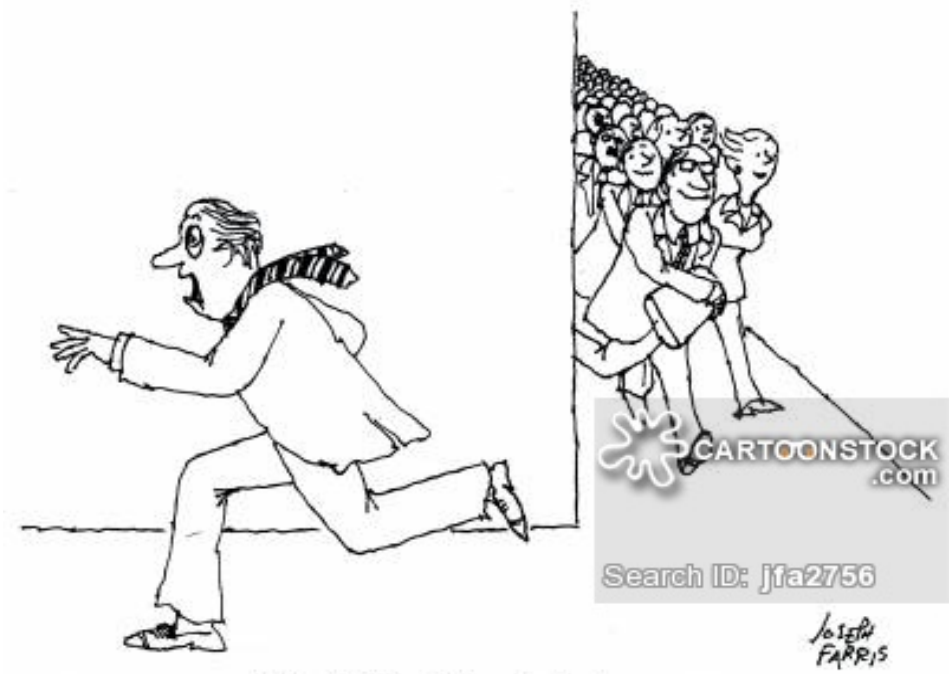


Increments in Life Expectancy

- The life expectancy in U.S. has an increment of 0.3 year annually during the 20th century. The trend in Taiwan is similar but it seems that the slope is steeper.

→According to U.N., the world has an annual increment of 0.25 year, during the second half of 20th century. The trend is likely to continue, at least for a while.

"We're launching a campaign to get people to take up smoking again!"



"Run! 73 million baby boomers are about to retire!"

Impacts of Prolonging Life

Actuaries
Risk is Opportunity.℠

- We are experiencing the longest life ever in the history, and this has changed our lives.

→The life expectancies at age 65 were 12.20 and 14.63 years for Taiwan male and female in 1974, increased to 17.91 and 21.33 years in 2014. It increases about 50% more financial burden for retirement preparation.

→Taiwan started national pension in 2008, in addition to other social insurance programs.

Soon they may live for 200 years

THE day may come when people will celebrate the start of middle age on their 100th birthday. Some of the world's most eminent experts on ageing have predicted that average life expectancy in the developed world could rise to 200 years by the end of the century.

From the end of the 19th century to the present day, the average life span has almost doubled. In new research some scientists predict a jump of even greater proportions over the next 100 years, thanks to advances in genetic medicine.

Out of 60 experts on ageing who were asked to predict life expectancy for a baby born in 2100, more than half believed it would be more than 100 years. Seven who were interviewed in the research project for the Journal of Anti-Aging Medicine believed it could be between 150 and 200.

If such a change were to happen, it would mean a world dominated by the over-100s and a radical increase in the retirement age.

In the past century, increases in life expectancy were a result of cleaner living conditions and

Roger Dobson and Nina Goswami

the defeat or control of mass infectious diseases, such as smallpox and tuberculosis. Over the next century, scientists say genetic advances will push the average life span significantly higher.

Michael Fossel, clinical professor of medicine at Michigan State University, was among the experts who thought life expectancy could rise to 200 years or more. He said: "People haven't realised it, but we are in a similar position to the 1870s with regard to stopping the spread of infectious diseases.

"As you get older, your cells slowly stop repairing themselves. I think we are going to be able to reverse that process and, through genetic intervention, will be able to tell the cells to repair themselves."

Other experts interviewed for the study agreed that dramatic advances in genetic research may unlock the secrets to long life in this century. Elizabeth Blackburn, professor of biochemistry at the University of California San Francisco, said life expectancy could reach 175 years in 2100.

She said: "In experiments in small animals, when some genes are mutated away from their natural form, they can increase life span twofold. We don't yet have an easy picture of how this might work in humans, but it's theoretically possible. We know there is a genetic component [affecting ageing] but don't yet know whether it will be a few genes or a large number."

The sequencing of the human genetic code — or genome — is the main reason for the predictions of such dramatic increases in average life spans. The breakthrough was made four years ago by two parallel projects to map human DNA: a private-sector venture led by American scientist Dr Craig Venter and the international state-funded human genome project, in which the Sanger Centre in Cambridge played a leading role.

The code offers huge potential in the battle against ageing and research has already shown that transplanted aged skin cells can be rejuvenated by manipulation of DNA. Other scientists are less convinced, however, believing the human body has a fixed limit on life span that it will not be possible to breach.

To date, though, there is no evidence of life expectancy levelling off. A male born in England in the 1850s had a life expectancy of just over 40 years while a female had a life expectancy of 42. By 2000, a man's life expectancy was 76 years and a woman's 80. The increase is expected to continue over the next few decades.

Professor Tom Kirkwood, head of biogerontology at Newcastle University's Institute for Ageing and Health, said many in the scientific community had been surprised that life expectancy is still rising.

He said: "Most people would have predicted that, with the removal of most causes of premature death through infectious disease, life expectancy would start to reach a plateau. What has taken people by surprise is that over the past 25 years we have seen expectancy increase, which tells us the ageing process is undergoing change."

Kirkwood believes most of the gains in life expectancy have already been made and that there is little prospect of a genetic breakthrough this century that will reverse ageing. He estimates life expectancy will be 90 by the year 2100.

He said: "Living for 200 years is unrealistic. To do that we would have to wipe out things like cancer, heart disease and other major health problems. Despite the billions being spent on these areas, that type of eradication of disease is frustratingly slow."

It is not just genetic advances that may boost longevity. Research on animals has shown that reducing calorie intake can increase life span by 30%.

Scientists are now trying to develop a "magic bullet" that could simulate the effect of calorie restriction without people having to eat less. Research published last week suggested this could be done by a protein, Sirt1, which controls when cells store or release fat.

If there are dramatic increases in life expectancy, it is likely to mean an even greater burden on the health system and pensions. It will also mean one of the greatest social upheavals in history.

The world's population aged 60 and over was about 600m in 2000, compared with about 200m in 1950. By 2050, the numbers are likely to have tripled to 2 billion.

In a report last year, the Center for Strategic and International Studies, a US think tank, warned that "countries will have to race against time to insure their economic and social fabric against the shock of global ageing".

Scientists such as Blackwood, however, are excited by the possibilities of a longer life. She said: "How many of us have wanted to do something else in our lives, such as be a novelist, but not had the time? So much human potential is untapped. Perhaps with longer lives, we could start to tap it."

Older, bolder and better
The Magazine, pages 28-36

The great leap

Life expectancy in England and Wales

Unlocking the secrets to long life

DNA
Scientists believe interventions in the ageing genes may be able to counteract the effects of old age

Nutrition
A significant reduction in calorie intake may be able to increase lifespan by up to 50%. Scientists are now trying to devise drugs that will mimic the effects of eating less

Beating disease
Human trials are already being conducted on cancer vaccines that stimulate the body to attack cancerous cells. In future decades, it may be possible to reverse heart disease by replacing diseased cells with healthy functioning ones

Stem cell research
Doctors last month announced that within the next decade people may be able to grow new teeth from stem cells implanted in their gums. As the method develops, faulty organs could be replaced or repaired as the body begins to deteriorate

Born 1875

The longest recorded lifespan for a human, Jeanne-Louise Calment, a Frenchwoman, was born on February 21, 1875 and died in 1997 at the age of 122 years and 164 days

Andorra in the Pyrenees has the highest life expectancy in the world, at 83 years. Mozambique has the lowest life expectancy in the world, at 31 years

Sunday Times 06/06/04

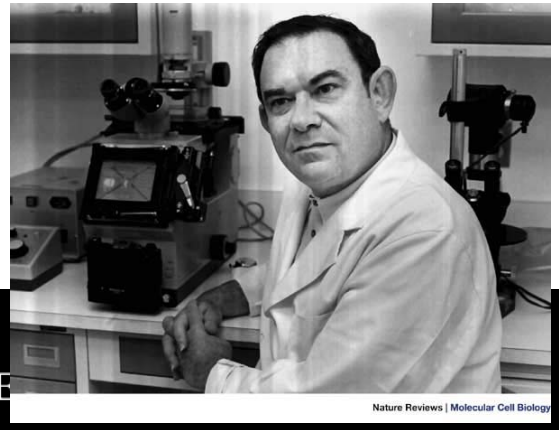
黑弗克極限(Hayflick Limit)

Actuaries
Risk is Opportunity.℠

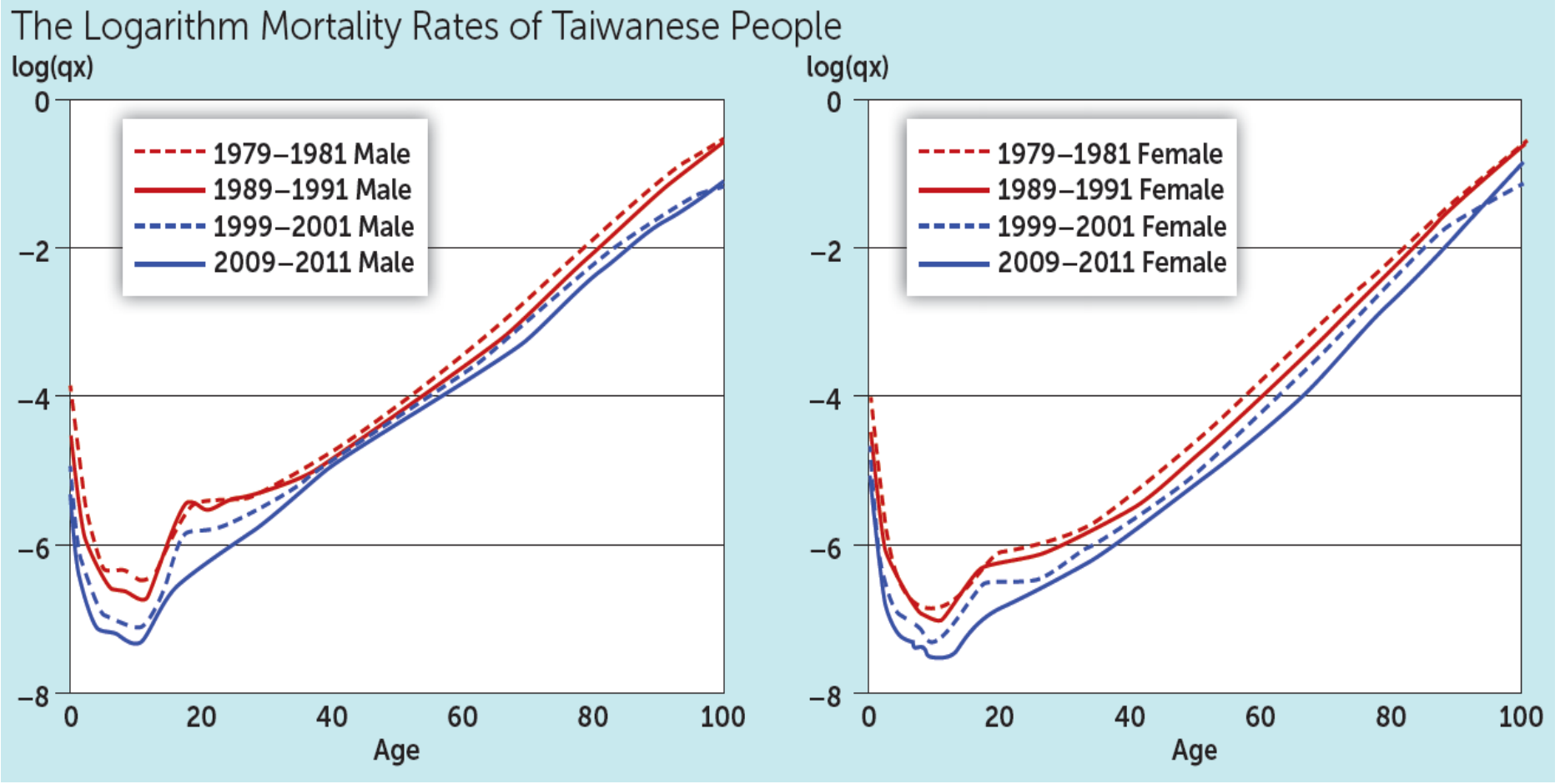
過去在學術界瀰漫著「正常脊椎動物的細胞，只要在最適宜的環境下進行培養，將永生不死」之概念。提出理論的諾貝爾獎得主卡爾(Carrel)，據說他主持的實驗室，成功地培養雞心臟的纖維母細胞長達34年。

然而，黑弗克在1960年前後的一連串實驗發現，他實驗室裡正常的人類纖維母細胞，在分裂了50多代之後，就停止複製、而凋零死亡。

來源：http://blog.roodo.com/thinkfly/archives/2254977.html



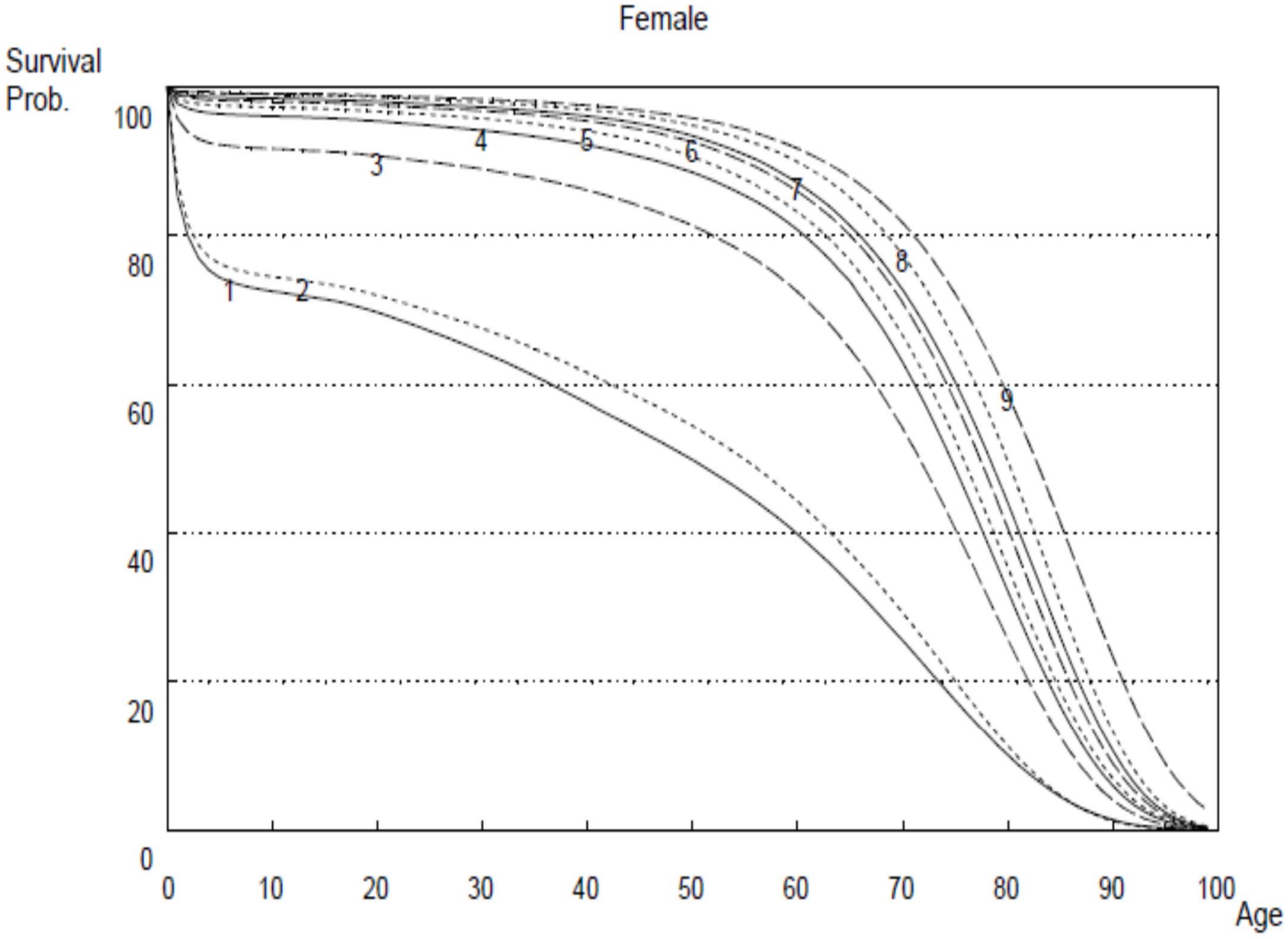
Mortality Improvement Continues……

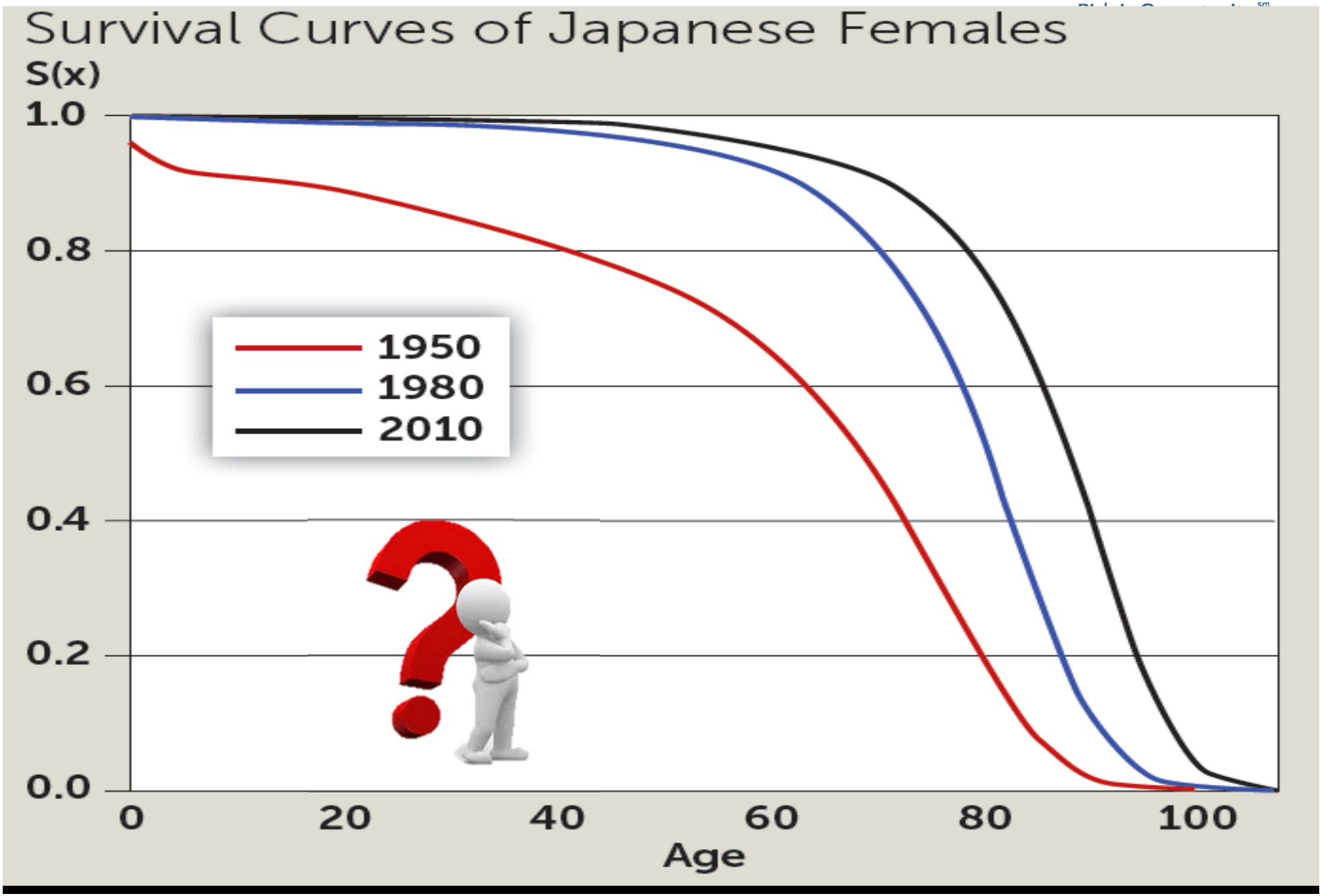


Mortality Compression?

Ages of Death Probability for Taiwanese Females

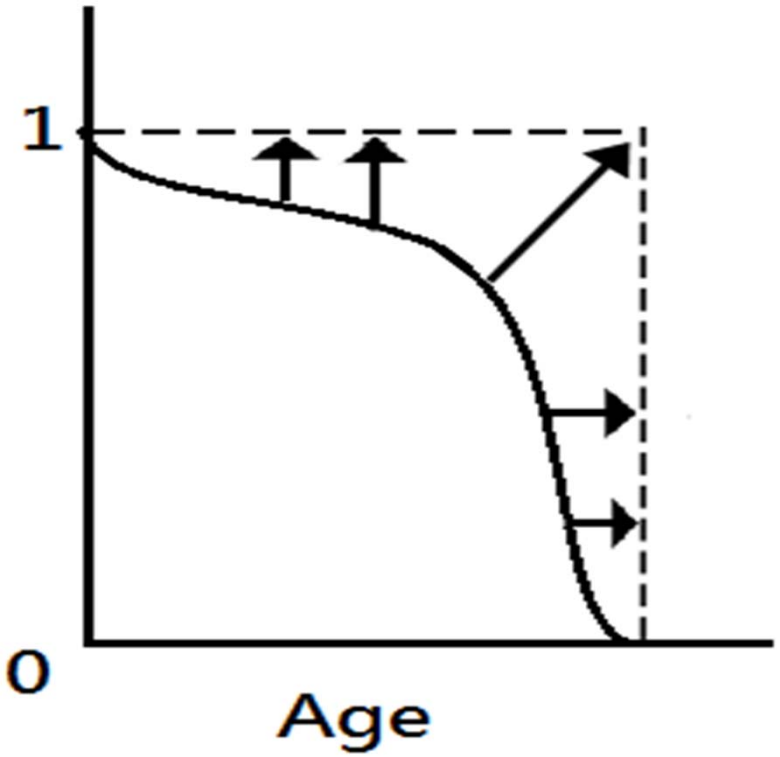
	25%	50%	75%	90%	95%
1979-1981	69	79	86	91	93
1989-1991	72	80	87	92	94
1999-2001	74	83	90	95	98
2009-2011	78	86	92	97	99


Female
Survival
Prob.
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Age
1
2
3
4
5
6
7
8
9

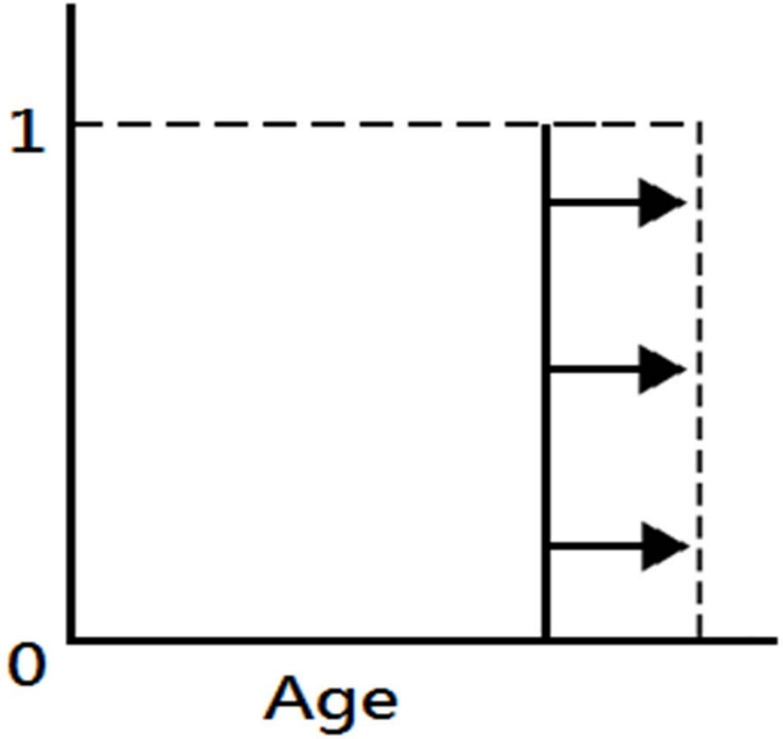

Survival Curves of Japanese Females
S(x)
1.0
0.8
0.6
0.4
0.2
0.0
1950
1980
2010
0
20
40
60
80
100
Age

About the Human Longevity

- Life with a limit!



- Life without a limit!



Work Supporting "No Limit"

- Oeppen and Vaupel (2002) predicted a life expectancy of 100 in 2060 in U.S.
- Wilmoth and Robine (2003) found maximum recorded life span has been steadily increasing at least for 140 years in Sweden.
- Robine and Vaupel (2002) reported that a probability of dying at age 110 of 0.52 based on the International Database on Longevity.

Work Supporting "Limit"

- Olshansky et al. (1990) consider that attaining a figure of 100 in 2060 is implausible.
- Decline in the death rate from the major cardiovascular diseases.
- The death rate from cancer increased 24% between 1970 and 2000 (US NCHs, 2004).

Rectangularization and Lifespan

- Regarding the theory of lifespan, there are two opinions: life with or without a limit.

→The rectangularization is a consensus.

→Premature deaths (including infants) will gradually decrease and some postulates that the distribution of death number will behave like a normal curve.

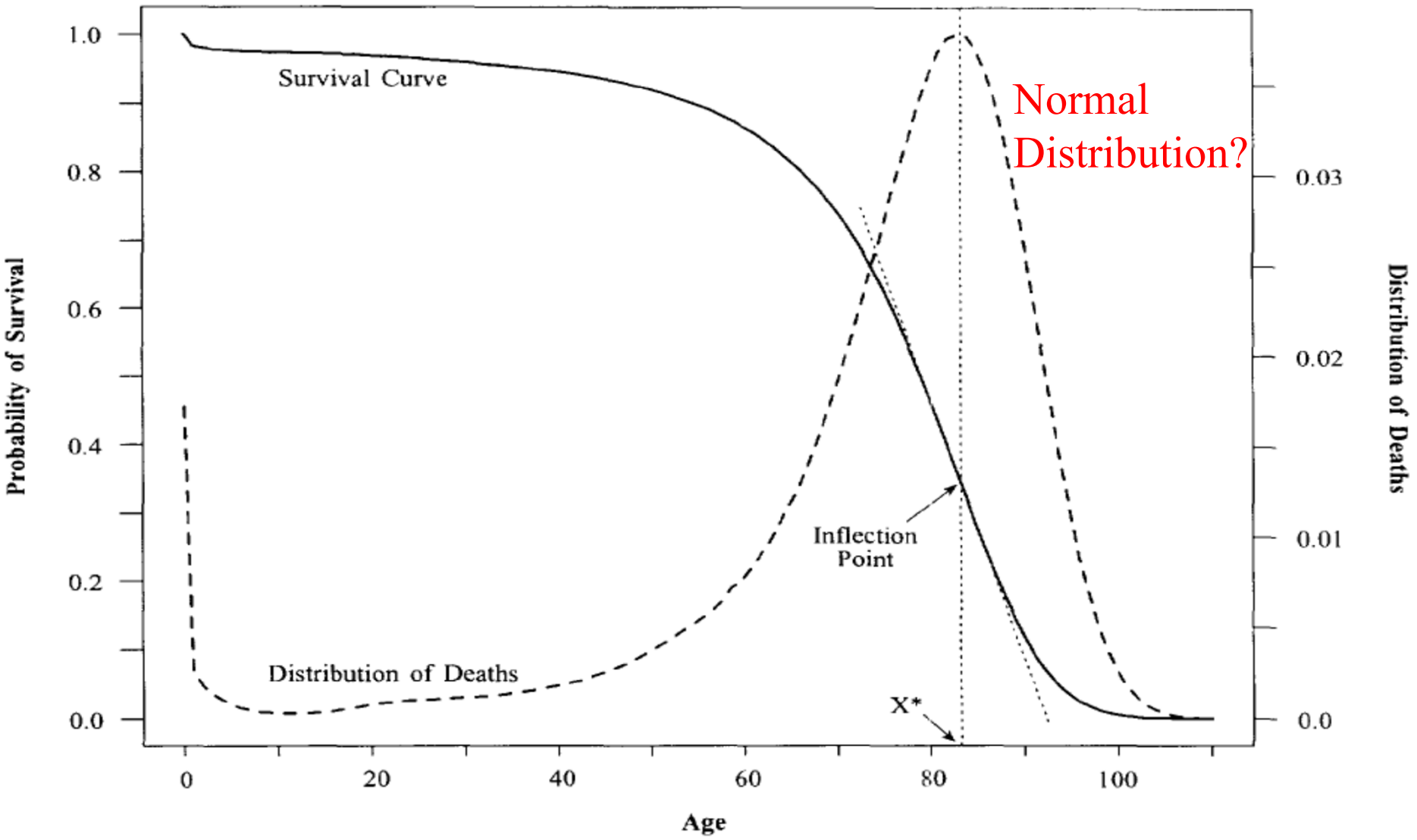
What is Mortality Compression?

- Mortality Compression is (Fries, 1980)

→ Rectangularization of the survival curve

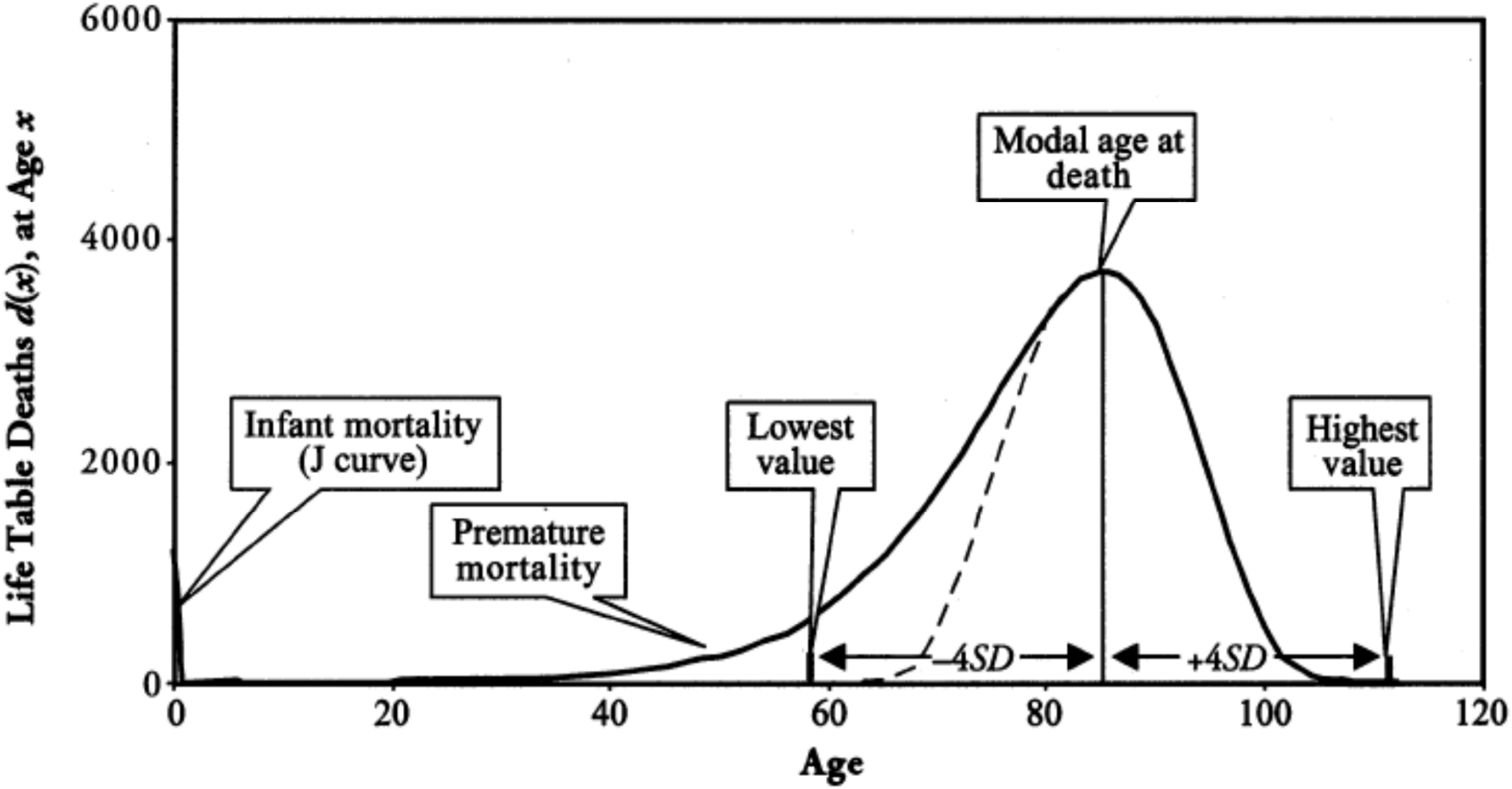
→ A state in which mortality from exogenous causes is eliminated and the remaining variability in the age at death is caused by genetic factors.

- Mortality compression is linked with morbidity compression.



Mortality Compression (Wilmoth and Horiuchi, 1999)

Horizontalization, Longevity Extension, Verticalization



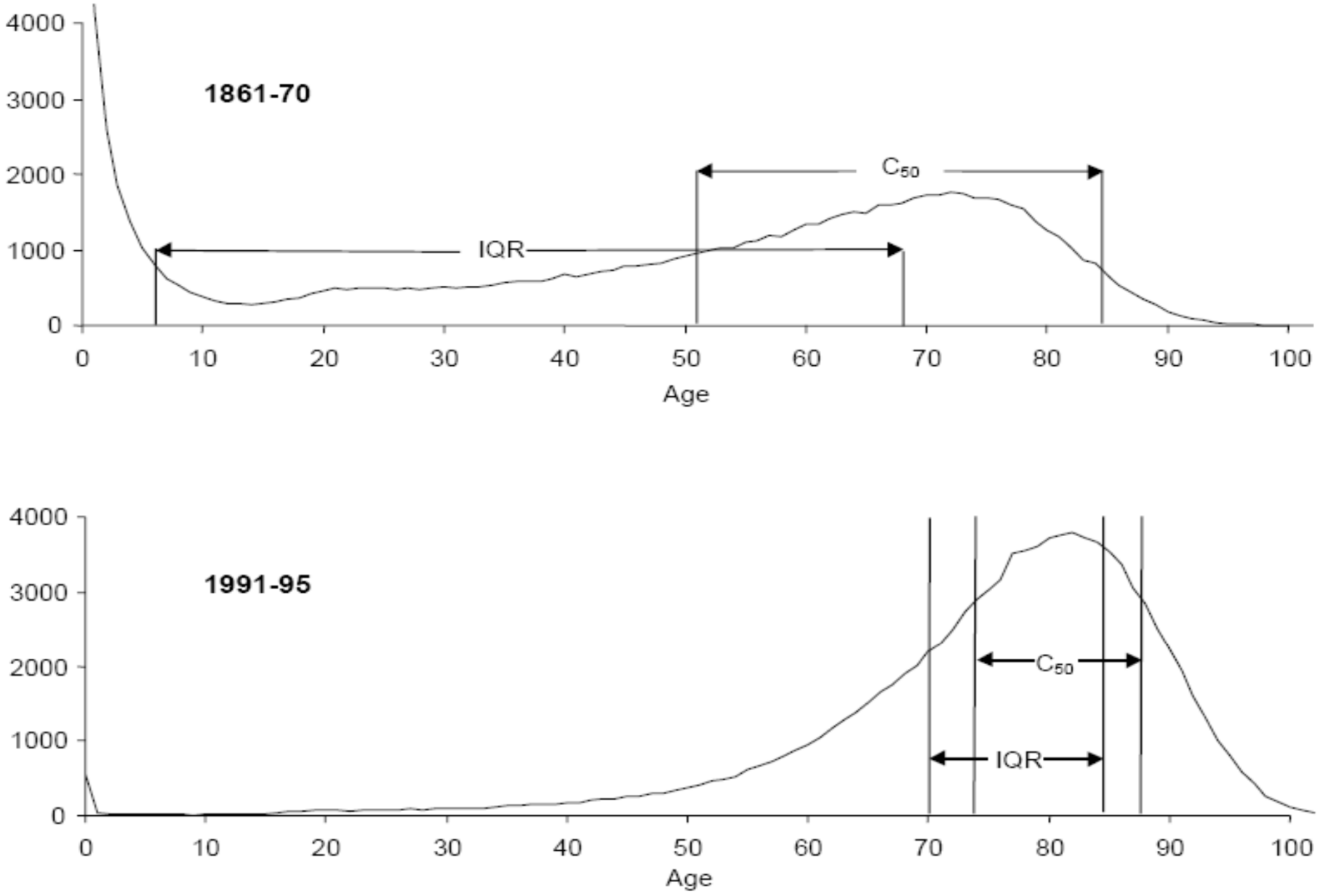
Mortality Compression (Cheung et al., 2005)

Measuring Compression

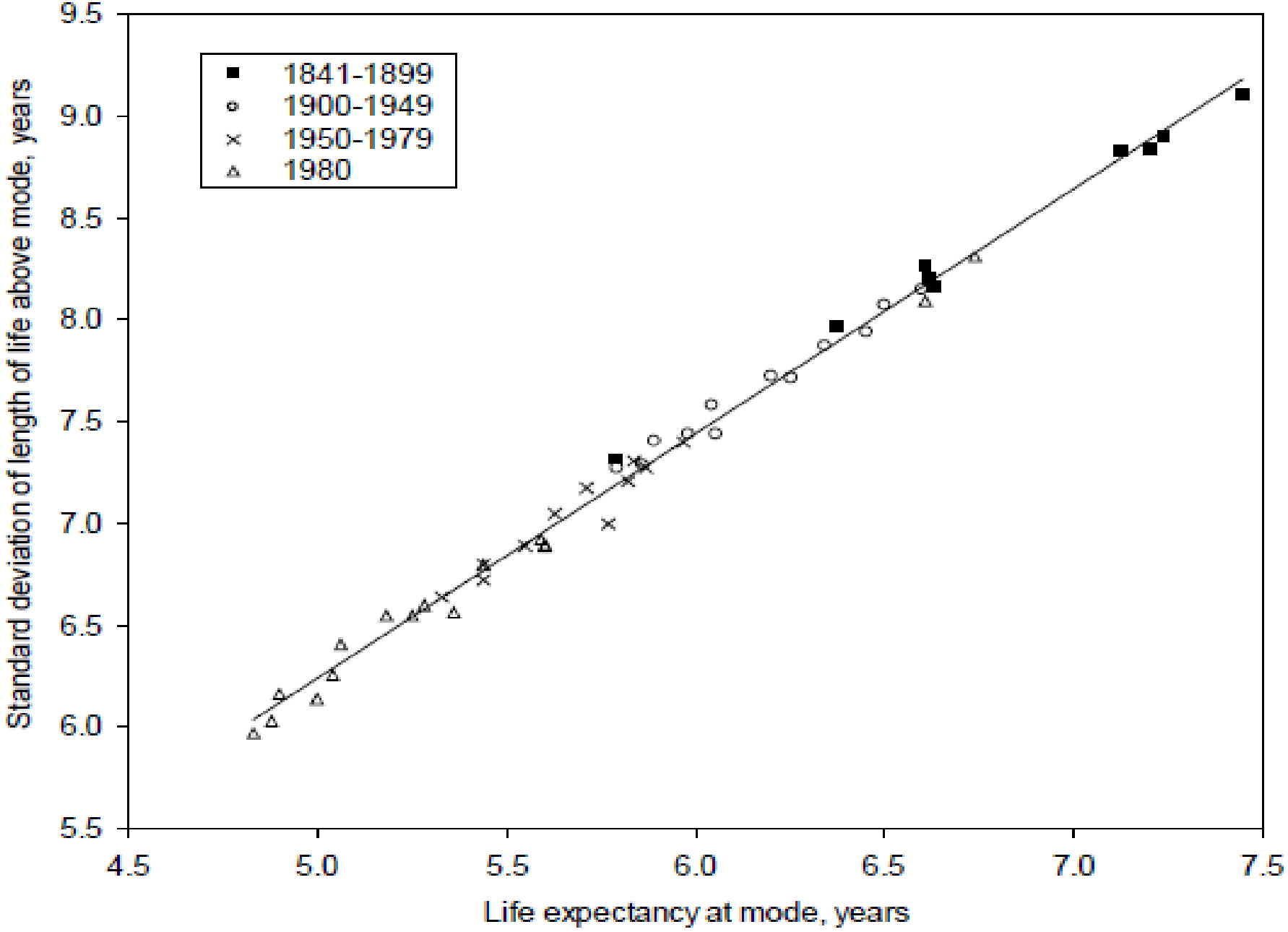
- Wilmoth and Horiuchi (1999) proposed 10 measurements and they recommended the Interquartile (IQR).
- Kannisto (2000, 2001) calculated percentiles, IQR, shortest age interval (e.g., C50) on numbers of deaths from 22 countries.
- Cheung et al. (2005) computed SD(M+) for Hong Kong data.
- Thatcher et al. (2010) computed SD(M+) for 6 countries from HMD.

Distribution of deaths by age. IQR and C50. Sweden, Male, 1861-70 and 1991-95.

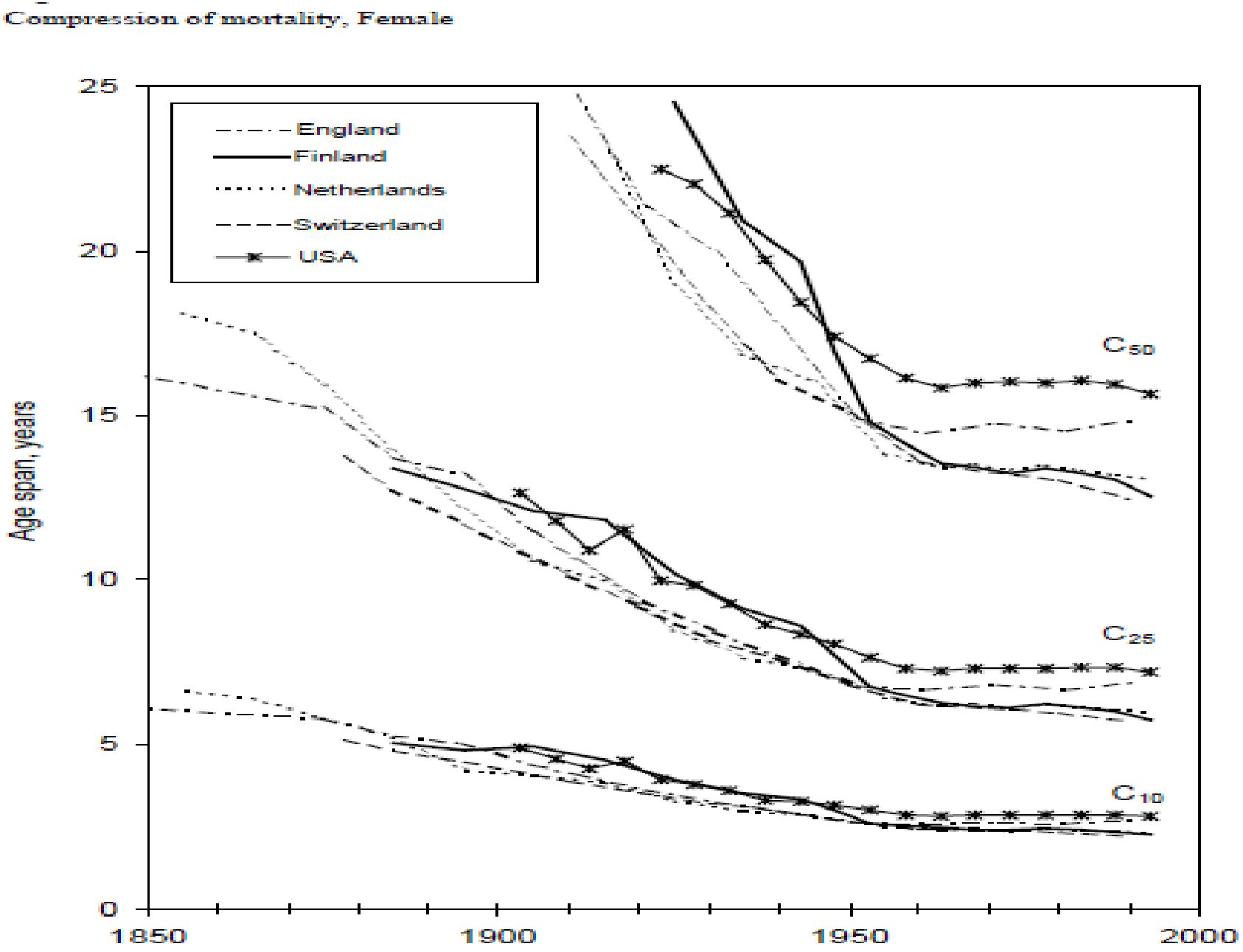
Age of Death is converging!(Sweden Male)



Mode and Standard Deviations (Kannisto, 2000)



Shortest Age Intervals (Kannisto, 2000)



3D Measures (Hong Kong data)

- Cheung et al.(2005) proposed 3-D measures, Horizontalization, Verticalization, and Longevity Extension.

→They applied the idea to complete life tables in Hong Kong (1976-2001) and found "the increase in human longevity is meeting some resistance."

Note: The mortality rates of ages 85 to 120 were graduated using logistic curve.

3 Dimensions of Survival Curve

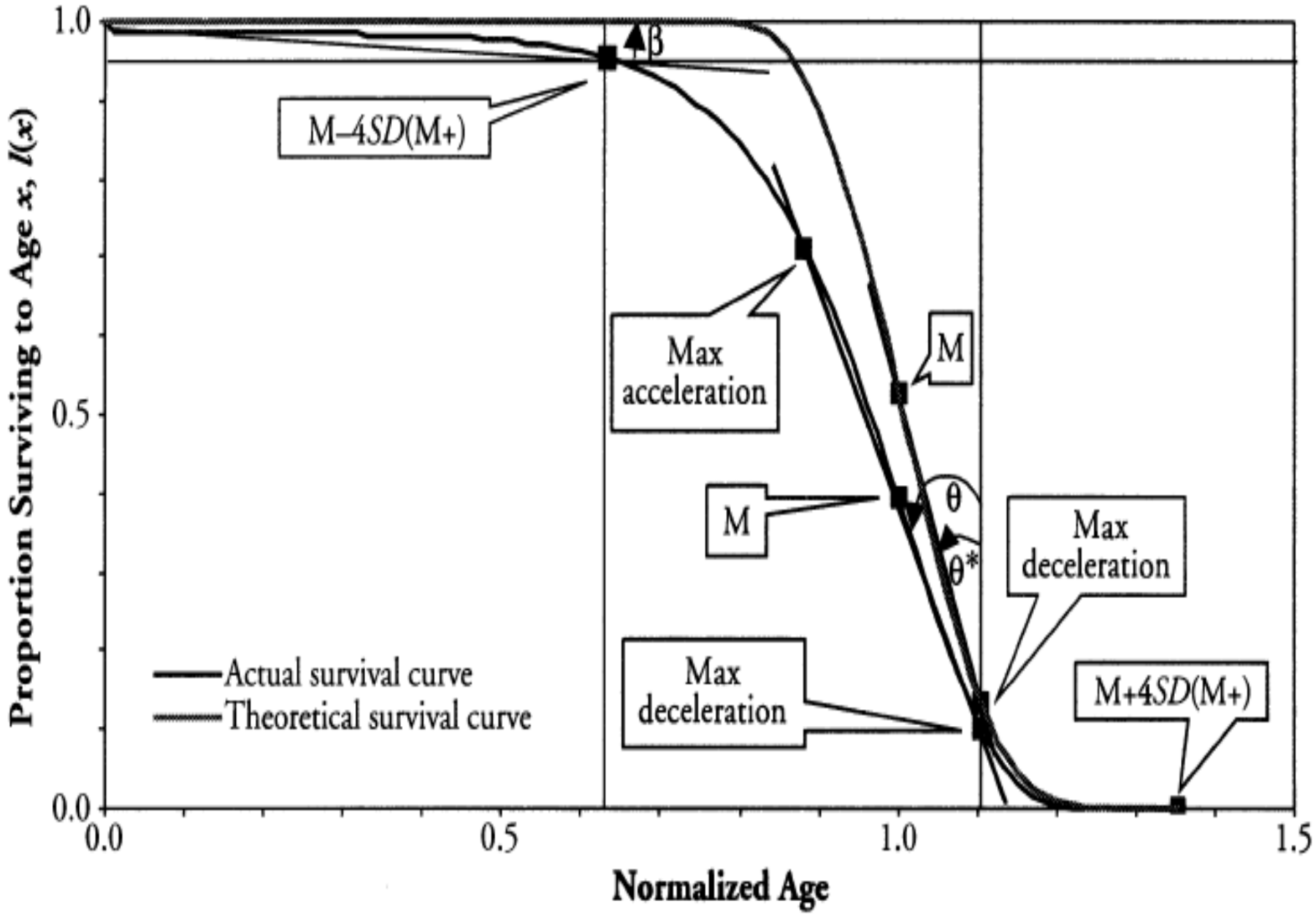
- Cheung et al. (2005) proposed 3-dimension measurements to describe the survival curve.

→Horizontalization: *how many survivors can live before aging-related deaths significantly decrease*

→Verticalization: *how concentrated aging-related deaths are around the modal age at death*

→Longevity Extension: *how far the highest normal life durations can exceed Mode*

3 Dimensions of Survival Curve (Cheung et al., 2005)



Some Questions

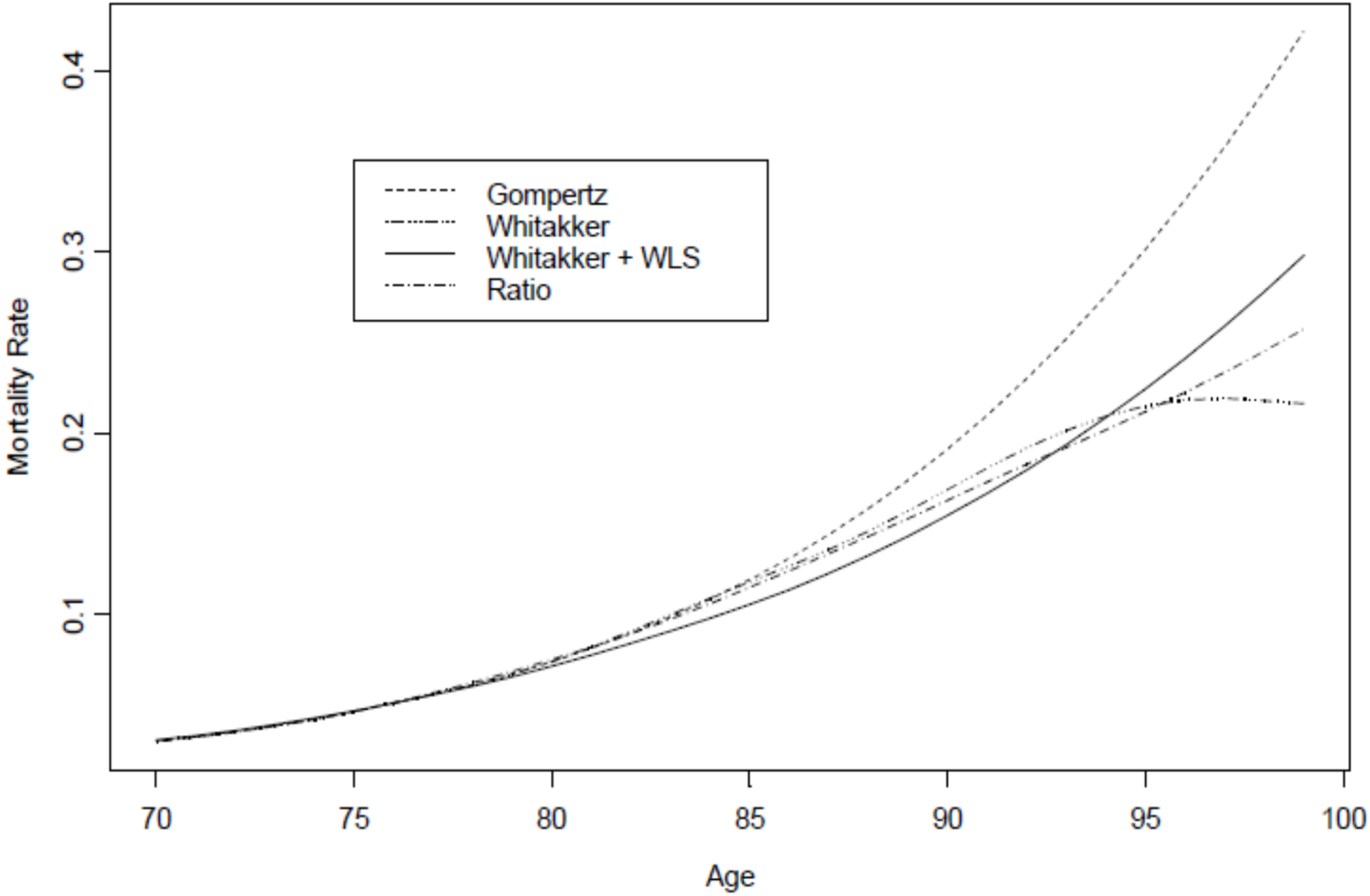
- The calculations rely on values from the life tables, which are being graduated.

→ The elderly mortality rates (and ex) are influenced the most.

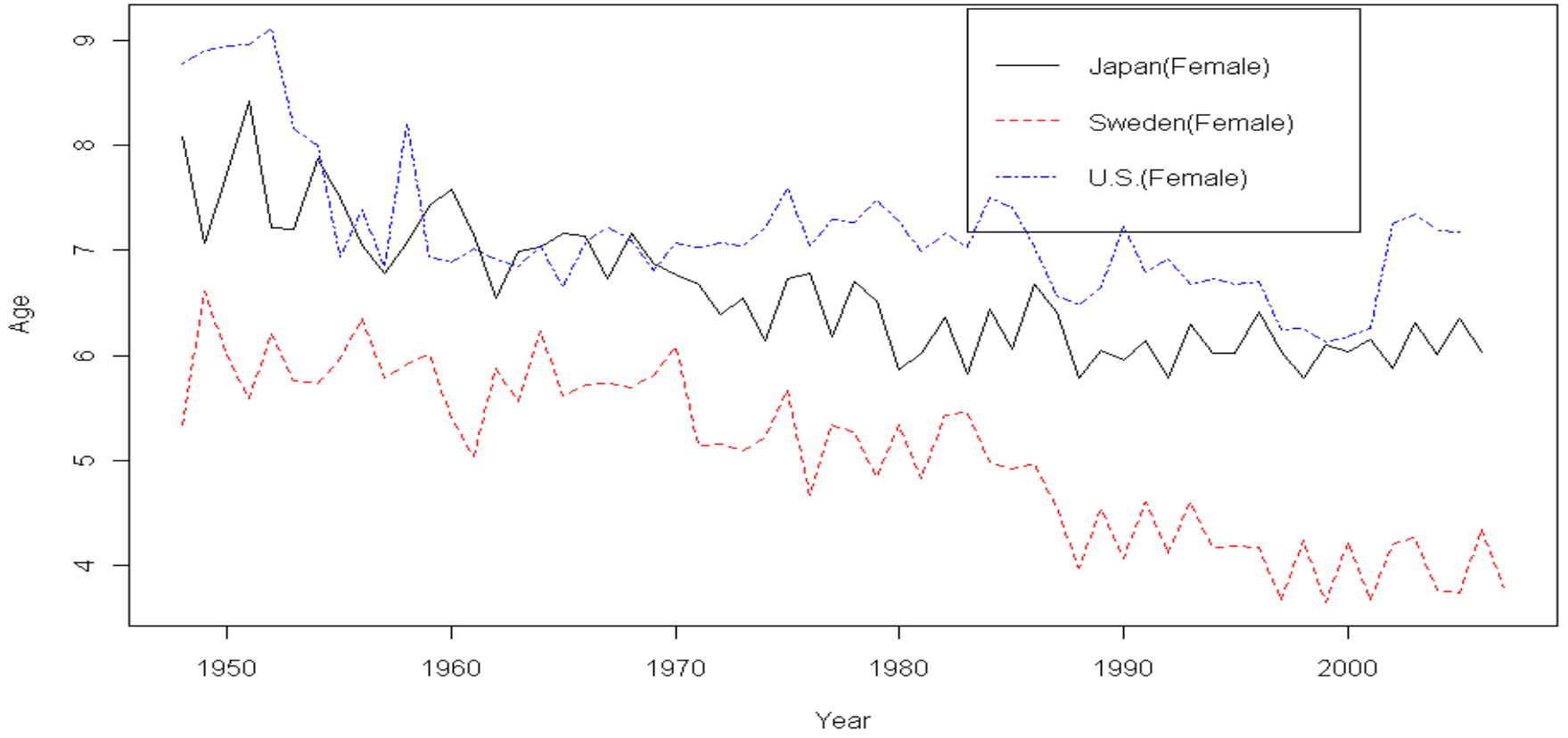
- Like in the Gompertz model, the estimation of parameter can be modified.

→ Yue (2002) considered 3 estimation methods for the parameter C, where $\mu_x = BC^x$.

Graduated Mortality Rates (Taiwan Male, 1999-2001)



Standard Deviation of Number of Deaths (Raw Data)



Source: Yue (2012)

Measures of Compression (Kannisto, 2000)

- Modal Age, M, or the age with the maximal number of deaths.

→ $$M^* = x + \frac{f(x) - f(x-1)}{[f(x) - f(x-1)] + [f(x) - f(x+1)]}$$

- Standard deviation (σ) of the age at death above the mode, SD(M+).

$$SD(M+) = \sqrt{\frac{\sum_{M}^{\omega} f(x)(x-M)^2}{\sum_{M}^{\omega} f(x)}} \quad or \quad \sqrt{\frac{\int_{M^*}^{\omega} f(x)(x-M^*)^2}{\int_{M^*}^{\omega} f(x)}}$$

Proposed Approaches

- Three estimation methods: (Yue, 2002)

→Maximal Likelihood Estimation (MLE), Non-linear Maximization (NM), and Weighted Least Squares (WLS).

→The MLE is expected to produce the most reliable estimates (smallest mean squared error), and the WLS is easy to use.

→We choose the NM method since it has the best overall performance.

Proposed Approaches (Conti.)

- The optimization method is model dependent and two distributions are used to verify the NM method.

→Normal distribution (Number of deaths d_x)

$$d_x \propto \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-M)^2}{2\sigma}}$$

→Logistic distribution (Force of Mortality μ_x)

$$\mu_x \propto \frac{a e^{bx}}{1 + a e^{bx}}$$

Proposed Approaches (Conti.)

- Numerical optimization of the NM method:

→Normal distribution,

$$\arg\min_{M,\sigma} \sum_{x=M}^{M+2k} w_x \left(\frac{1}{\sqrt{2\pi}\sigma} \exp\left[\frac{-1}{2\sigma^2} (x-M)^2 \right] - d_x \right)^2$$

→Logistic distribution,

$$\arg\min_{M,a,b} \sum_{x=M}^{M+2k} w_x \left\{ \left(\frac{1+be^{-bM}}{1+be^{b(x-M)}} \right)^{1/b} \times \frac{be^{b(x-M)}}{1+be^{b(x-M)}} - d_x \right\}^2$$

About the Estimation

- The parameter estimates are influenced by the number of observations, or the data range *k*.

  →The estimation results using **M~M+2*k*** and **M–*k*~M+*k*** are similar, we will show only the results of **M~M+2*k***.

  →The data format is "age-last-birthday" and the estimation of M shall be modified.

Evaluating the Proposed Approaches

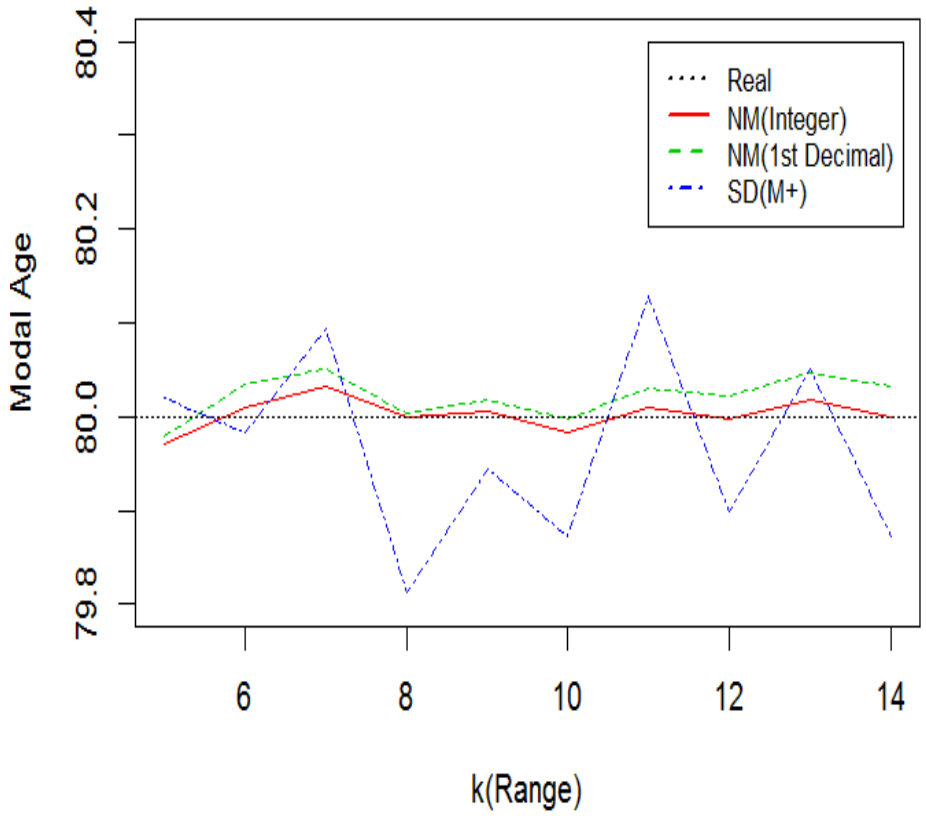
- Computer simulation:

→The modal age M is 80 and the standard deviation σ is 10. Randomly generate 100,000 deaths from normal or logistic distribution.

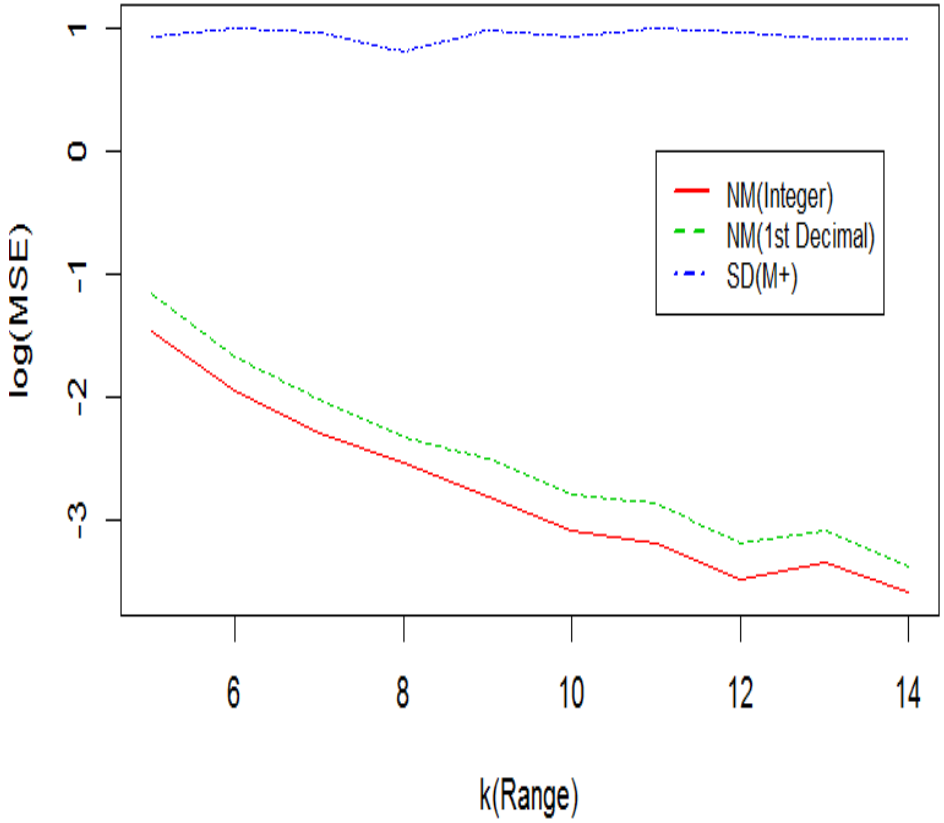
→Comparison criteria: Mean Squares Error (MSE), *Loss function (MSE)* = $Bias^2$ + *Variance.* and the probability of confidence interval covering true parameter (Coverage probability).

Modal Age of Normal Dist. (M=80)

Bias

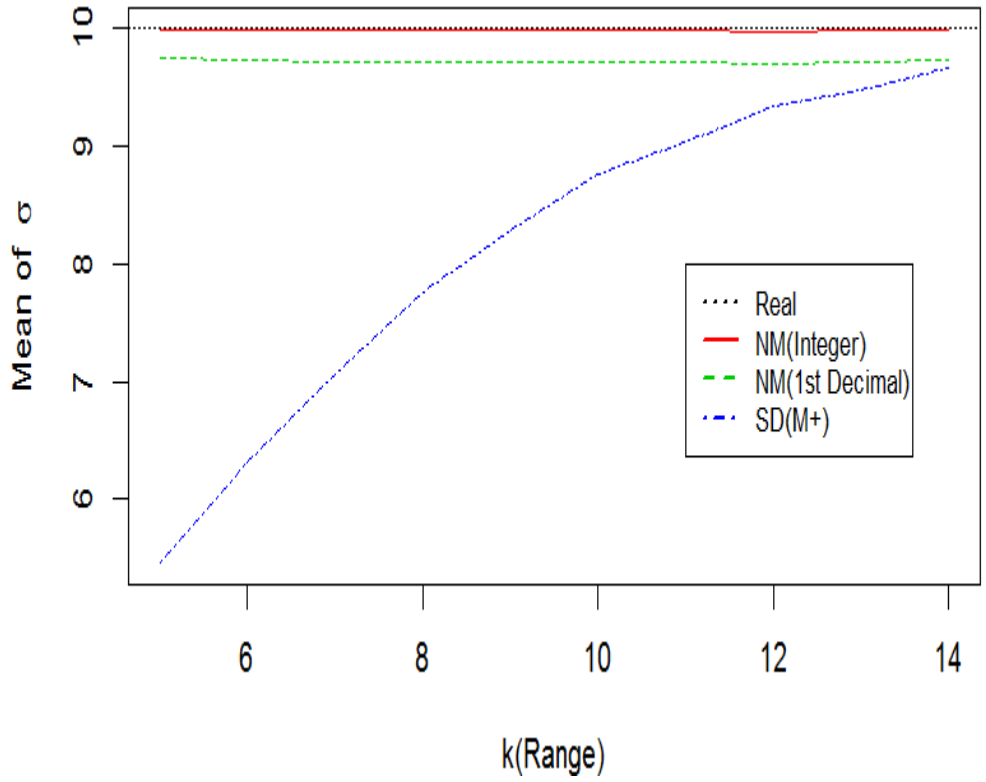


MSE

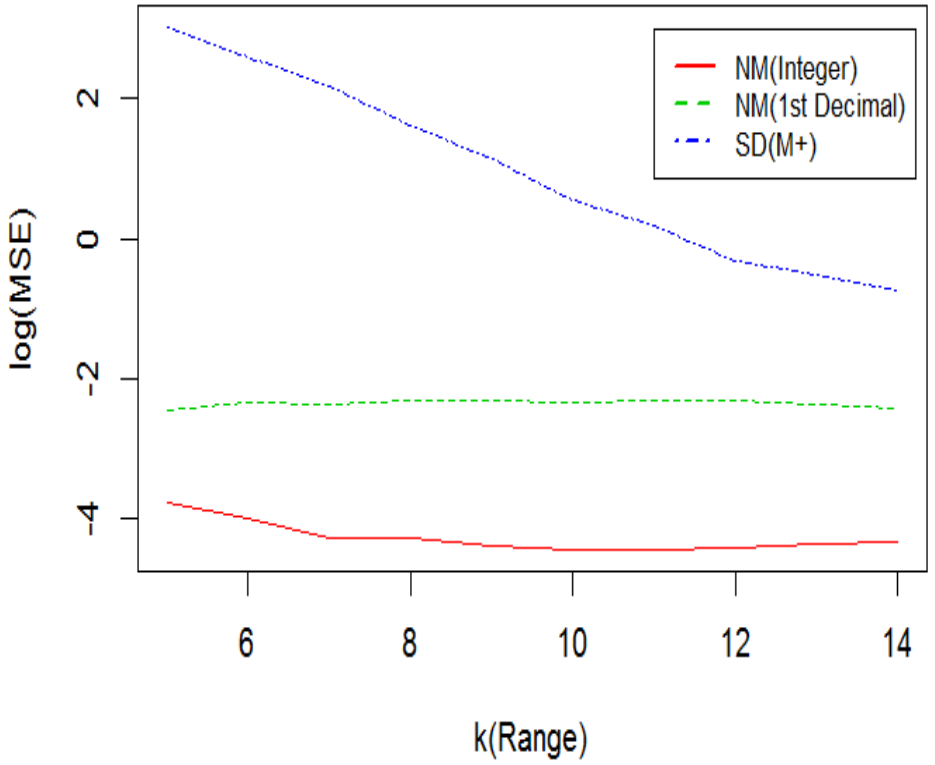


Standard Deviation of Normal Dist. (σ=10)

Bias



MSE



Coverage Probability of Normal Dist.

	NM		SD(M+)
	Integer Age	First Decimal	
M	.951	.952	.969
σ	.956	.937	**.000**

Note: M = 80 and σ = 10

Coverage Probability of Logistic Dist.

	NM		SD(M+)
	Integer Age	First Decimal	
M	.948	.924	.893
σ	.956	.927	.000

Note: $a = 80$ and $b = 0.1336837$

Empirical Studies

- We check if the graduation process would influence the estimation.

→Consider the Whittaker graduation

$$F = \sum_{x=1}^{n} w_x (v_x - u_x)^2 + h \sum_{x=1}^{n-z} (\Delta^z v_x)^2$$

→The age-at-death follows N(80,10^2), with 100,000 deaths for 1,000 simulation runs and h = ave. sample (W1) & 1,000×ave. sample (W2).

M Estimates for Raw and Graduated Data

M	NM			SD(M+)		
k	Raw	W1	W2	Raw	W1	W2
5	79.98	80.07	80.38	79.45	79.37	75.02
6	80.01	79.87	80.37	79.37	79.51	75.02
7	80.00	79.98	80.50	79.43	79.46	75.02
8	79.99	79.82	80.60	79.48	79.66	75.02
9	79.99	80.02	80.58	79.41	79.40	75.04
10	79.99	80.01	80.57	79.37	79.35	75.04

σ Estimates for Raw and Graduated Data

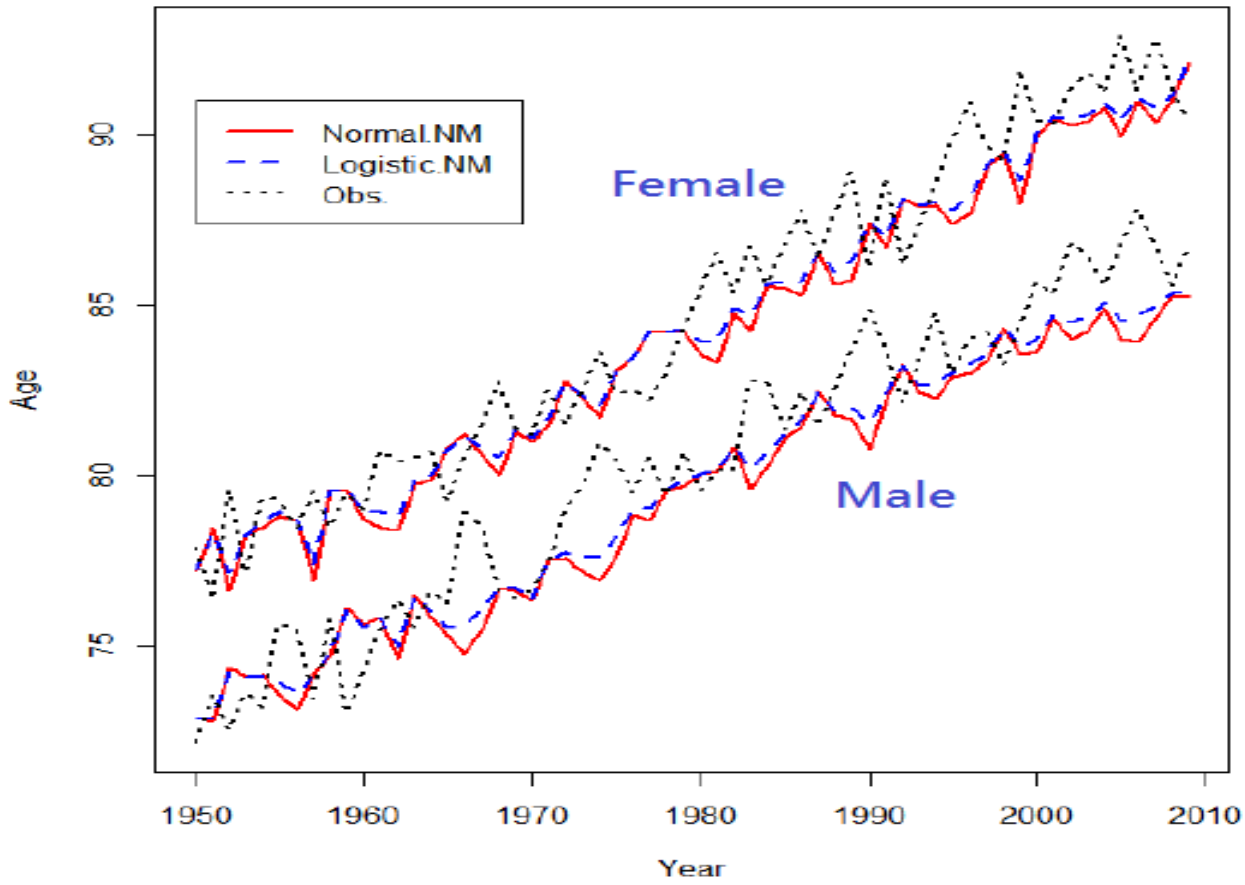
σ	NM			SD(M+)		
K	Raw	W1	W2	Raw	W1	W2
5	9.99	10.00	9.73	5.47	5.47	5.50
6	10.00	10.00	9.70	6.34	6.34	6.39
7	9.99	10.00	9.67	7.10	7.09	7.19
8	10.00	10.00	9.67	7.71	7.71	7.89
9	10.00	10.00	9.66	8.31	8.31	8.46
10	10.01	10.01	9.66	8.69	8.69	8.91

Empirical Studies (Conti.)

- Apply the mortality data from the Human Mortality Database and assume the age-at-death follows normal or logistic distribution.

→Using NM or SD(M+) estimation;

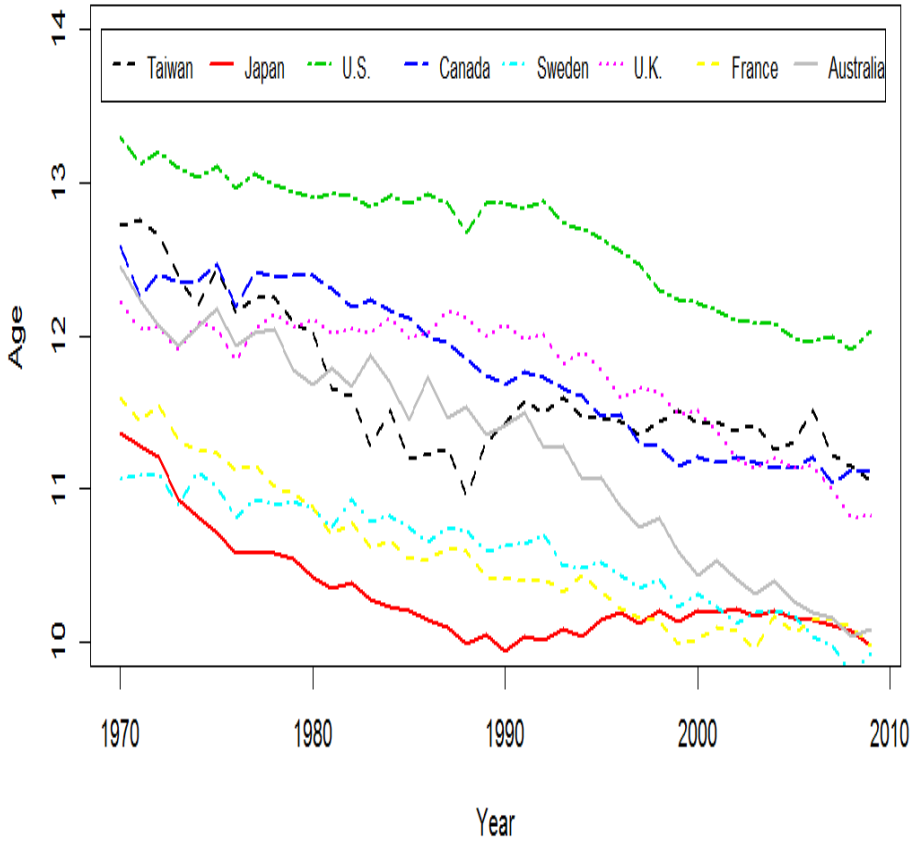
→Several countries are considered and the σ estimates are used to evaluate the mortality compression.



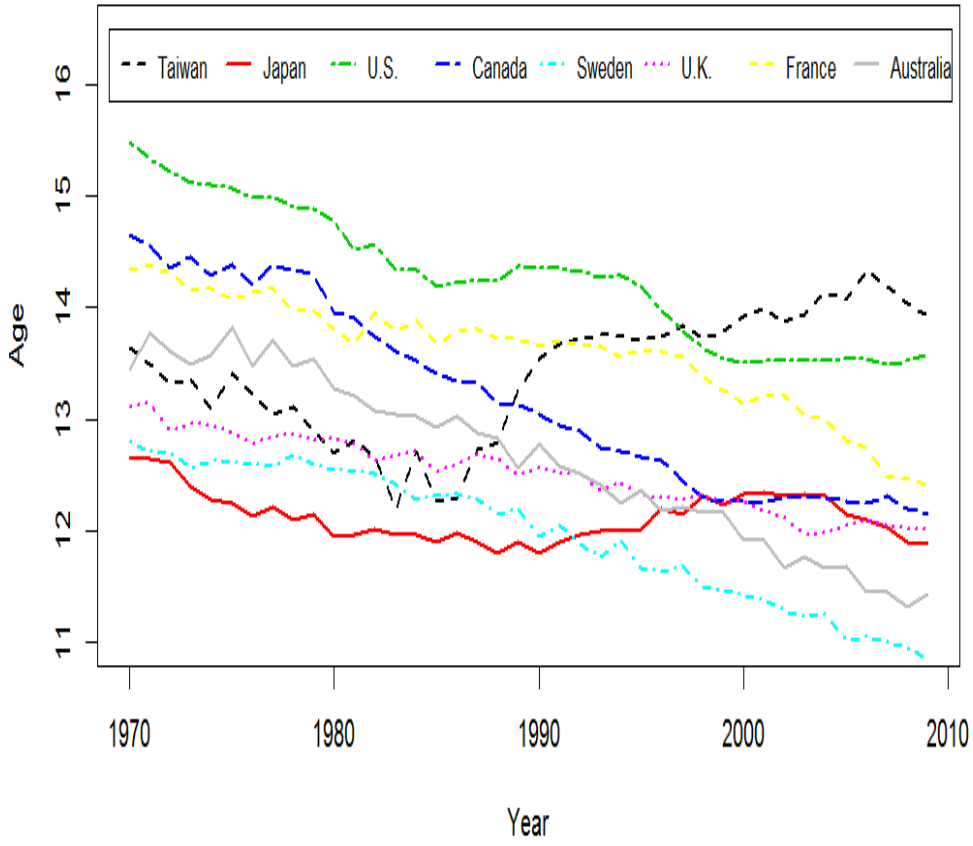
Japan Modal estimates for NM

The Estimate of σ (NM)

Female

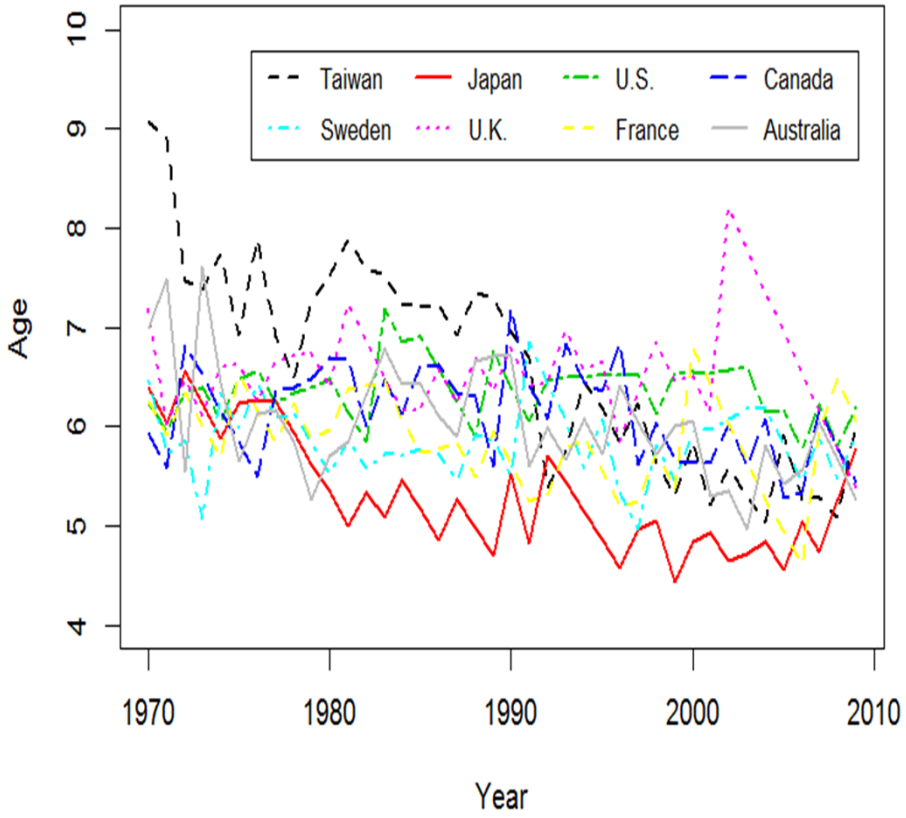


Male

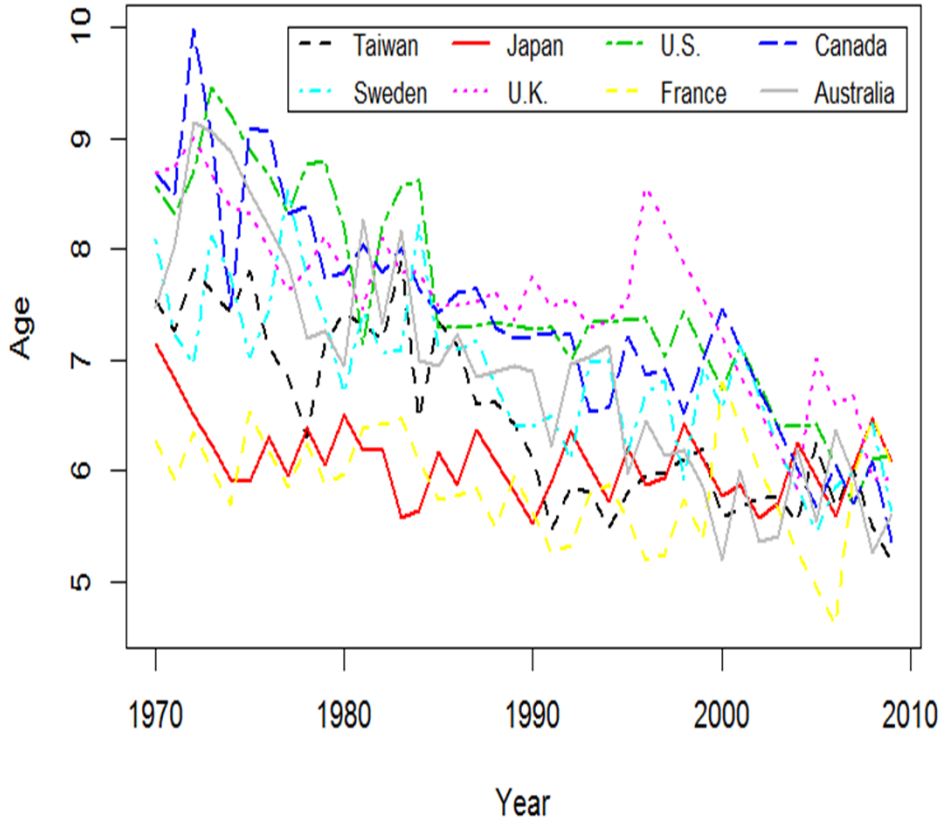


The Estimate of σ (SD(M+))

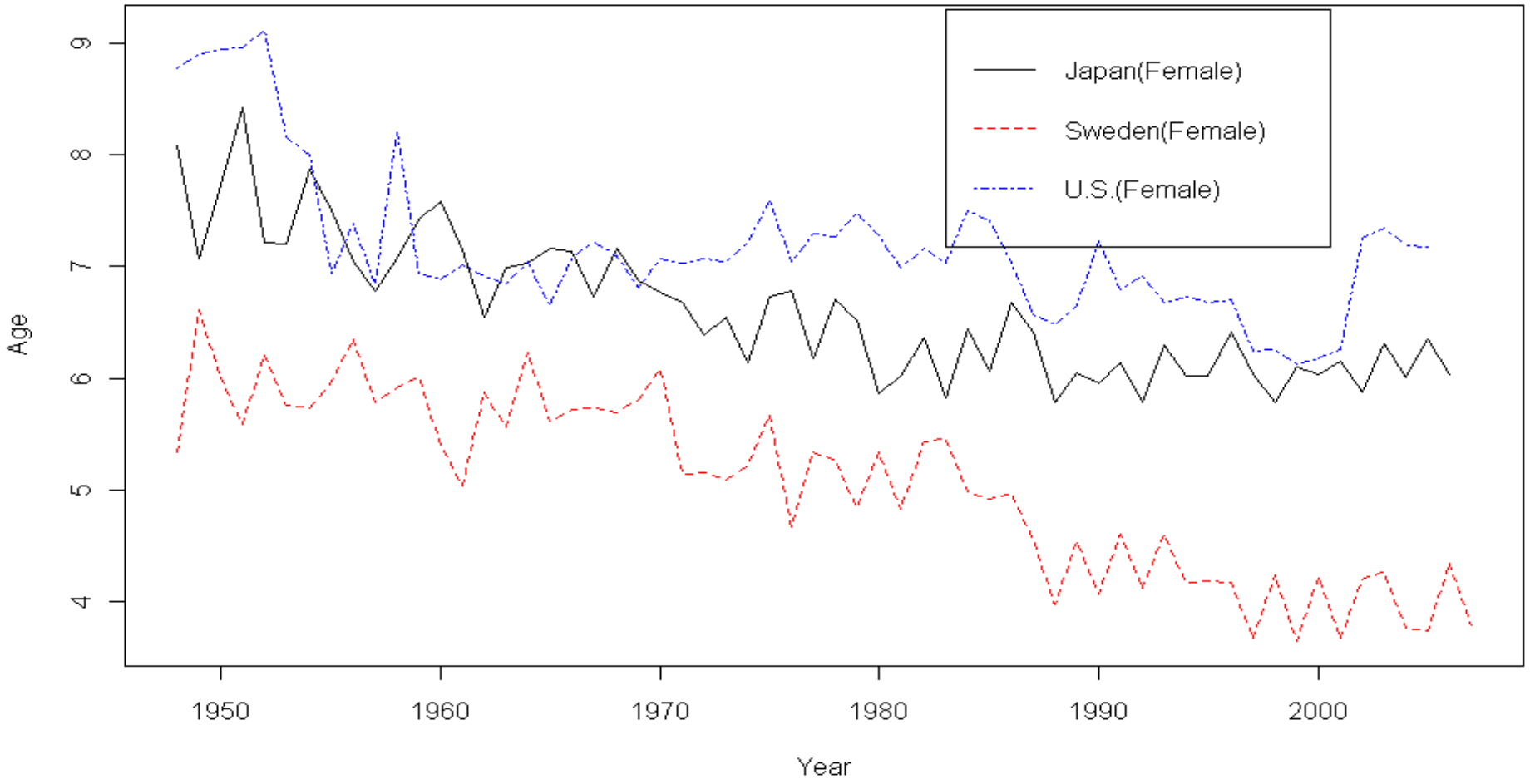
Female



Male

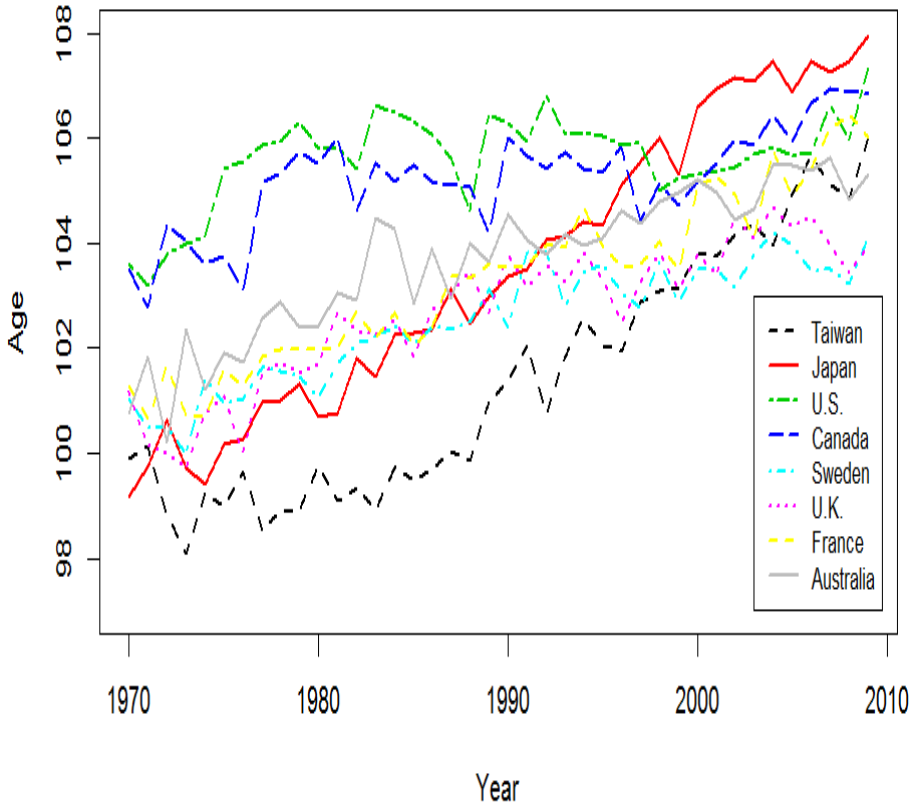


The Estimate of σ (WLS; Yue, 2012)

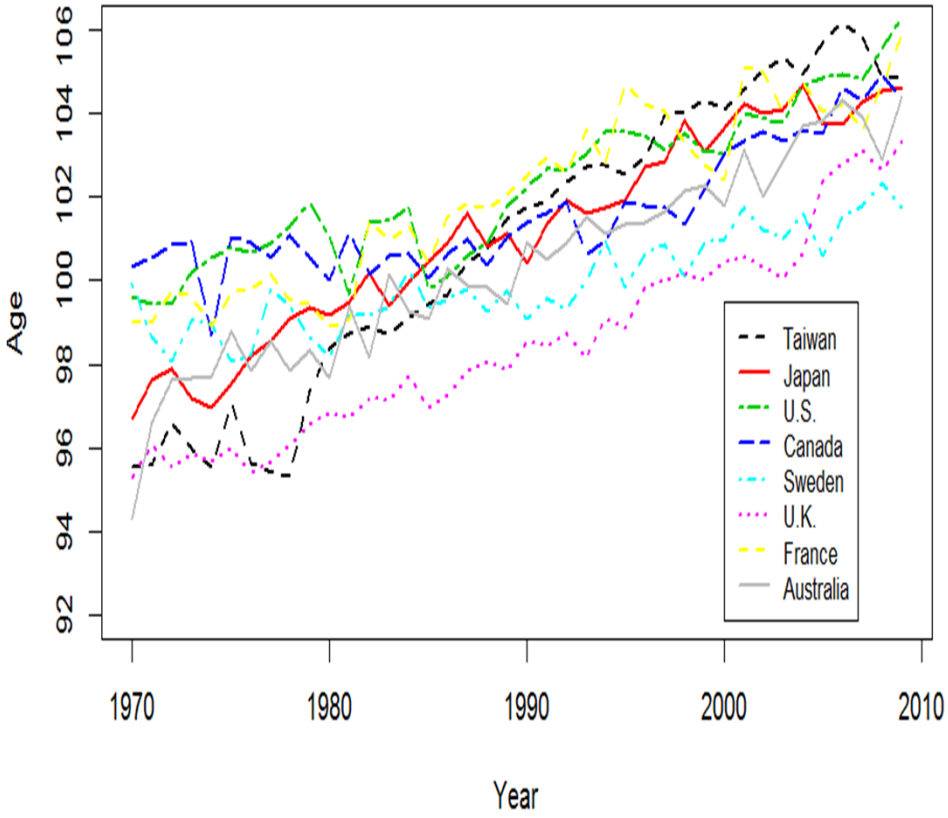


The Estimate of P97.5, M+1.96σ (NM)

Female



Male



Conclusions and Discussions

- The proposed approaches are more reliable in estimating the modal age M and σ.

→NM (& WLS) are preferred.

→Raw data are preferred.

→The estimation method is model sensitive.

- The mortality compression is still not clear.

→Some countries show a decreasing pattern, but some don't. However, the probability of surviving beyond age M+1.96σ is increasing.

Conclusions and Discussions (Conti.)

- The normal assumption is questionable.

→The estimation methods are influenced by the distribution assumption.

- Using the standard deviation as the measure of mortality compression is questionable.

→Are there alternative measures, such as the IQR and percentile?

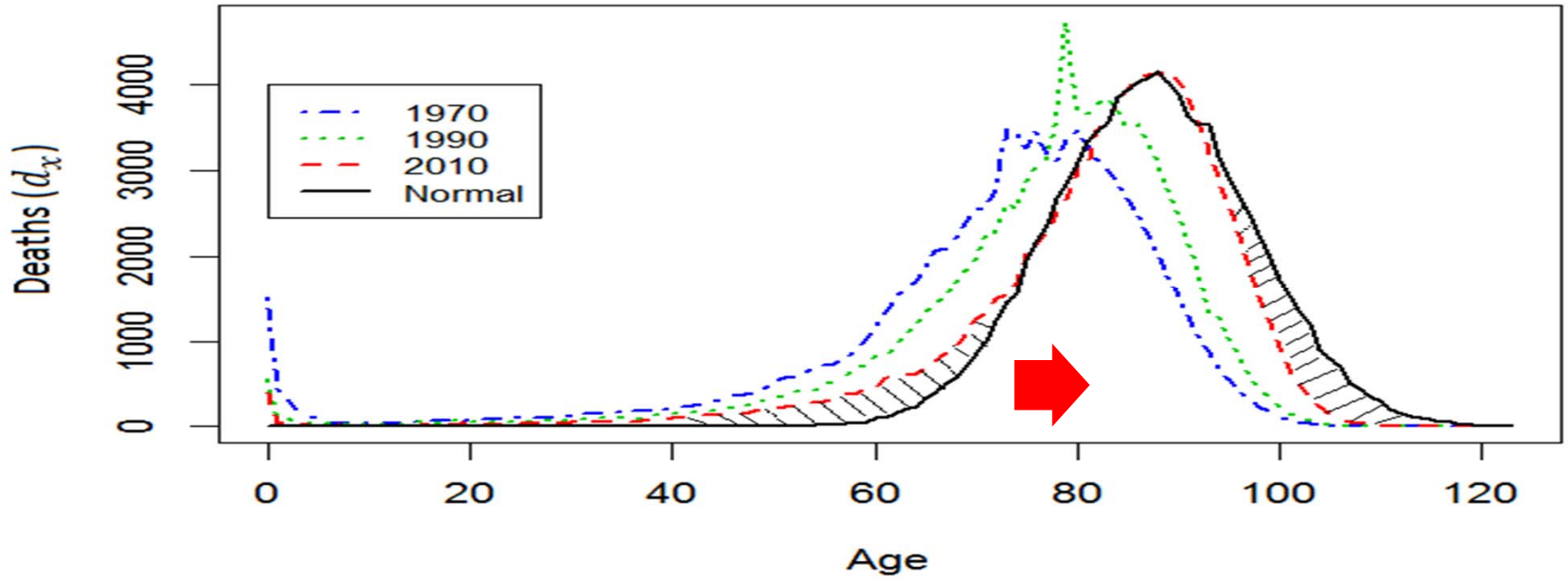
Normality Test (Permutation Test)

Group	1	2	3	4	5	6	7	8
Ei	11504	12690	10262	11560	15778	10786	13856	13563

Note: The expected numbers are based on 10,000 simulation runs.

Normality Test (Taiwan Female)

Year	1	2	3	4	5	6	7	8
2007	24232	11093	11378	13046	13570	11771	10116	4792
2008	23977	11085	11321	13176	13576	11859	10197	4814
2009	23104	10682	11062	13111	13757	12140	10744	5399



Conclusions and Discussions (Conti.)

- The probability of surviving to very high age cannot be ignored and if the life expectancy has a limit is still unknown. (Longevity Risk!)
- Some possible future study topics:

→Modify the idea of mortality compression and apply it in dealing with longevity risk.

→Apply the extreme value theory.


Thank you!