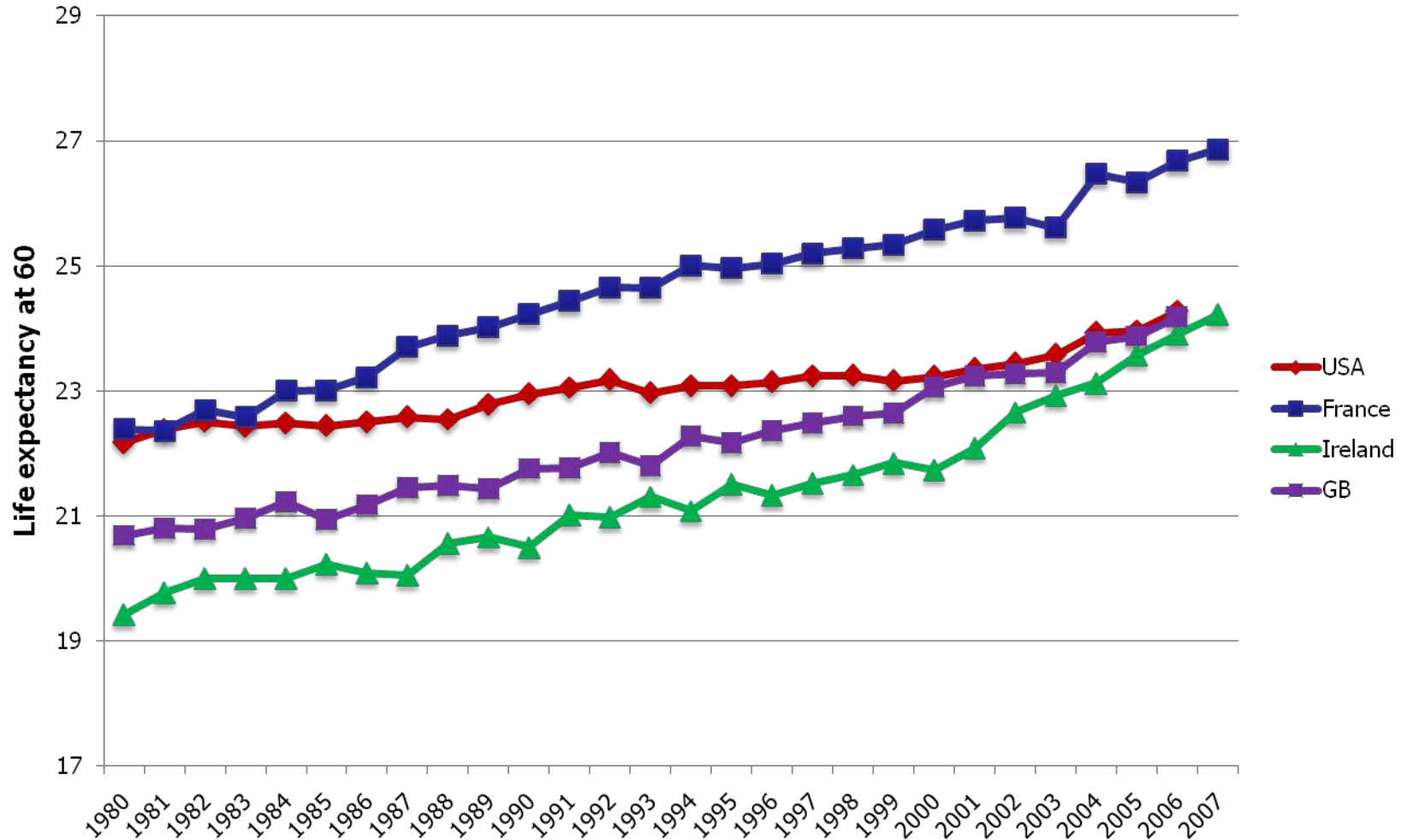# How Long Will We Live in the 21st Century?

Dr. Leonid A. Gavrilov, Ph.D.

Dr. Natalia S. Gavrilova, Ph.D.

Center on Aging

NORC and the University of Chicago

Chicago, Illinois, USA

Trends in Life Expectancy at 60
Females

■ **Source: Human Mortality Database**

In 2006 slow progress in life expectancy improvement in the United States has been noticed

- **Mesle, F, Vallin, J. Diverging trends in female old-age mortality: The United States and the Netherlands versus France and Japan.** *Population and Development Review*. **2006.**

- **NRC Panel on Diverging Mortality**

New breakthrough in understanding and predicting human mortality:
Delayed effects of smoking behavior are much more important than previously thought

- **Forecasting United States mortality using cohort smoking histories. Wang H, Preston SH. *Proc Natl Acad Sci U S A*. 2009 Jan 13;106(2):393-8**
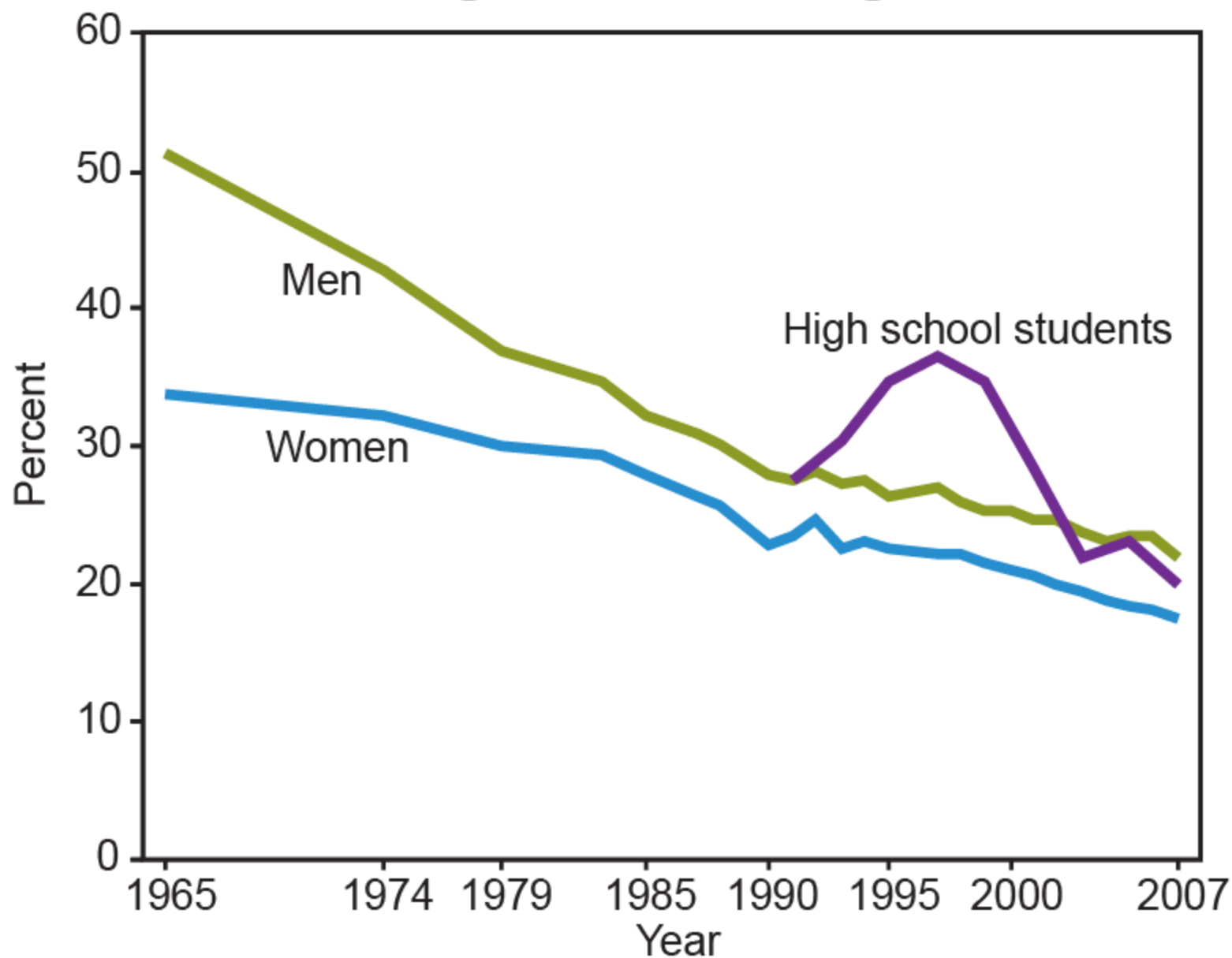
Proportion of deaths in different causes due to smoking
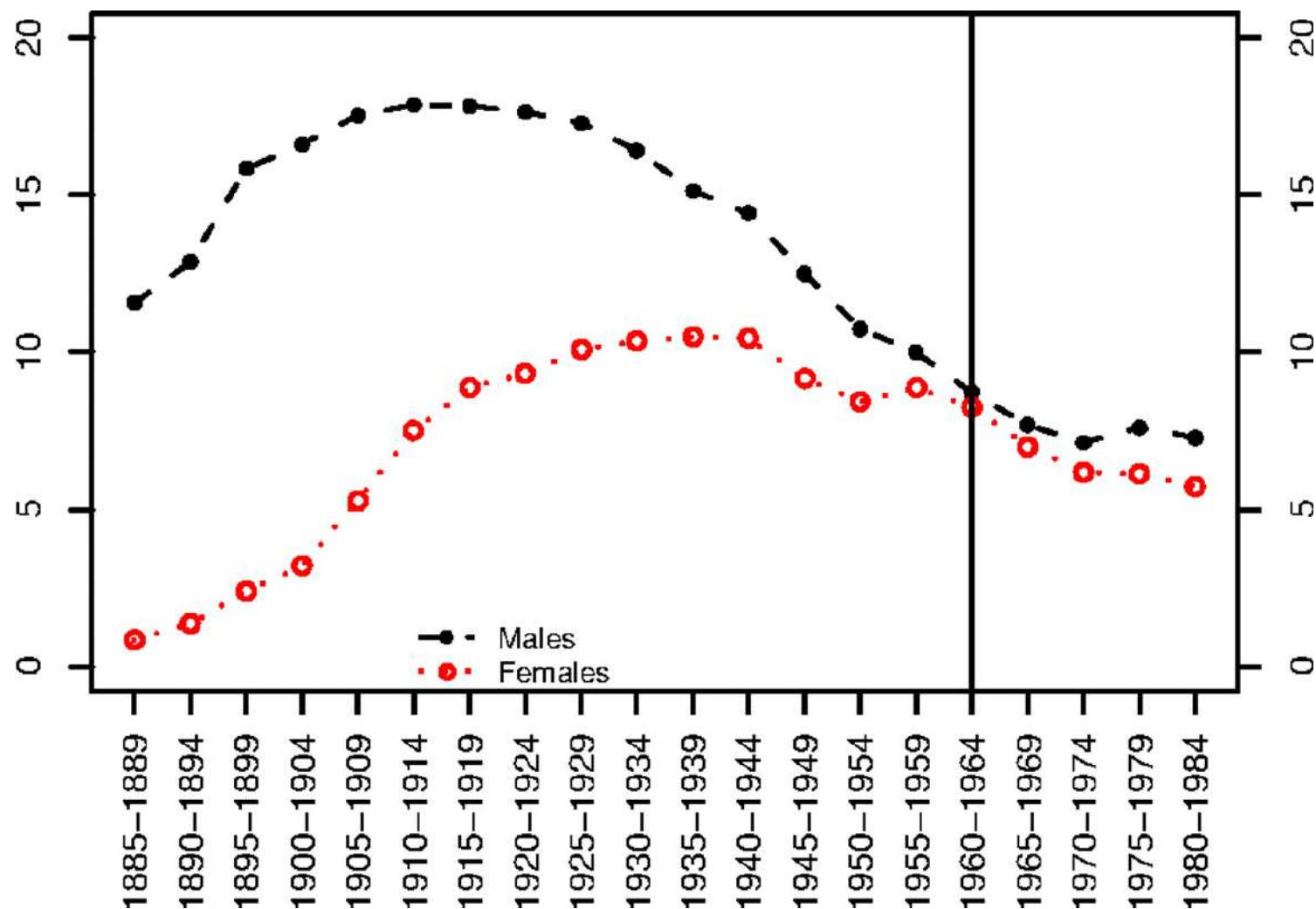## UK, 2000
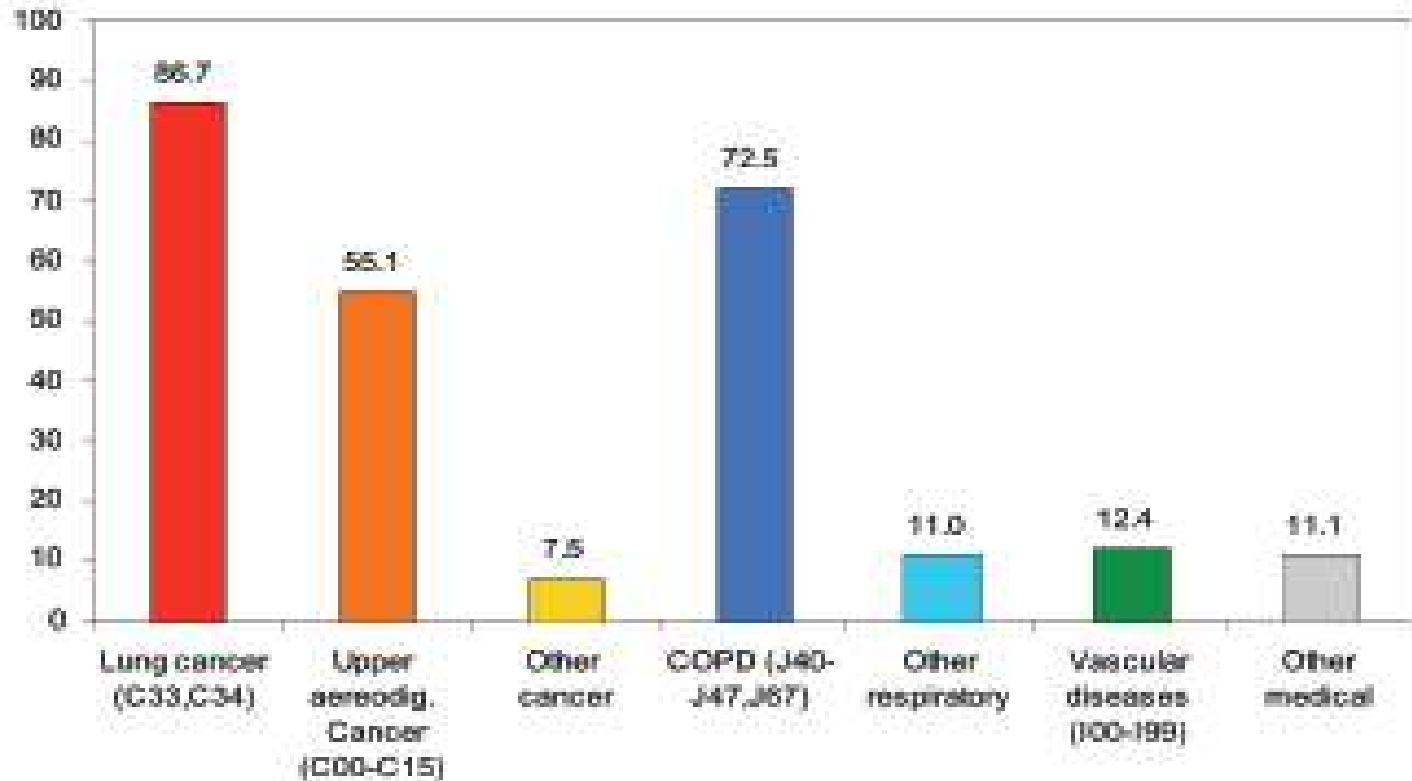
- **Source: Murphy, Di Cesare. Presentation at the 2010 Annual Meeting of the Population Association of America, Dallas, TX.**

Cigarette smoking

SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 6. Data from the National Health Interview Survey and the Youth Risk Behavior Survey.

Average number of years spent as a cigarette smoker before age 40 among men and women in different birth cohorts.

PNAS

Probability of surviving from age 50 to 85 using different projection methods: United States, 2004–2034.
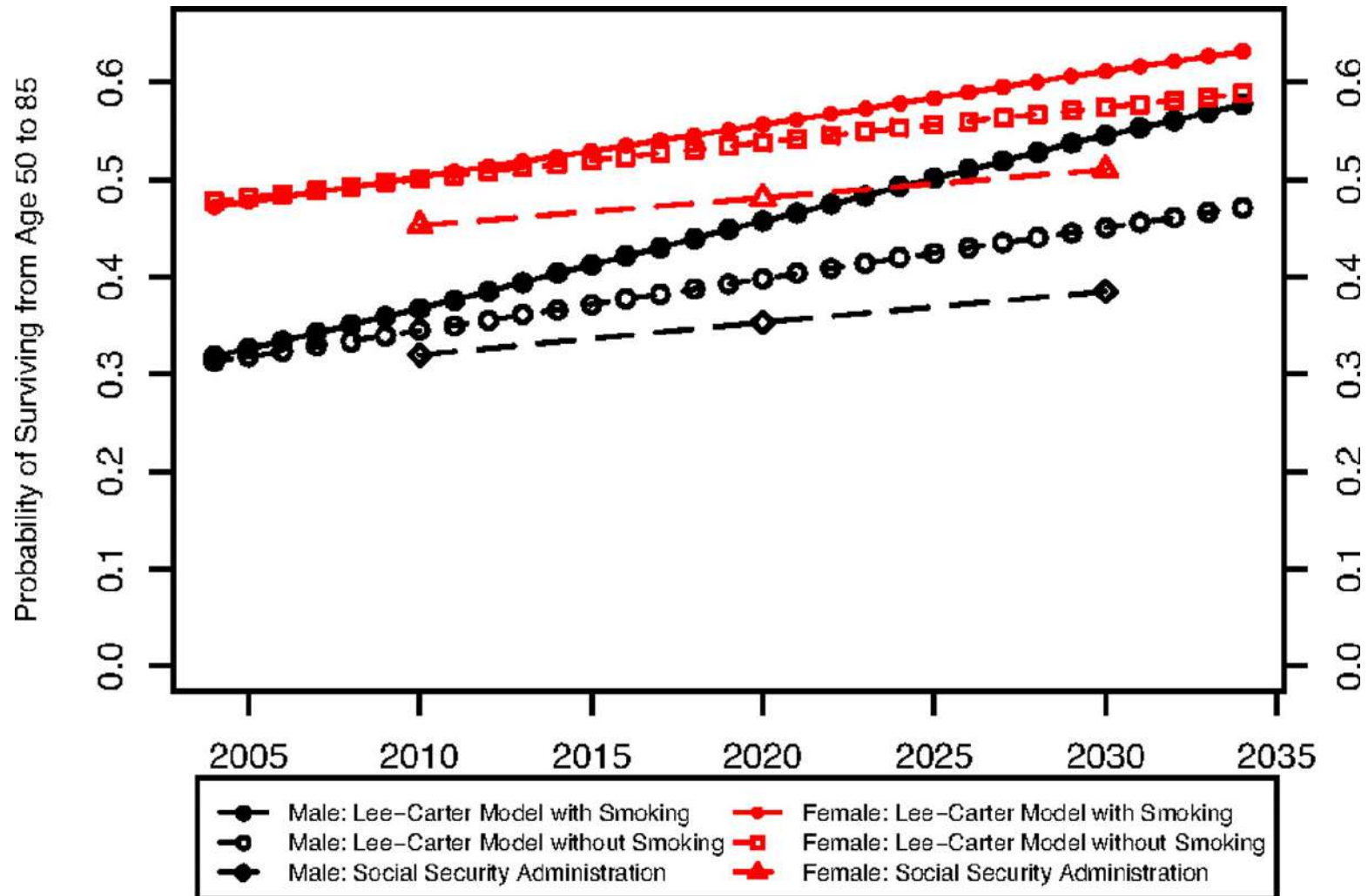
Wang H , Preston S H PNAS 2009;106:393-398

PNAS

New Breakthrough (2)
Most Recent References:

- **Contribution of Smoking to International Differences in Life Expectancy. by Samuel H. Preston, Dana A. Glei, and John R. Wilmoth. In:** *International Differences in Mortality at Older Ages: Dimensions and Sources*. **US National Research Council, The National Academies Press, 2010. http://www.nap.edu/catalog.php?record_id=12945**

- **A new method for estimating smoking-attributable mortality in high-income countries. Preston SH, Glei DA, Wilmoth JR.**
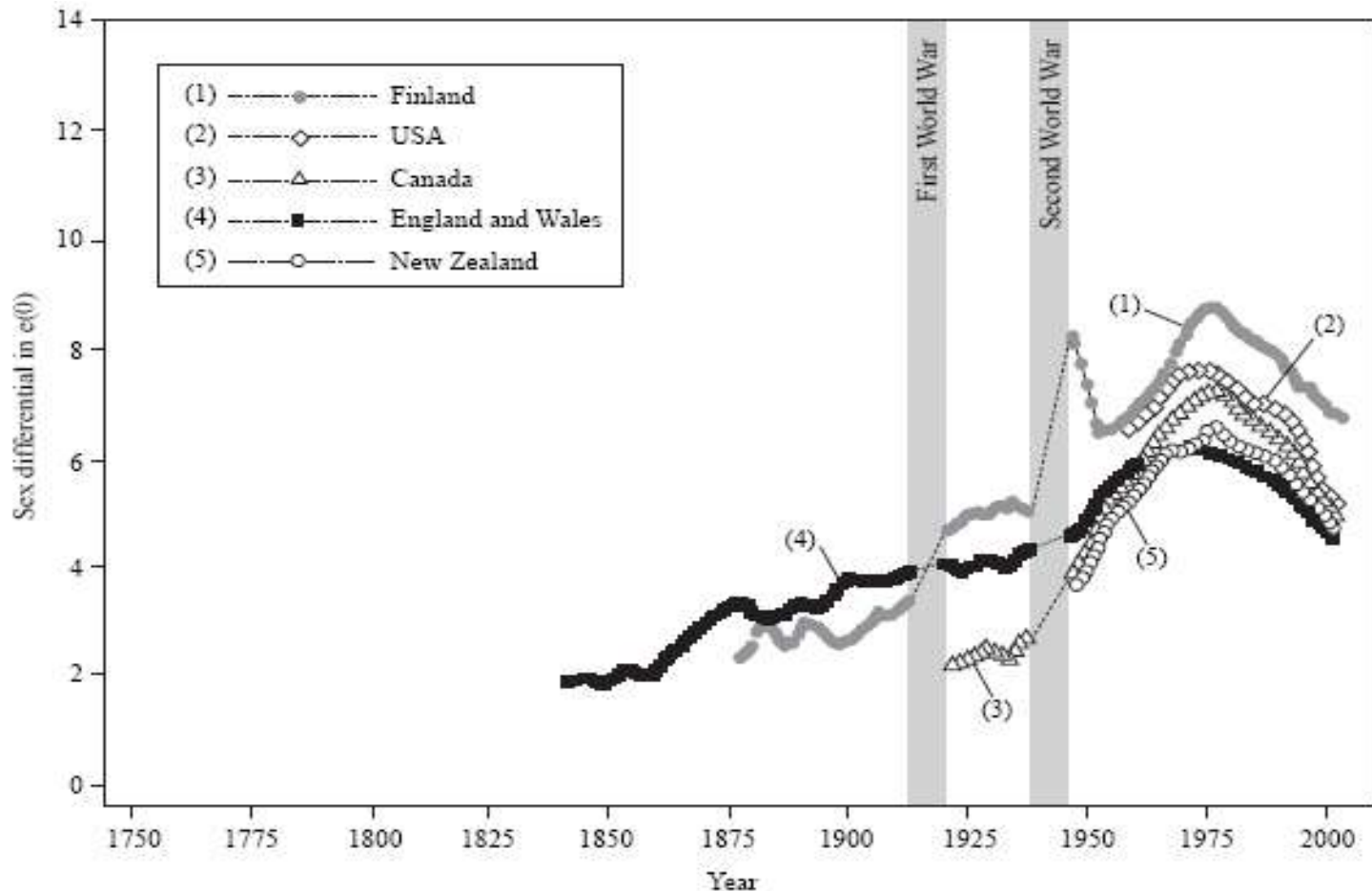
The Future (men)

- **The smoking epidemic among men has receded in nearly all industrialized countries.**

- **In view of the lag between smoking behavior and smoking-attributable mortality, it is reasonable to expect that men in nearly all the study countries will benefit from reductions in the smoking-attributable fraction of deaths, thereby boosting life expectancy.**

Preston, Glei, Wilmoth, International Differences in Mortality

The Future (women)

- **Among women, however, a later uptake of smoking has produced an upsurge in smoking-attributable deaths. In most countries in this study, the prevalence of smoking among women has begun to decline, albeit much later than for men. But the effects of earlier increases have been playing a more powerful role in women's mortality profiles and are likely to continue doing so for some time to come.**

Preston, Glei, Wilmoth. International Differences in Mortality at Older Ages: Dimensions and Sources. NAS. 2010.

New trend: gender differential in life expectancy is narrowing

■ **Source: Glei, Horiuchi (2007), Population Studies, 61: 141 - 159**

Gender differential in LE at age 65

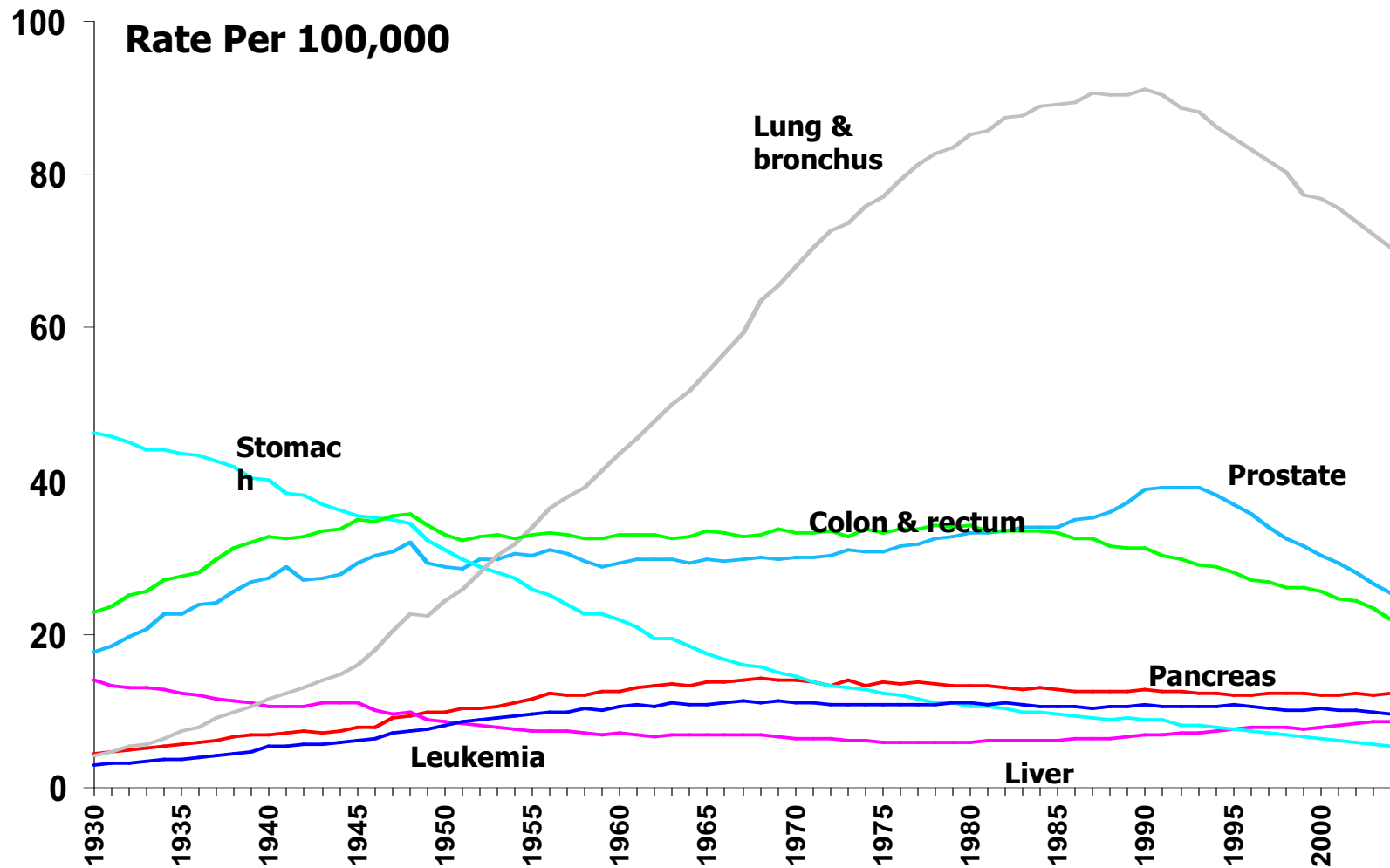Gender difference in life expectancy at 65 (all countries)
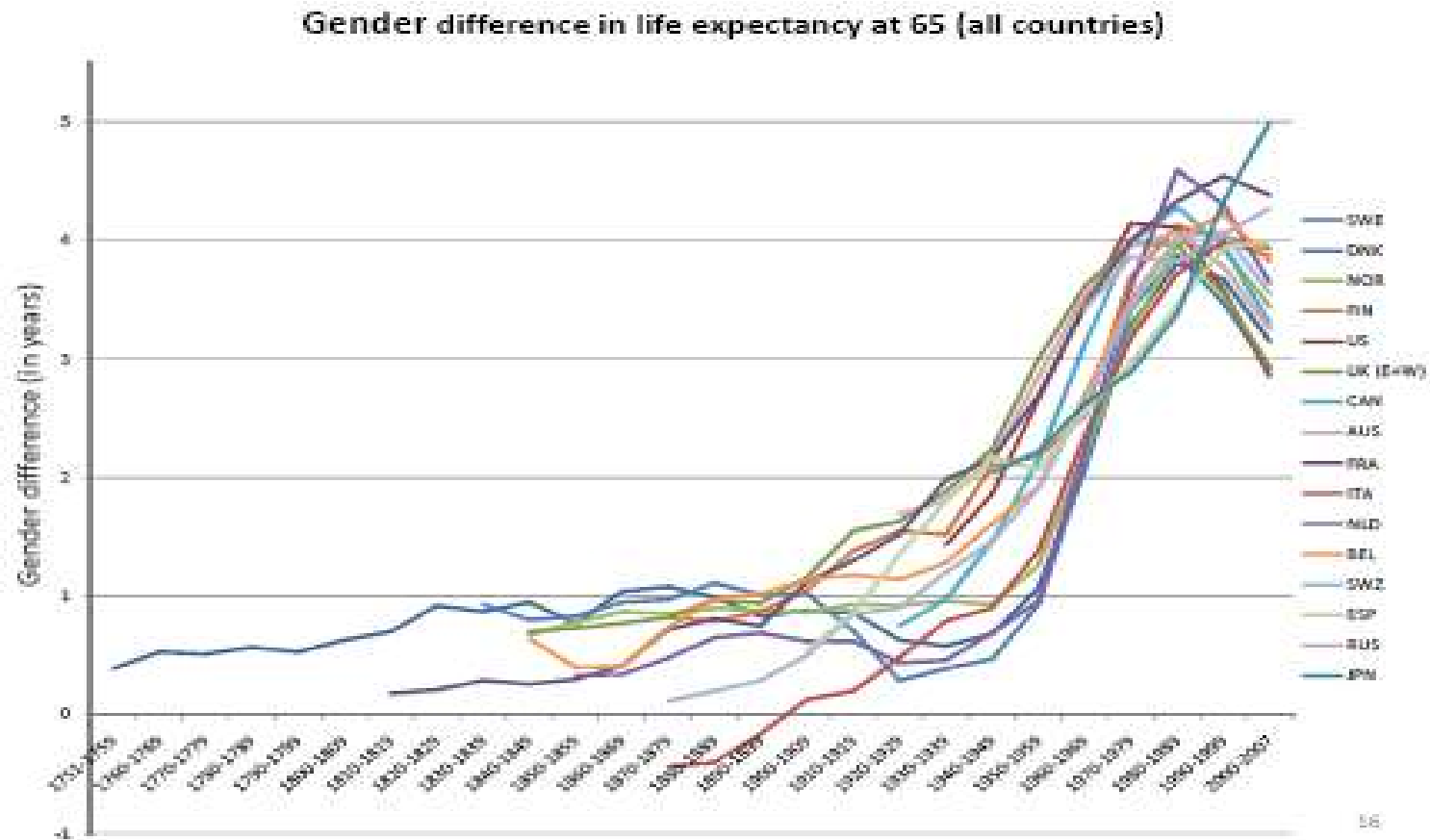
- **Source: Thorslund et al. Presentation at the REVES meeting in Havana (2010).**

Age-Adjusted Death Rates for Selected Causes of Death in the United States, 1950–2000
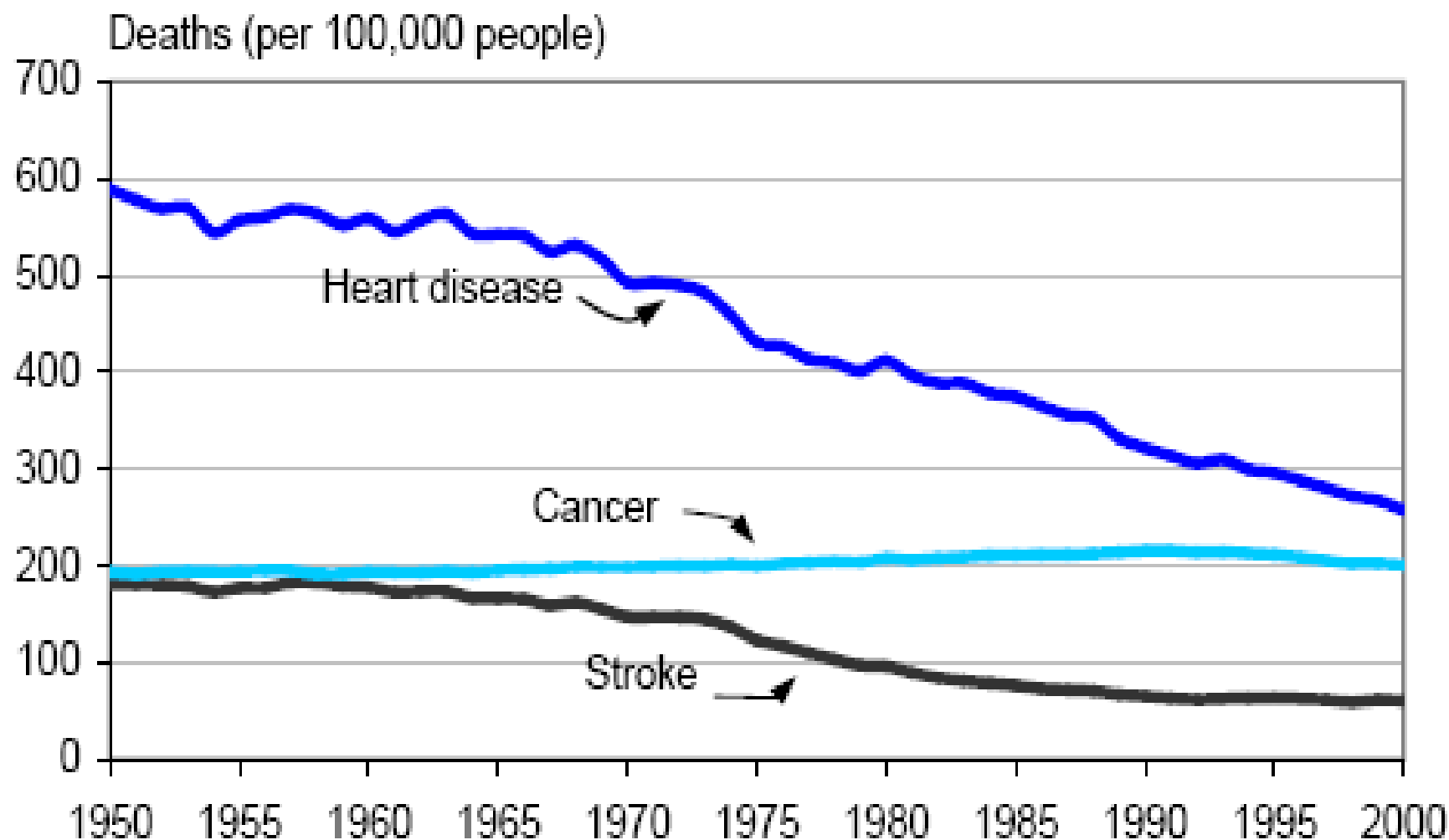
Source: AmeriStat, analysis of data from the National Center for Health Statistics.

Cancer Death Rates* Among Men, US,1930-2004

Rate Per 100,000

Lung & bronchus

Stomach

Prostate

Colon & rectum

Pancreas

Leukemia

Liver

*Age-adjusted to the 2000 US standard population.
Source: US Mortality Data 1960-2004, US Mortality Volumes 1930-1959,
National Center for Health Statistics, Centers for Disease Control and Prevention, 2006.

Cancer Death Rates* Among Women, US,1930-2004
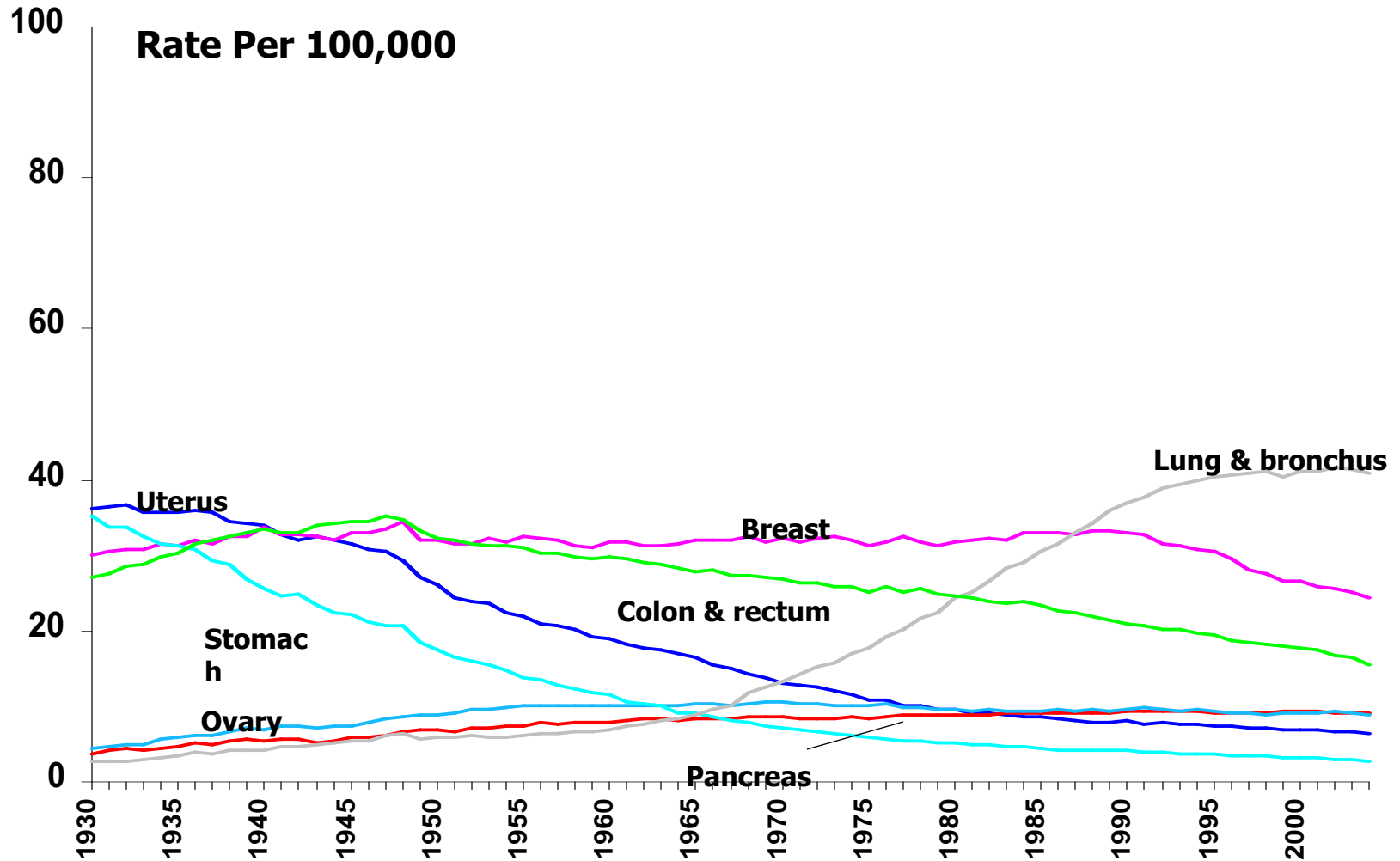
Rate Per 100,000

Uterus

Stomach

Ovary

Breast

Colon & rectum

Lung & bronchus

Pancreas

*Age-adjusted to the 2000 US standard population.
Source: US Mortality Data 1960-2004, US Mortality Volumes 1930-1959,
National Center for Health Statistics, Centers for Disease Control and Prevention, 2006.
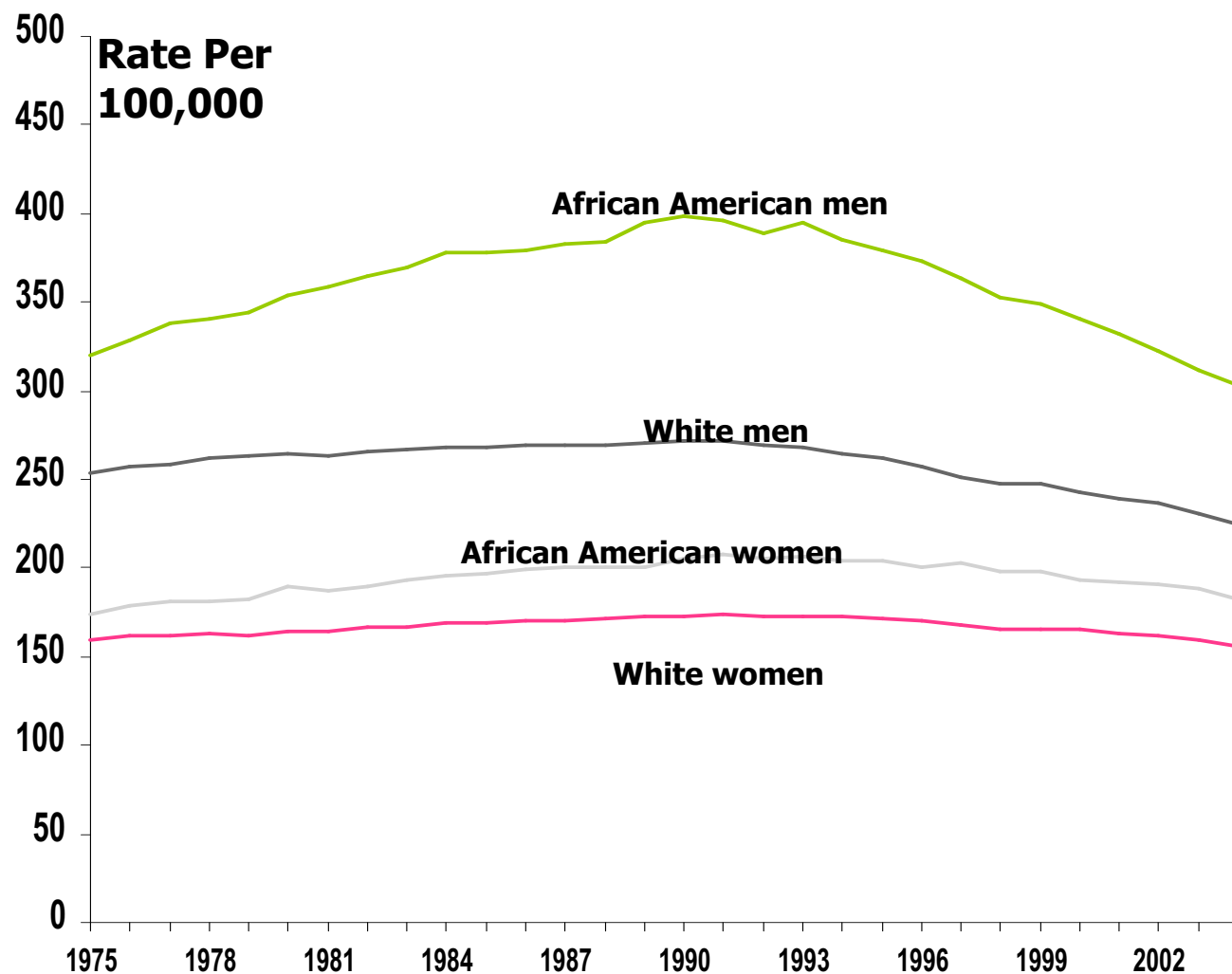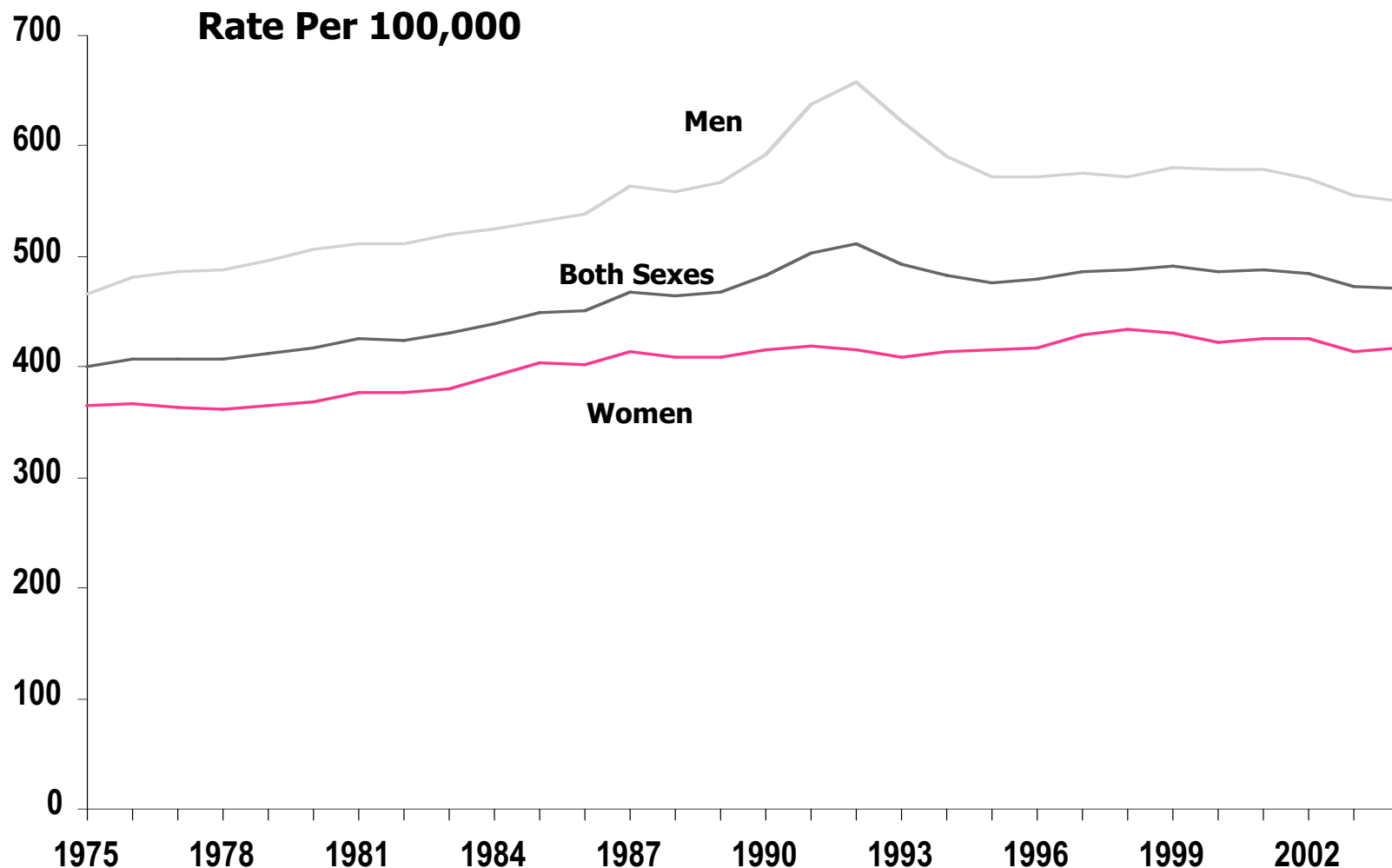
Cancer Death Rates* by Sex and Race, US, 1975-2004

*Age-adjusted to the 2000 US standard population.
Source: Surveillance, Epidemiology, and End Results Program, 1975-2004, Division of Cancer Control and Population Sciences, National Cancer Institute, 2007.

Cancer Incidence Rates* by Sex, US, 1975-2004

Rate Per 100,000

Men

Both Sexes

Women

*Age-adjusted to the 2000 US standard population and adjusted for delays in reporting.
Source: Surveillance, Epidemiology, and End Results Program, Delay-adjusted Incidence database:
SEER Incidence Delay-adjusted Rates, 9 Registries, 1975-2004, National Cancer Institute, 2007.

Mammography within the past 2 years among women age 40+
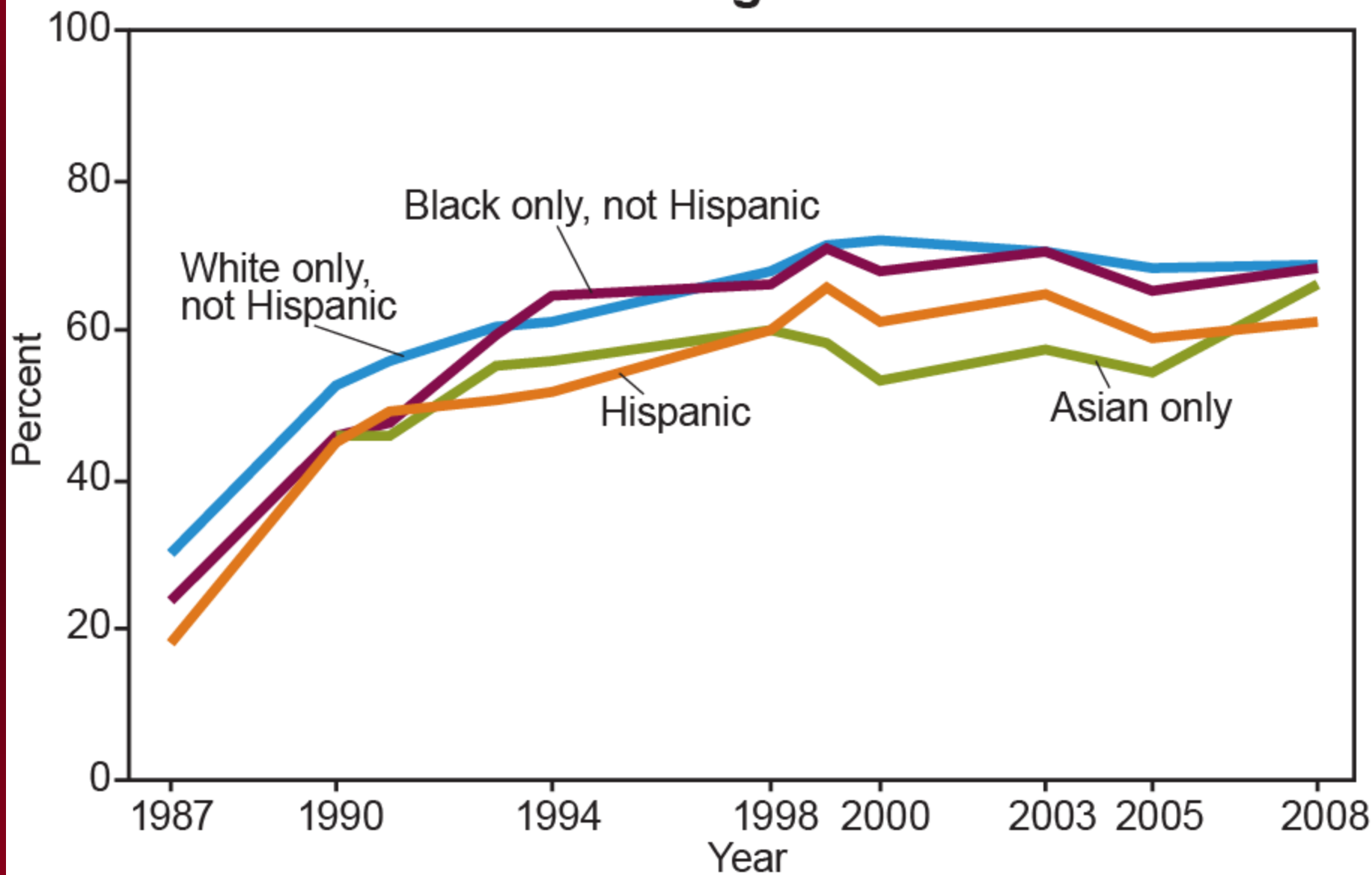
Black only, not Hispanic

White only, not Hispanic

Hispanic

Asian only

Percent

Year

Breast cancer mortality rates (age 35-74) in selected developed countries
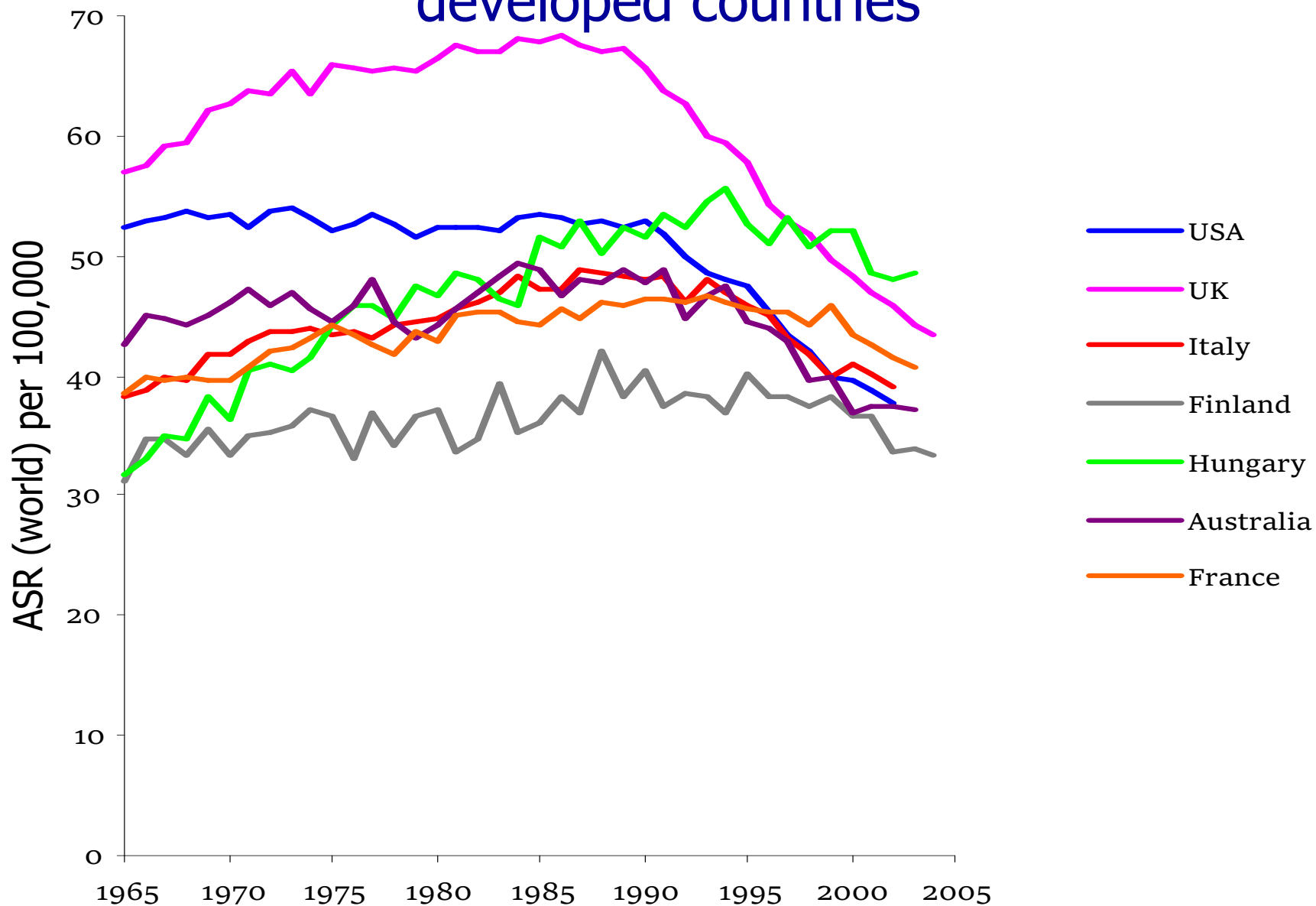
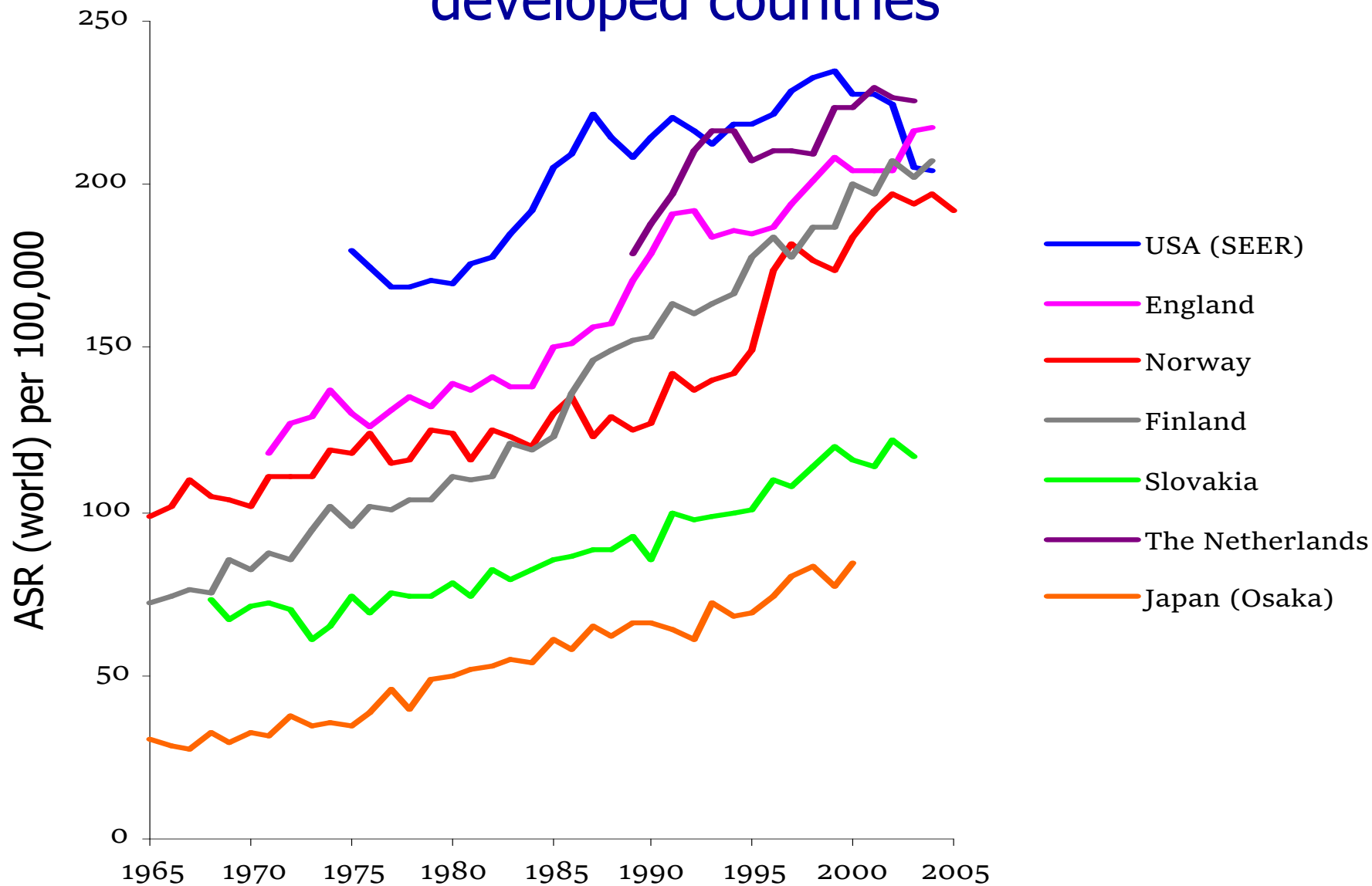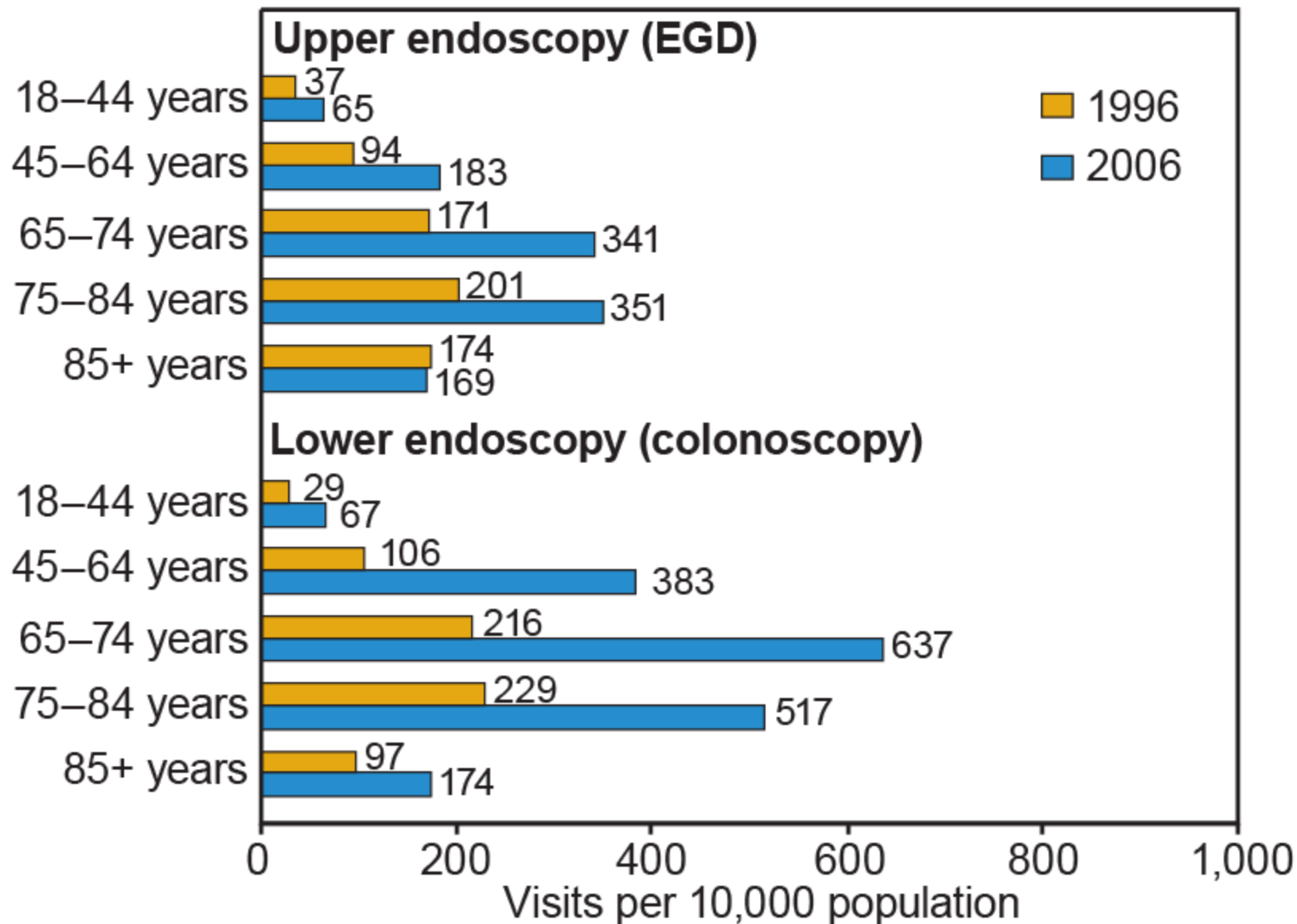Breast cancer incidence rates (age 35-74) in selected developed countries

Ambulatory visits for upper endoscopy and colonoscopy

Upper endoscopy (EGD)

Age	1996	2006
18–44 years	37	65
45–64 years	94	183
65–74 years	171	341
75–84 years	201	351
85+ years	174	169

Lower endoscopy (colonoscopy)

| Age	1996	2006
18–44 years	29	67
45–64 years	106	383
65–74 years	216	637
75–84 years	229	517
85+ years	97	174

Visits per 10,000 population

EGD is esophagogastroduodenoscopy.
SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 30. Data from the National Survey of Ambulatory Surgery.

US advantage in cancer screening and treatment

■ **Compared to European countries, the US performs particularly well in terms of cancer screening and cancer survival. (Ho, Preston, 2010)**

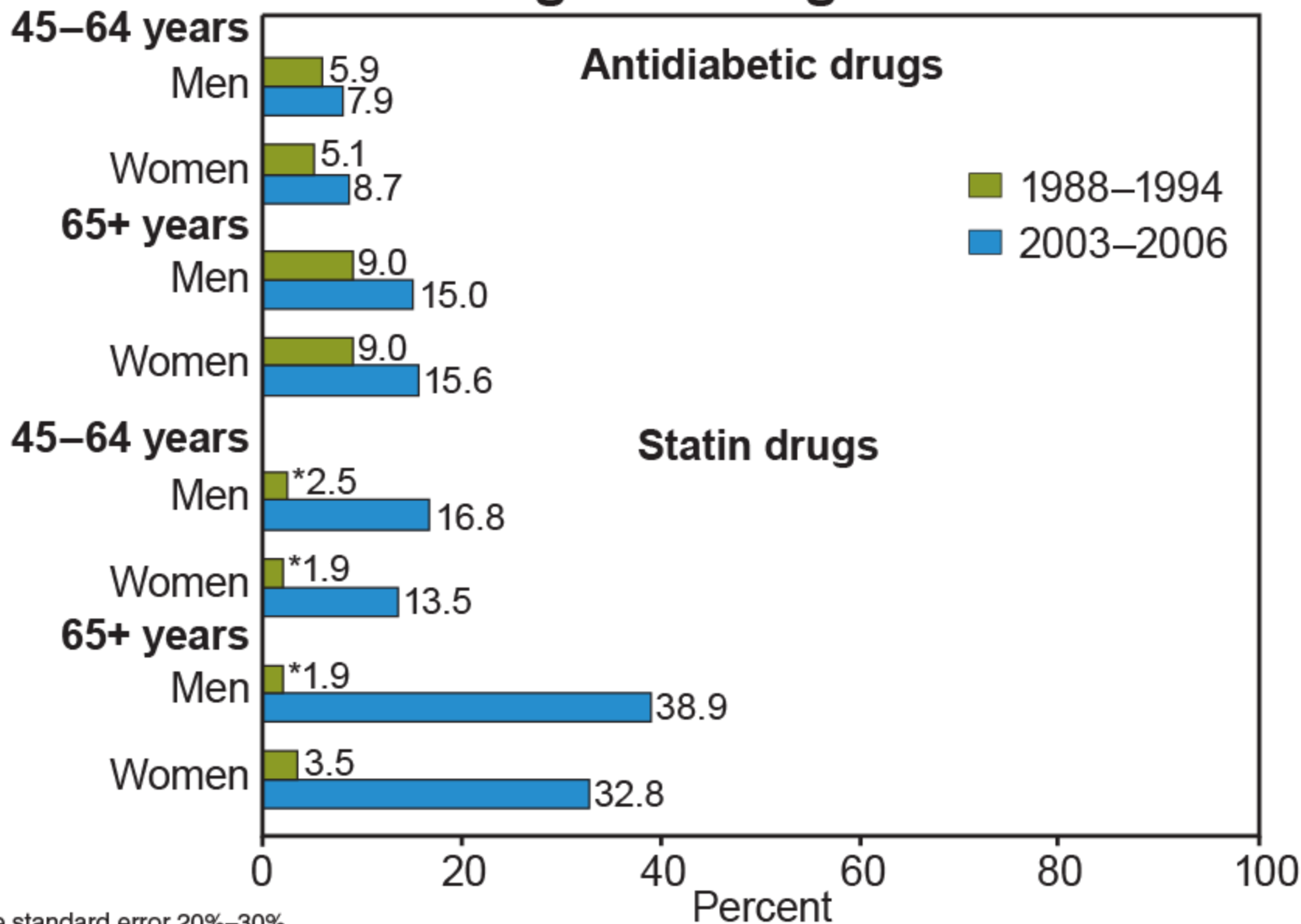# Change in the US Death Rates* by Cause, 1950 & 2005

Rate Per 100,000
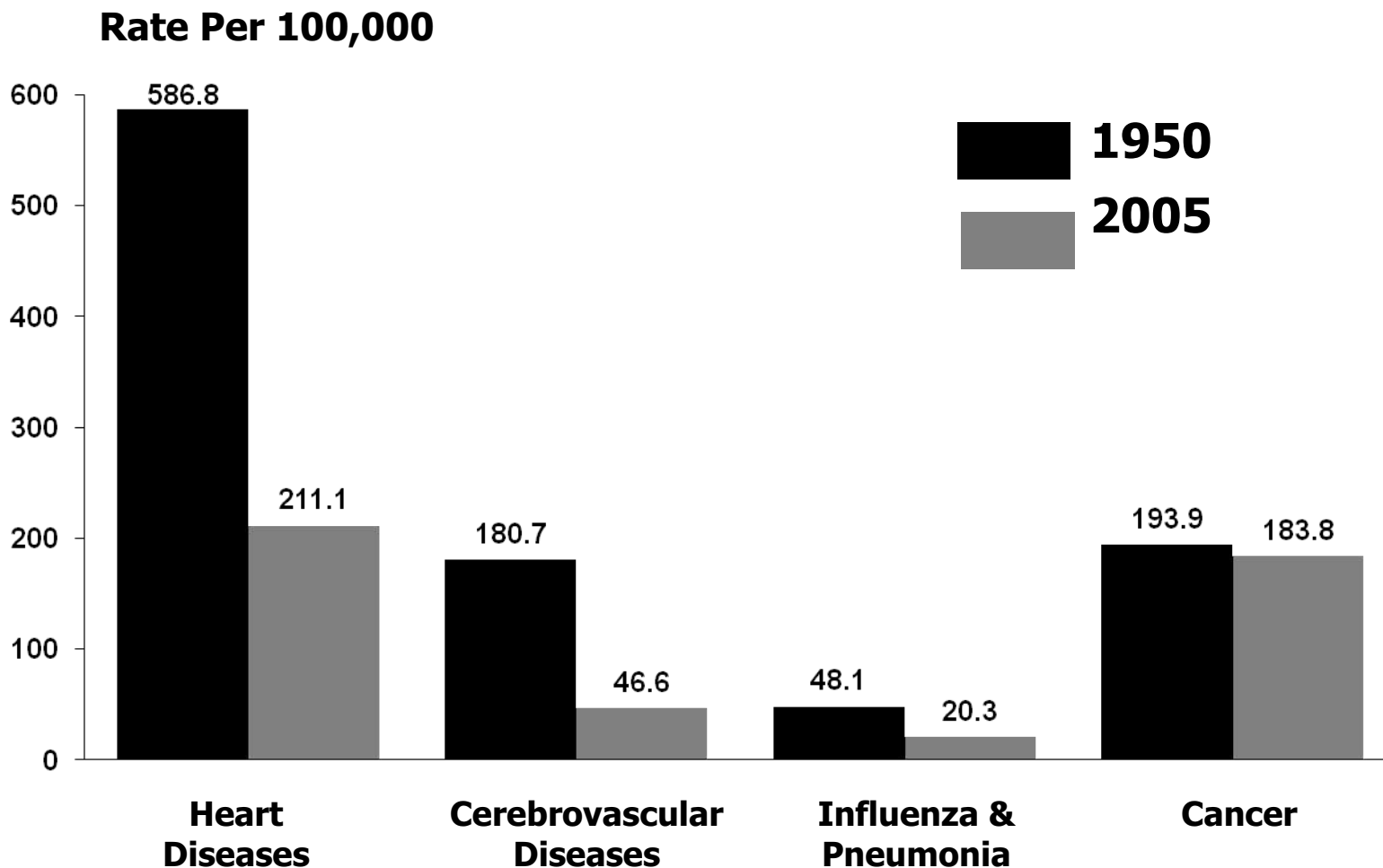
* Age-adjusted to 2000 US standard population.
Sources: 1950 Mortality Data - CDC/NCHS, NVSS, Mortality Revised.
2005 Mortality Data: US Mortality Data 2005, NCHS, Centers for Disease Control and Prevention, 2008.

Antidiabetic drug use and statin use in the past month among adults age 45+

Antidiabetic drugs

45–64 years
- Men: 5.9 (1988–1994), 7.9 (2003–2006)
- Women: 5.1 (1988–1994), 8.7 (2003–2006)

65+ years
- Men: 9.0 (1988–1994), 15.0 (2003–2006)
- Women: 9.0 (1988–1994), 15.6 (2003–2006)

Statin drugs

45–64 years
- Men: *2.5 (1988–1994), 16.8 (2003–2006)
- Women: *1.9 (1988–1994), 13.5 (2003–2006)

65+ years
- Men: *1.9 (1988–1994), 38.9 (2003–2006)
- Women: 3.5 (1988–1994), 32.8 (2003–2006)

Legend:
- 1988–1994
- 2003–2006

Percent (x-axis: 0, 20, 40, 60, 80, 100)
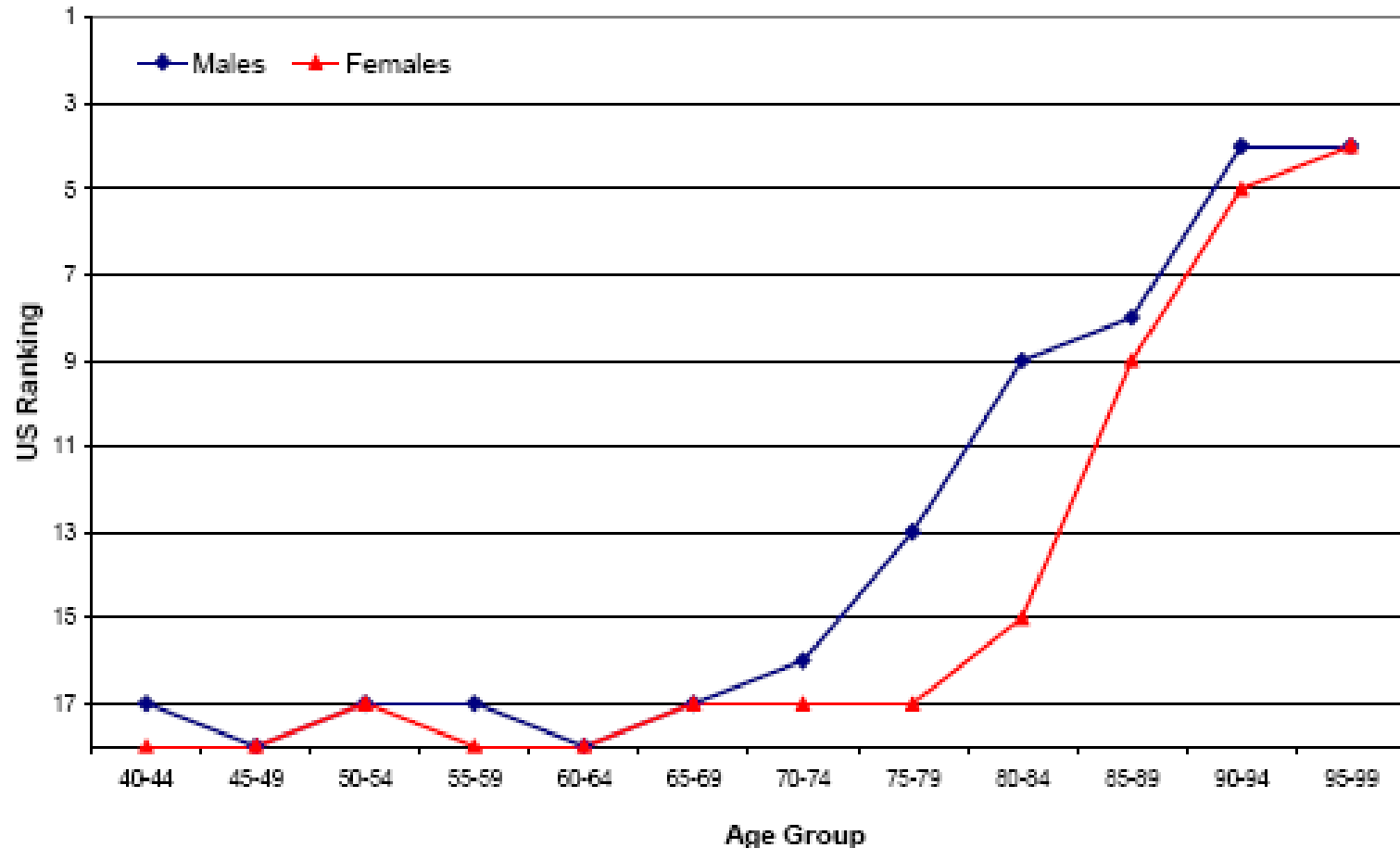
* Relative standard error 20%–30%.
SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 34. Data from the National Health and Nutrition Examination Survey.

Effect of Pharmaceutical Innovation on Mortality, by Age
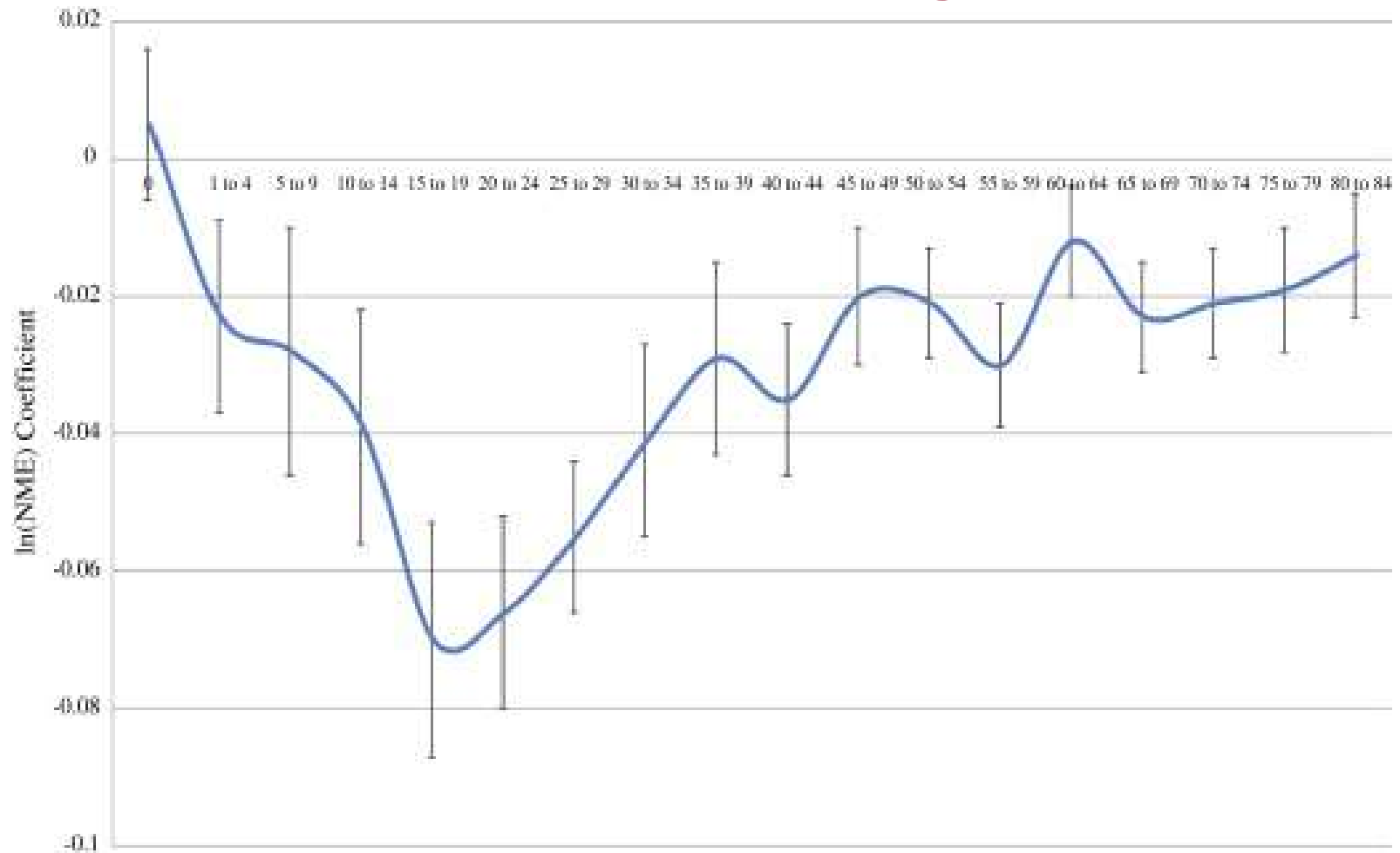
Source: Schnittker J, Karandinos G (2010). Social Science & Medicine.

# Ranking of US age-specific death rates among a comparison set of 18 of OECD countries in 2005

OECD – Organization for Economic Cooperation and Development.
From Ho and Preston (2010)

US life expectancy at age 75 has much better ranking among developed countries compared to LE at age 50

■ **"Unusually vigorous deployment of life-saving technologies by the US health care system at very old age is contributing to the age-pattern of US mortality rankings" (Ho, Preston, 2010 annual meeting of the Population Association of America, Dallas, TX)**

Changes in female LE at age 65 in the United States between 1984 and 2000, by cause
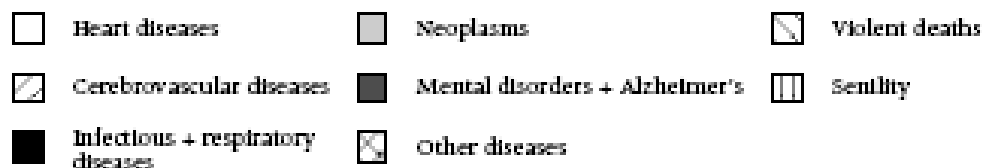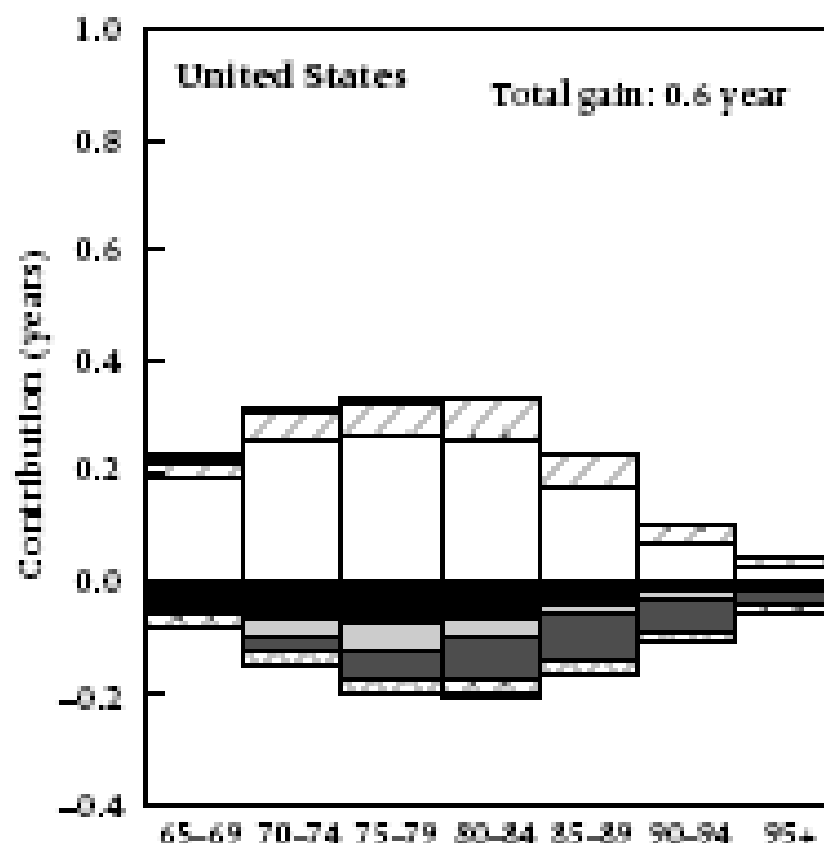
In the U.S. gains in life expectancy due to mortality reduction from heart diseases were offset by mortality increase from mental disorders, cancer, infectious and respiratory diseases.

At the same time, France and Japan enjoyed total gain in LE of more than 2.5 years with mortality reduction from almost all causes.

Mesle, Vallin, 2006. Population and Development Review, 32: 123-145.

# Mortality at older ages may be sensitive to many factors

- **Accessibility and quality of medical care**
- **Life style and proper nutrition**
- **Social networking, etc.**
- **Many risk factors of middle age do not work at older ages**
- **This may create divergent trends in different countries and uncertainty in longevity forecasts**
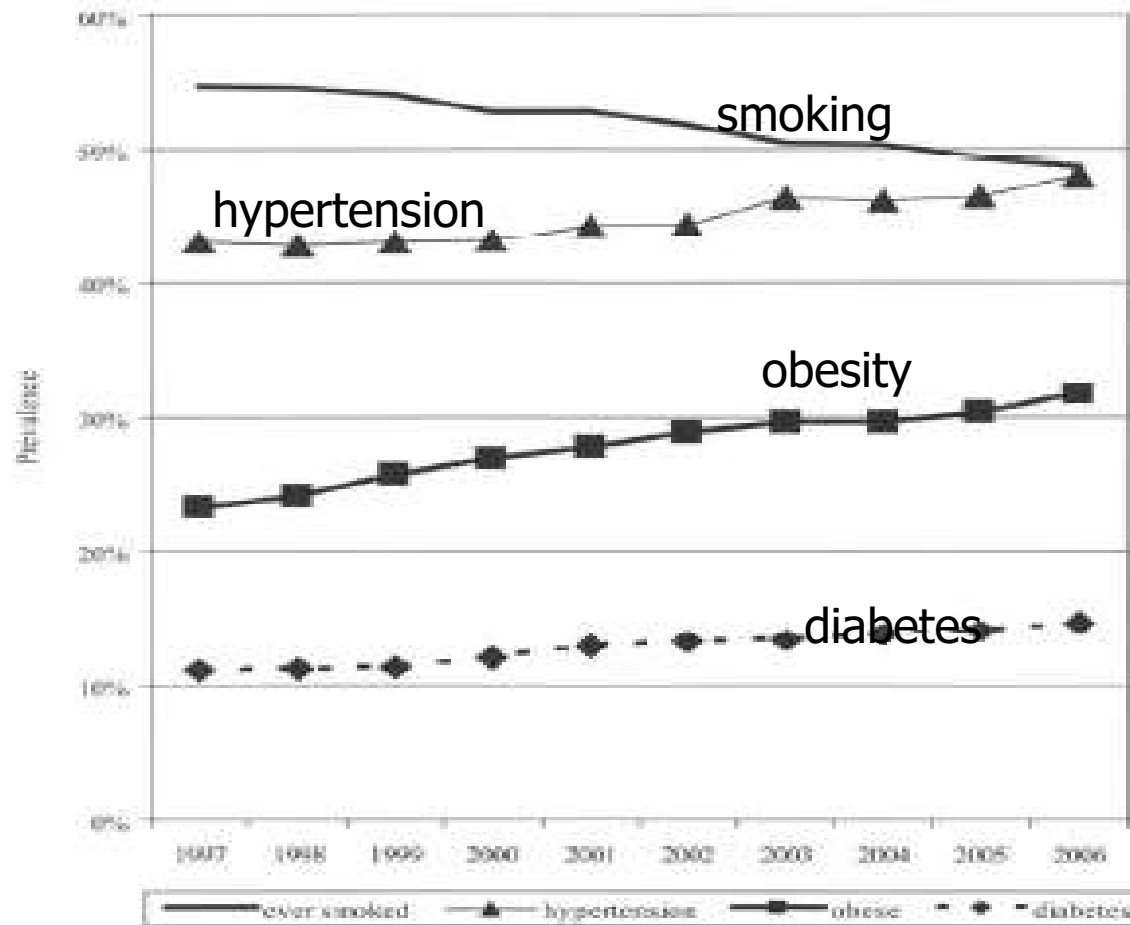
Life Expectancy and Month of Birth

Data source: Social Security Death Master File

Published in:

Gavrilova, N.S., Gavrilov, L.A. Search for Predictors of Exceptional Human Longevity. In: "*Living to 100 and Beyond*" Monograph. The Society of Actuaries, Schaumburg, Illinois, USA, 2005, pp. 1-49.
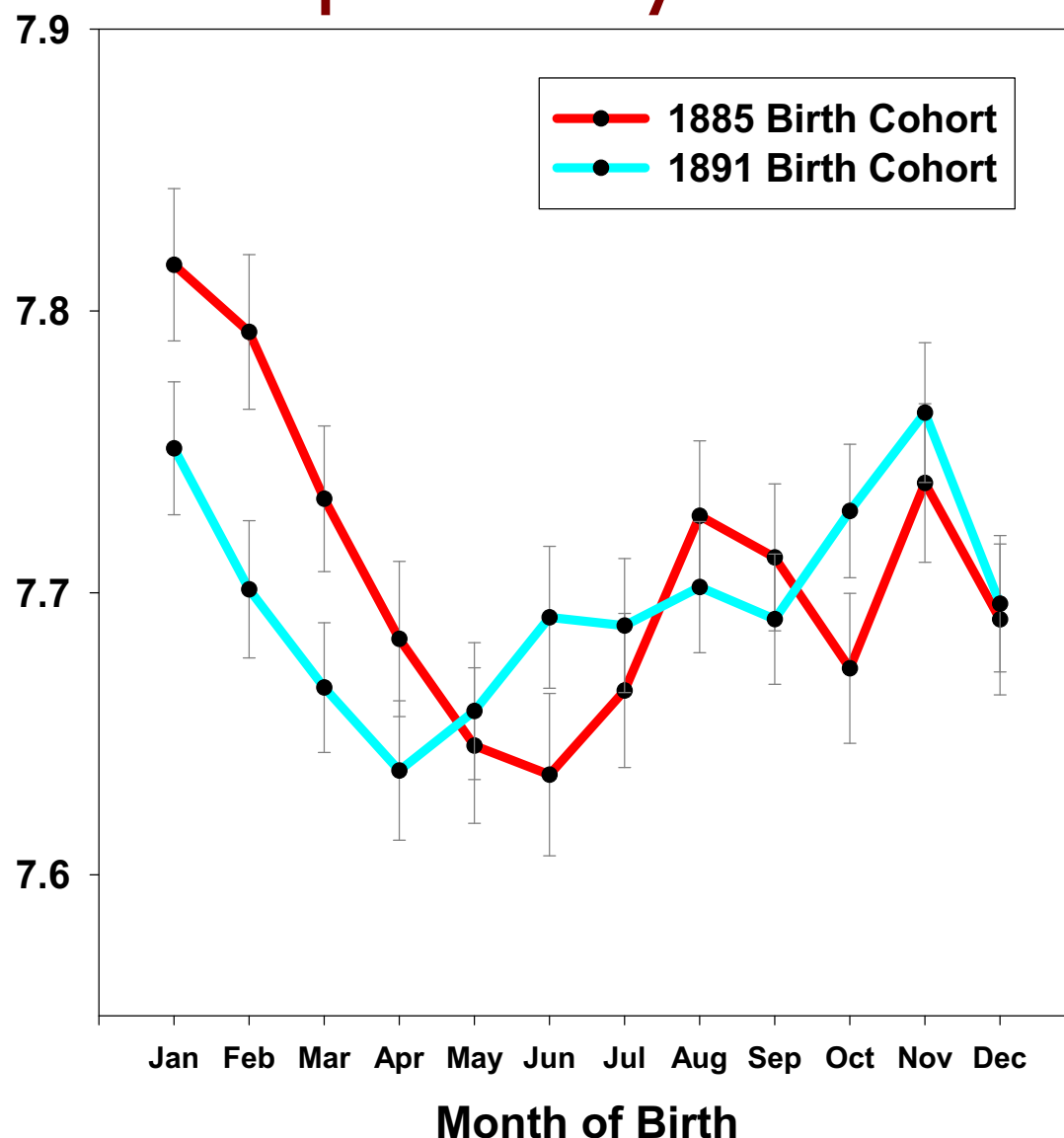
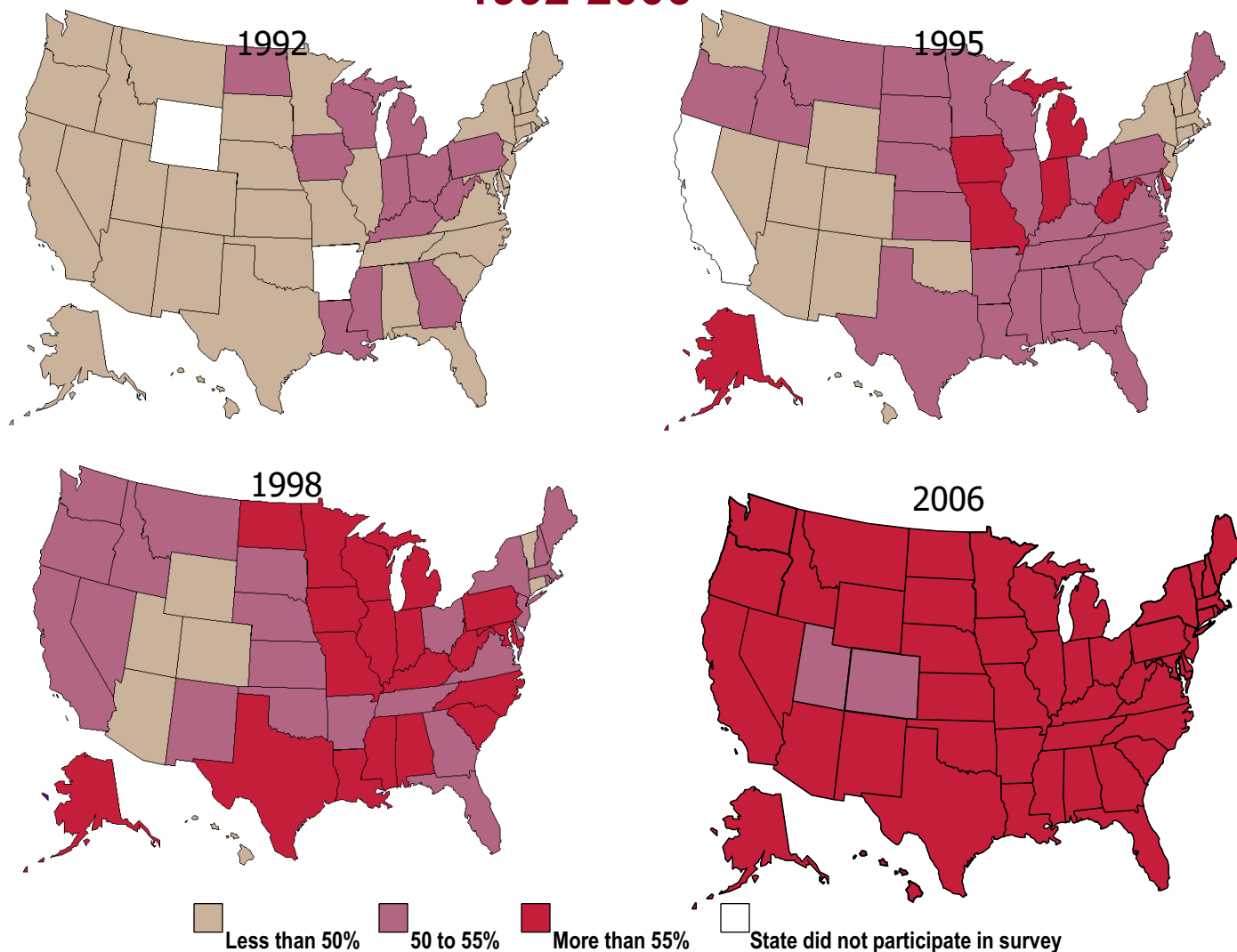# U.S. trends in selected health outcomes (age 50+)

Source: Goldman et al., National Tax Journal, 2010. Data from the National Health Interview Survey
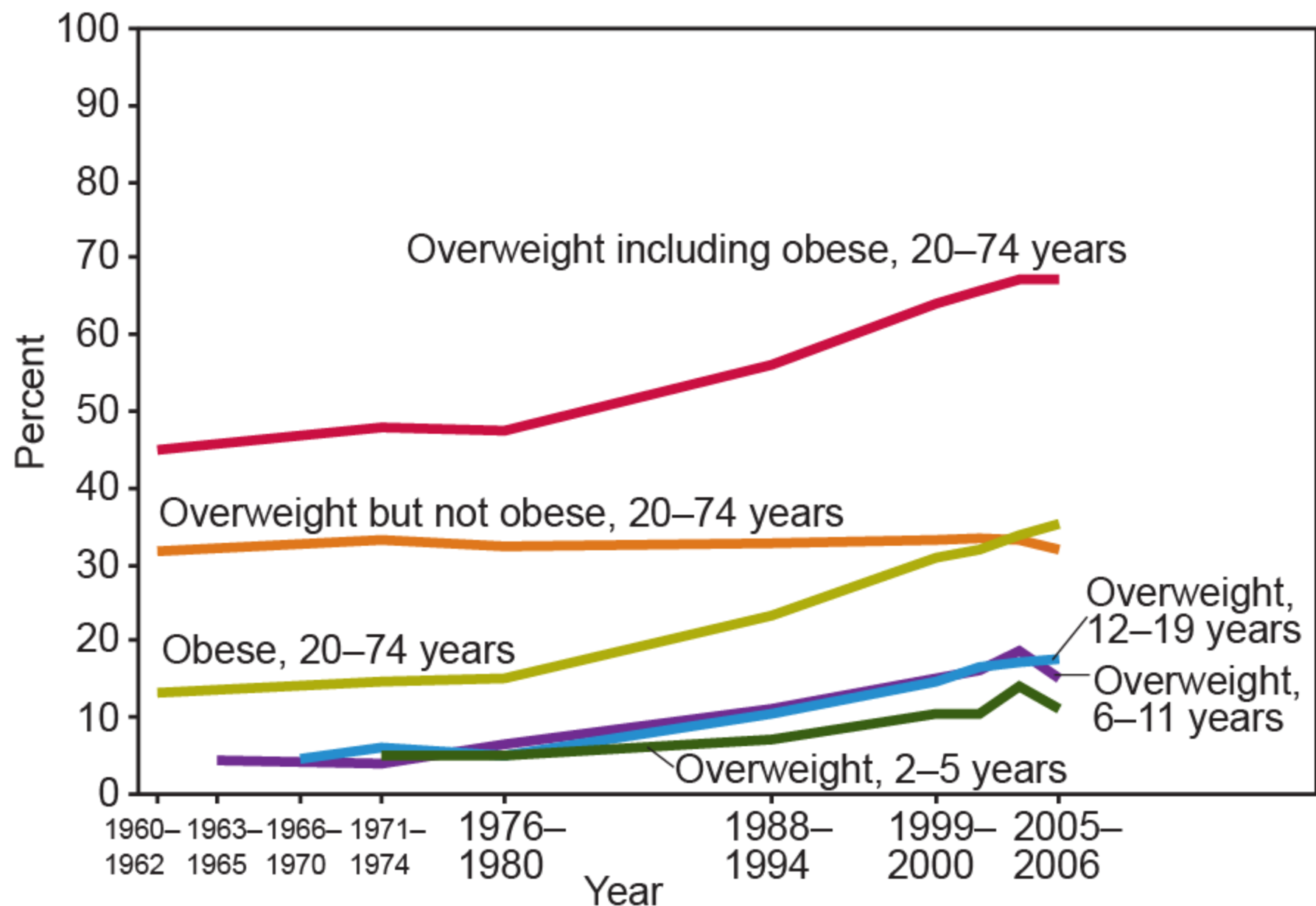
Obesity

- **Receives now the most attention of politicians and mass media**

Trends in Overweight* Prevalence (%), Adults 18 and Older, US, 1992-2006

1992

1995

1998

2006

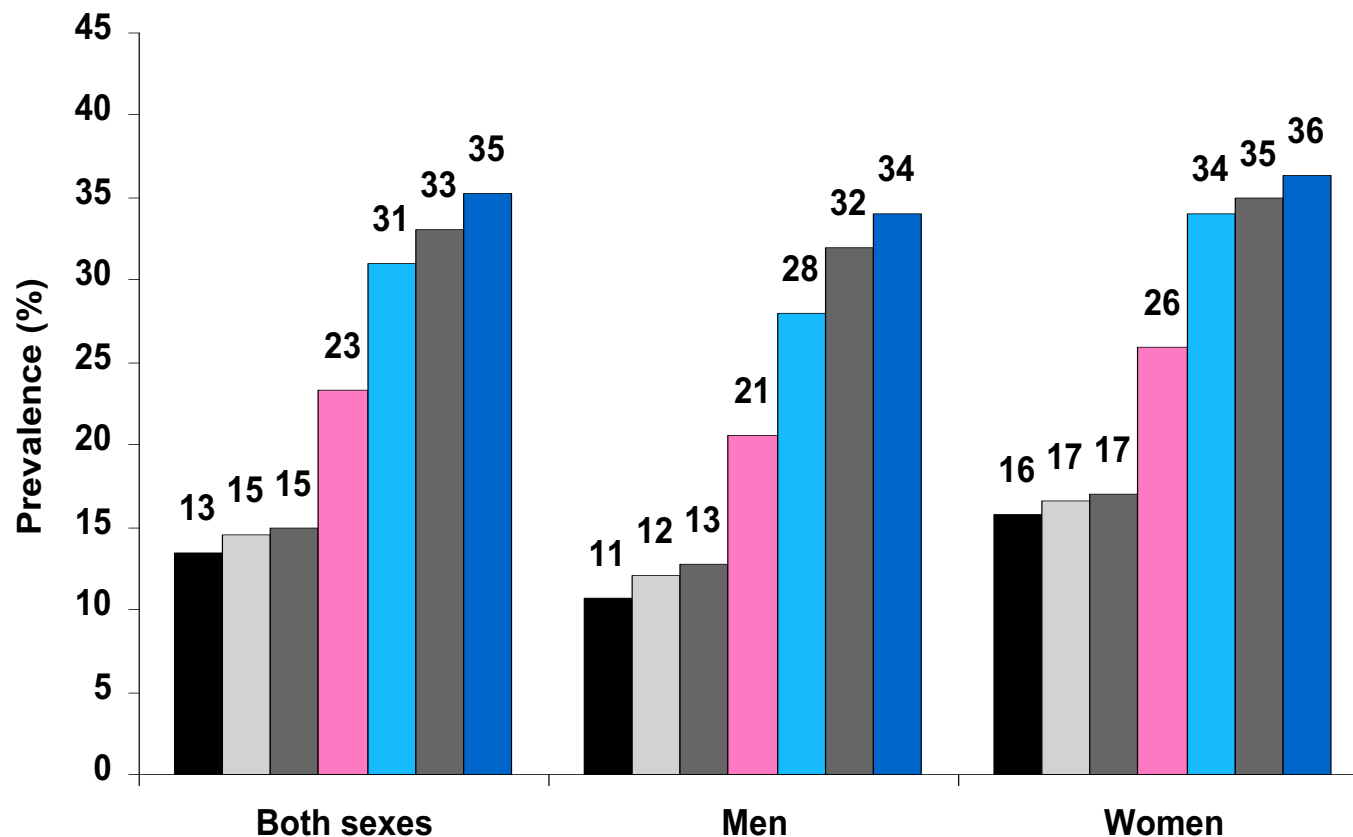Less than 50%   50 to 55%   More than 55%   State did not participate in survey

*Body mass index of 25.0 kg/m²or greater. Source: Behavioral Risk Factor Surveillance System, CD-ROM (1984-1995, 1998) and Public Use Data Tape (2004, 2006), National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 1997, 2000, 2005, 2007.

Overweight and obesity

Overweight including obese, 20–74 years

Overweight but not obese, 20–74 years

Obese, 20–74 years

Overweight, 12–19 years

Overweight, 6–11 years

Overweight, 2–5 years

(Y-axis: Percent; X-axis: Year — 1960–1962, 1963–1965, 1966–1970, 1971–1974, 1976–1980, 1988–1994, 1999–2000, 2005–2006)

Trends in Obesity* Prevalence (%), By Gender, Adults Aged 20 to 74, US, 1960-2006†

Prevalence (%) (y-axis)

Both sexes:
- NHES I (1960-62): 13
- NHANES I (1971-74): 15
- NHANES II (1976-80): 15
- NHANES III (1988-94): 23
- NHANES 1999-2002: 31
- NHANES 2003-2004: 33
- NHANES 2005-2006: 35

Men:
- NHES I (1960-62): 11
- NHANES I (1971-74): 12
- NHANES II (1976-80): 13
- NHANES III (1988-94): 21
- NHANES 1999-2002: 28
- NHANES 2003-2004: 32
- NHANES 2005-2006: 34

Women:
- NHES I (1960-62): 16
- NHANES I (1971-74): 17
- NHANES II (1976-80): 17
- NHANES III (1988-94): 26
- NHANES 1999-2002: 34
- NHANES 2003-2004: 35
- NHANES 2005-2006: 36

Legend:
- ■ NHES I (1960-62)
- ■ NHANES I (1971-74)
- ■ NHANES II (1976-80)
- ■ NHANES III (1988-94)
- ■ NHANES 1999-2002
- ■ NHANES 2003-2004
- ■ NHANES 2005-2006

*Obesity is defined as a body mass index of 30 kg/m² or greater. † Age adjusted to the 2000 US standard population. Source: National Health Examination Survey 1960-1962, National Health and Nutrition Examination Survey, 1971-1974, 1976-1980, 1988-1994, 1999-2002, National Center for Health Statistics, Centers for Disease Control and Prevention, 2002, 2004. 2003-2004, 2005-2006: National Health and Nutrition Examination Survey Public Use Data Files, 2003-2004, 2005-2006, National Center for Health Statistics, Centers for Disease Control and Prevention, 2006,

Trends in Overweight* Prevalence (%), Children and Adolescents, by Age Group, US, 1971-2004
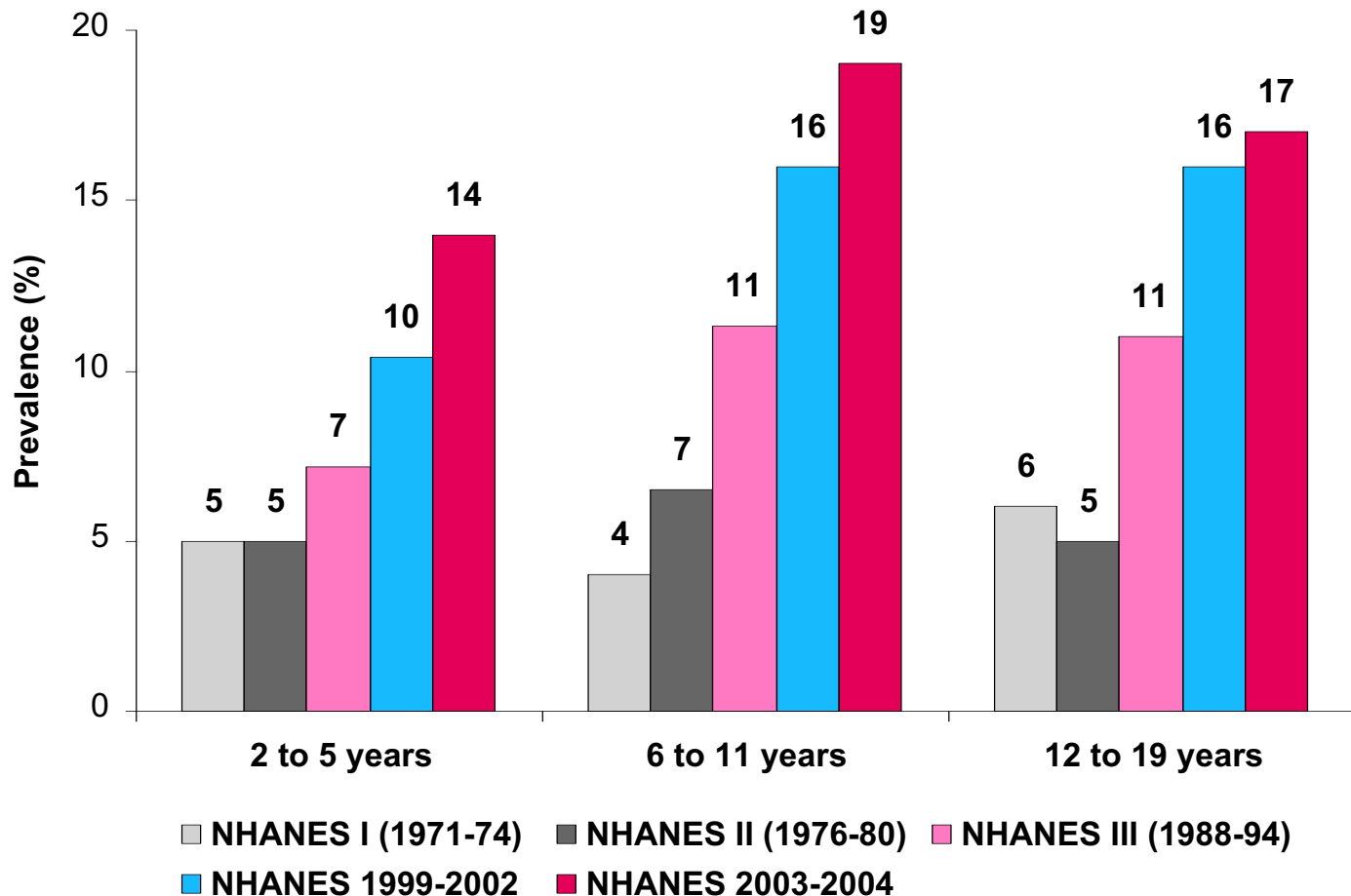
*Overweight is defined as at or above the 95th percentile for body mass index by age and sex based on reference data.

Source: National Health and Nutrition Examination Survey, 1971-1974, 1976-1980, 1988-1994, 1999-2002, National Center for Health Statistics, Centers for Disease Control and Prevention, 2002, 2004.

2003-2004: Ogden CL, et al. Prevalence of Overweight and Obesity in the United States, 1999-2004.

Obesity does not give much chance to survive to 100

A study of body height and body build of centenarians when they were young adults (aged 30) using WWI civil draft registration cards.

Gavrilova N.S., Gavrilov L.A. Can exceptional longevity be predicted? *Contingencies* [Journal of the American Academy of Actuaries], 2008, July/August issue, pp. 82-88.
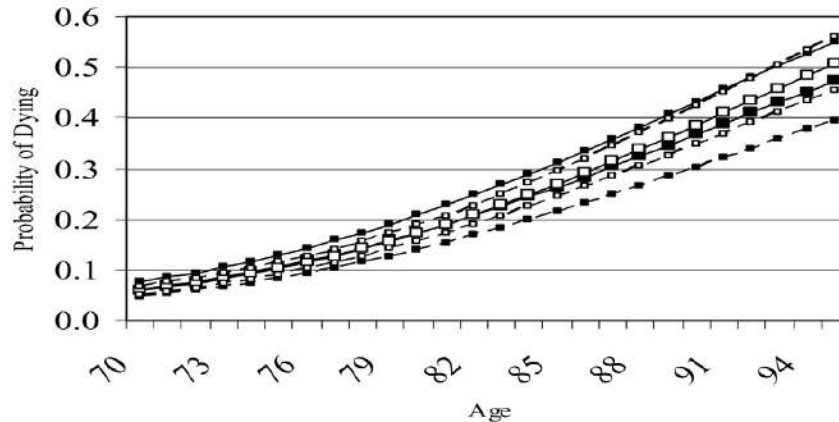
Results of multivariate study

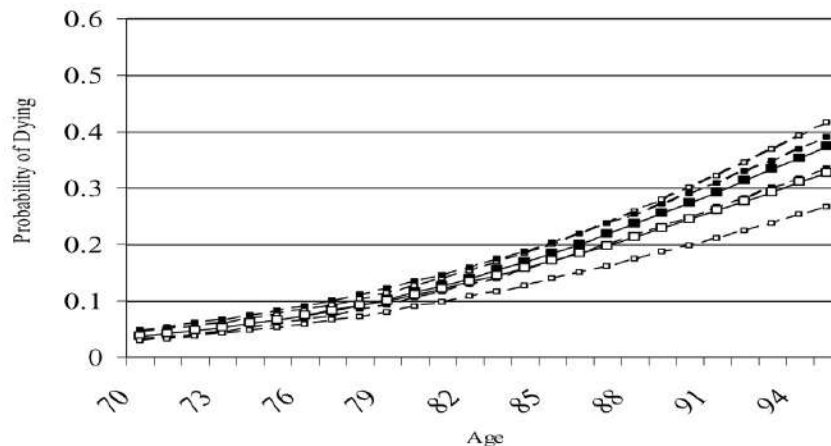| Variable	Odds Ratio	P-value
Medium height vs short and tall height	1.35	0.260
Slender and medium build vs stout build	2.63*	0.025
Farming	2.20*	0.016
Married vs unmarried	0.68	0.268
Native born vs foreign b.	1.13	0.682

Controversy of obesity:
Obesity may be beneficial at older ages at least for men

(A) Men

(B) Women

Estimated 2-year probability of dying (confidence intervals) for obese and nonobese men and women aged 70 and older: AHEAD 1993–1998 (a **black square represents obese individuals**, and a white box represents nonobese individuals).

**Reynolds S L et al. The Gerontologist 2005;45:438-444**

Smoking Kills, Obesity Disables:
A Multistate Approach of the US Health and Retirement Survey
Adults aged 55+

Loss or gains in life years	Men			Women		
	Total	Active	ADL disab	Total	Active	ADL disab
BMI 18.5-22.9	-1.8	-1.1	-0.7	0.4	0.1	-0.5
BMI 23-24.9 *	24.5	19.5	5.1	28.7	21.8	6.9
BMI 25-29.9	0.6	0.2	0.4	0.6	-1.5	+2.1
BMI 30-34.9	-0.6	-2.7	+2.0	-0.4	-3.6	+3.2
Never smoked *	27.6	21.4	6.2	30.4	22.0	8.4
Stopped smoking	-2.8	-1.9	-0.9	-1.6	-0.7	-0.9
Currently smoking	-7.7	-6.4	-1.3	-6.6	-5.2	-1.4
Low education	-2.8	-3.6	0.7	-3.2	-3.3	0.0
Medium education	-1.7	-2.1	0.4	-1.0	-0.4	-0.6
High education *	26.2	21.1	5.1	30.1	21.9	8.2
All (excl. severely obese)	24.6	19.1	5.5	28.7	20.8	7.9

- **Source: Reuser, Bonneux, Willekens. Obesity, 2009.**

BMI and risk of disability and mortality
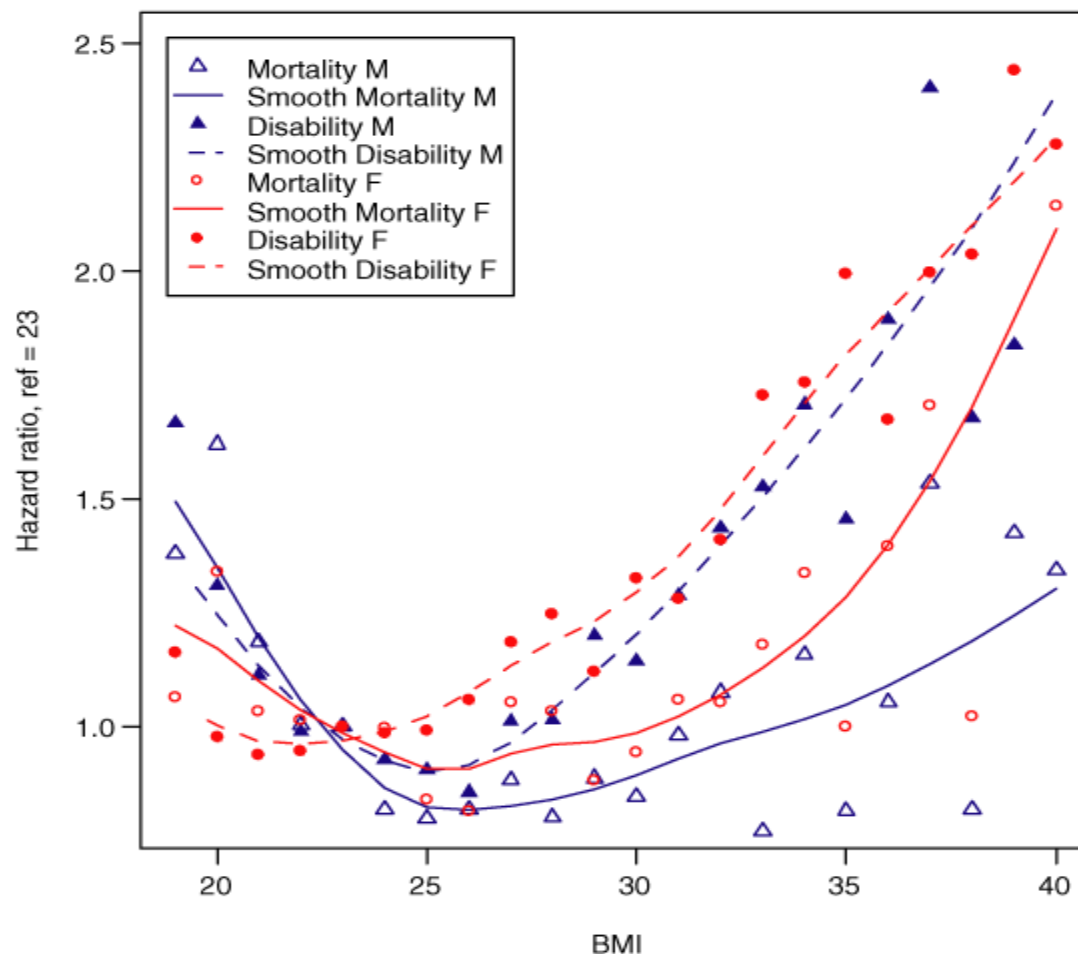
■ **Source: Reuser, Bonneux, Willekens. Obesity, 2010**

Is Caloric Restriction an Answer to the Obesity Epidemic at Older Ages?

**Professor John E. Morley is an authority in geriatric medicine**

John E. Morley et al., Current Opinion in Clinical Nutrition and Metabolic Care (2010):

- **"Dietary restriction in rodents has not been shown to be effective when started in older rodents. Weight loss in humans over 60 years of age is associated with increased mortality, hip fracture and increased institutionalization. Calorie restriction in older persons should be considered experimental and potentially dangerous. Exercise at present appears to be a preferable treatment for older persons."**

Slow improvement in physical activity among U.S. adults

Trends in Prevalence (%) of No Leisure-Time Physical Activity, by Educational Attainment, Adults 18 and Older, US, 1992-2006
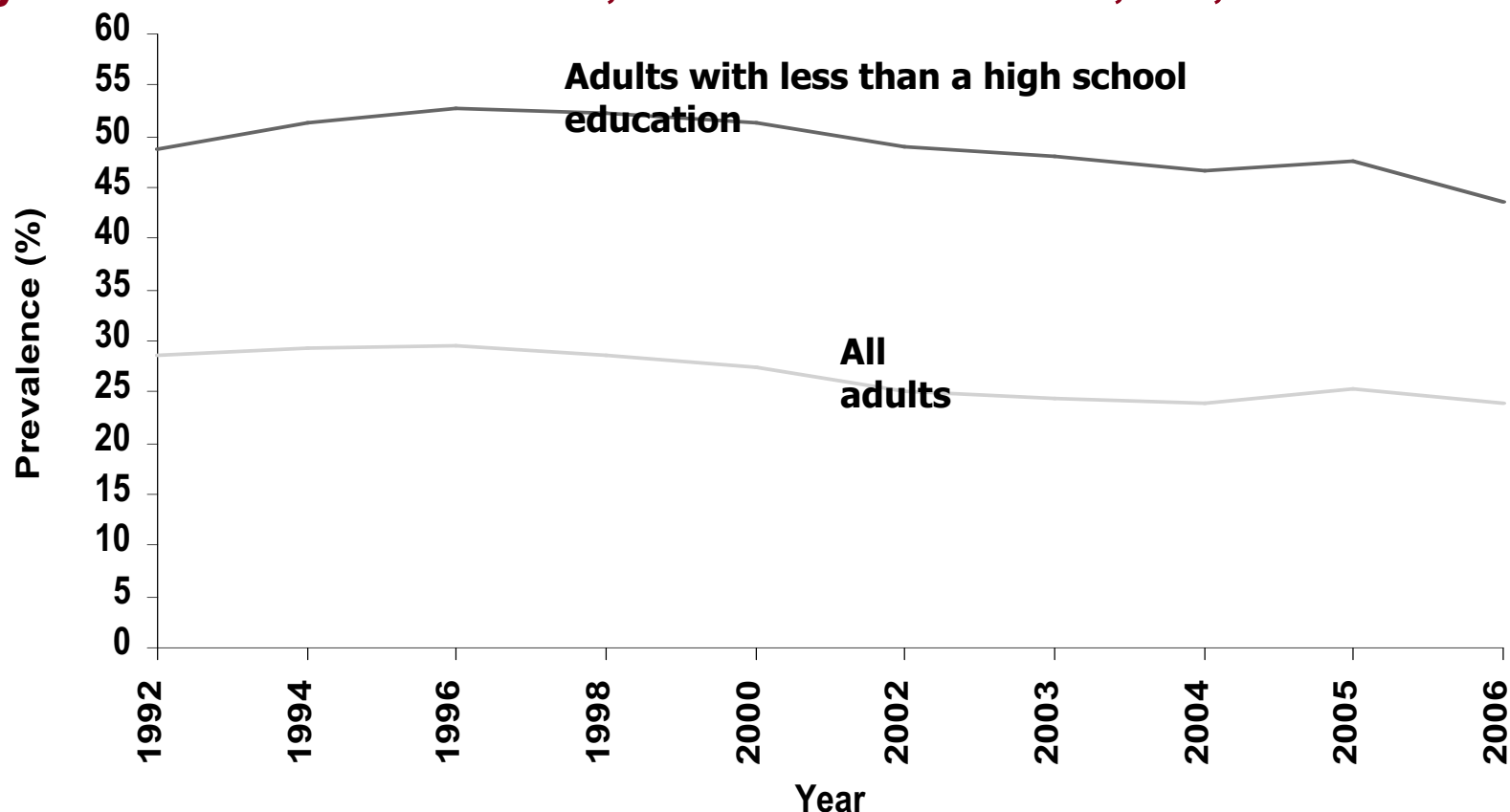
Note: Data from participating states and the District of Columbia were aggregated to represent the United States. Educational attainment is for adults 25 and older.
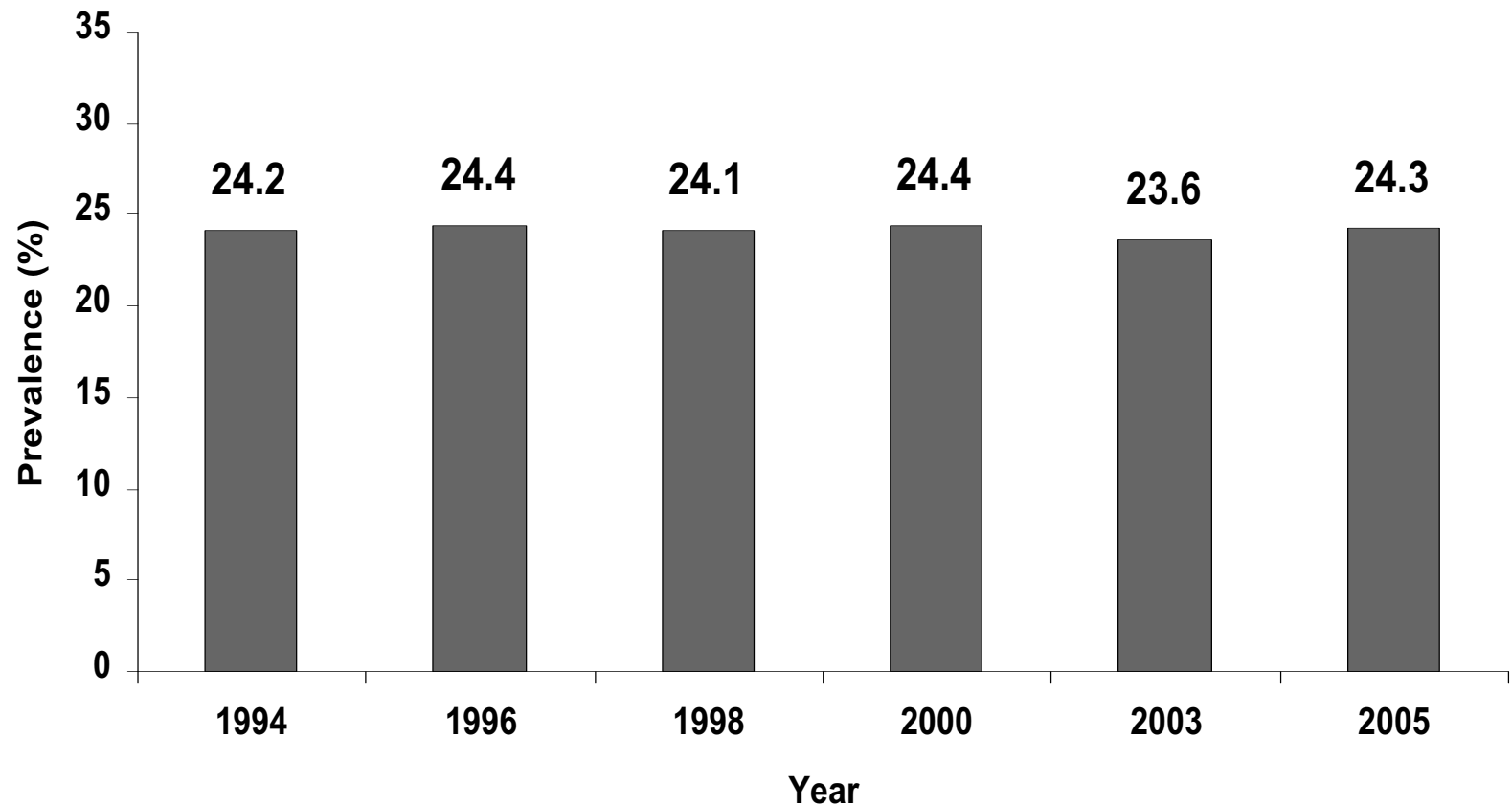Source: Behavioral Risk Factor Surveillance System CD-ROM (1984-1995, 1996, 1998) and Public Use Data Tape (2000, 2002, 2004, 2005, 2006), National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 1997, 1999, 2000, 2001, 2003, 2005, 2006, 2007.

Changes in Diet

Both good and bad trends

- **On one hand, improvement in food safety and quality. Better awareness that fruits and veggies are useful for health**

- **On the other hand, more salt and sugar in food and beverages. Higher consumption of carbs increases risk of diabetes**

Trends in Consumption of Five or More Recommended Vegetable and Fruit Servings for Cancer Prevention, Adults 18 and Older, US, 1994-2005


Note: Data from participating states and the District of Columbia were aggregated to represent the United States.
Source: Behavioral Risk Factor Surveillance System CD-ROM (1984-1995, 1996, 1998) and Public Use Data Tape (2000, 2003, 2005), National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 1997, 1999, 2000, 2001, 2004, 2006.
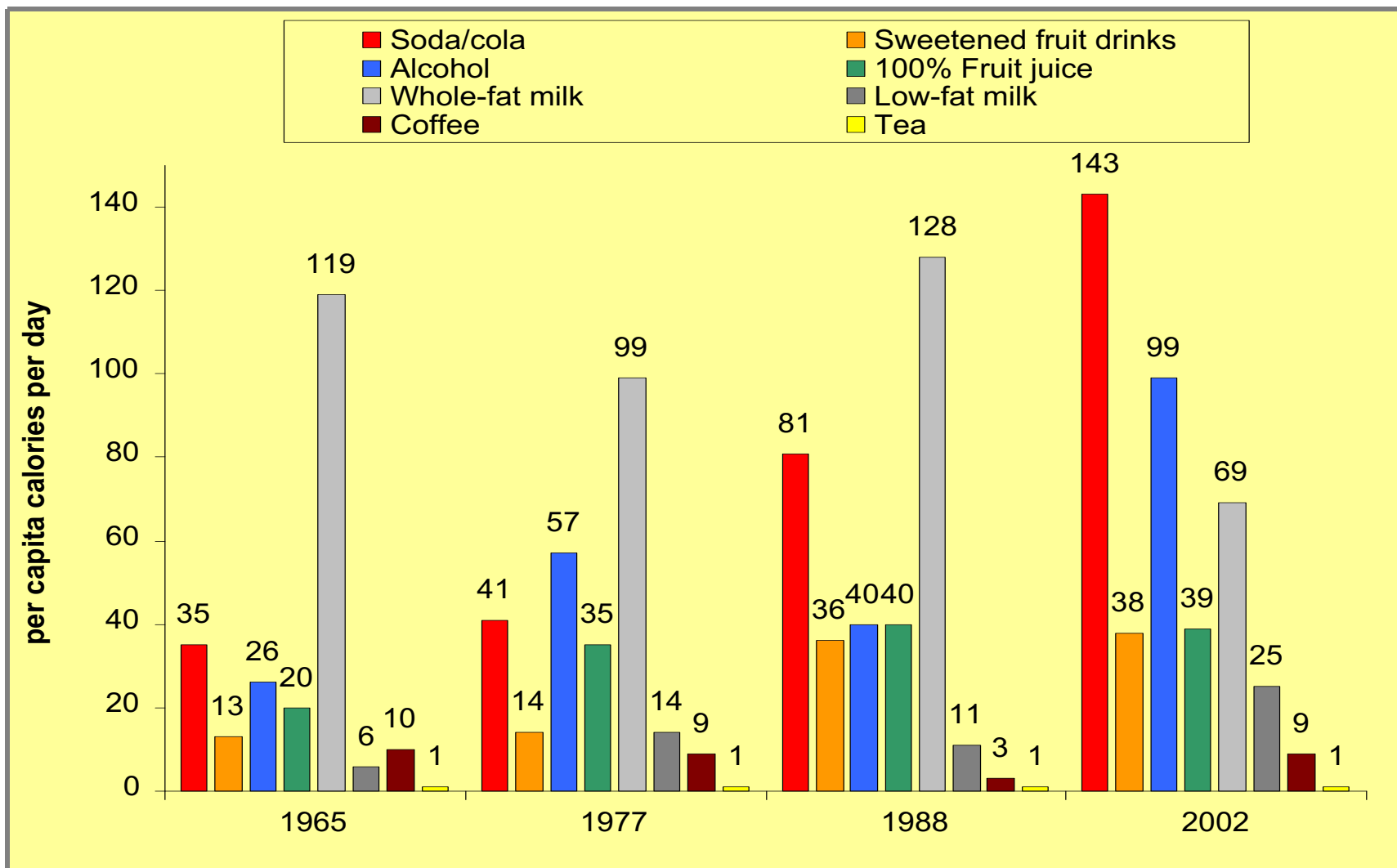
Per Capita Calories Consumed from Different Beverages by U.S. Adults (age 19 and older), 1965-2002.

Source: Nationwide Food Consumption Surveys (1965, 1977-78) and NHANES (1988-94, 1999-02); Duffey & Popkin, Obesity (Silver Spring) 2007
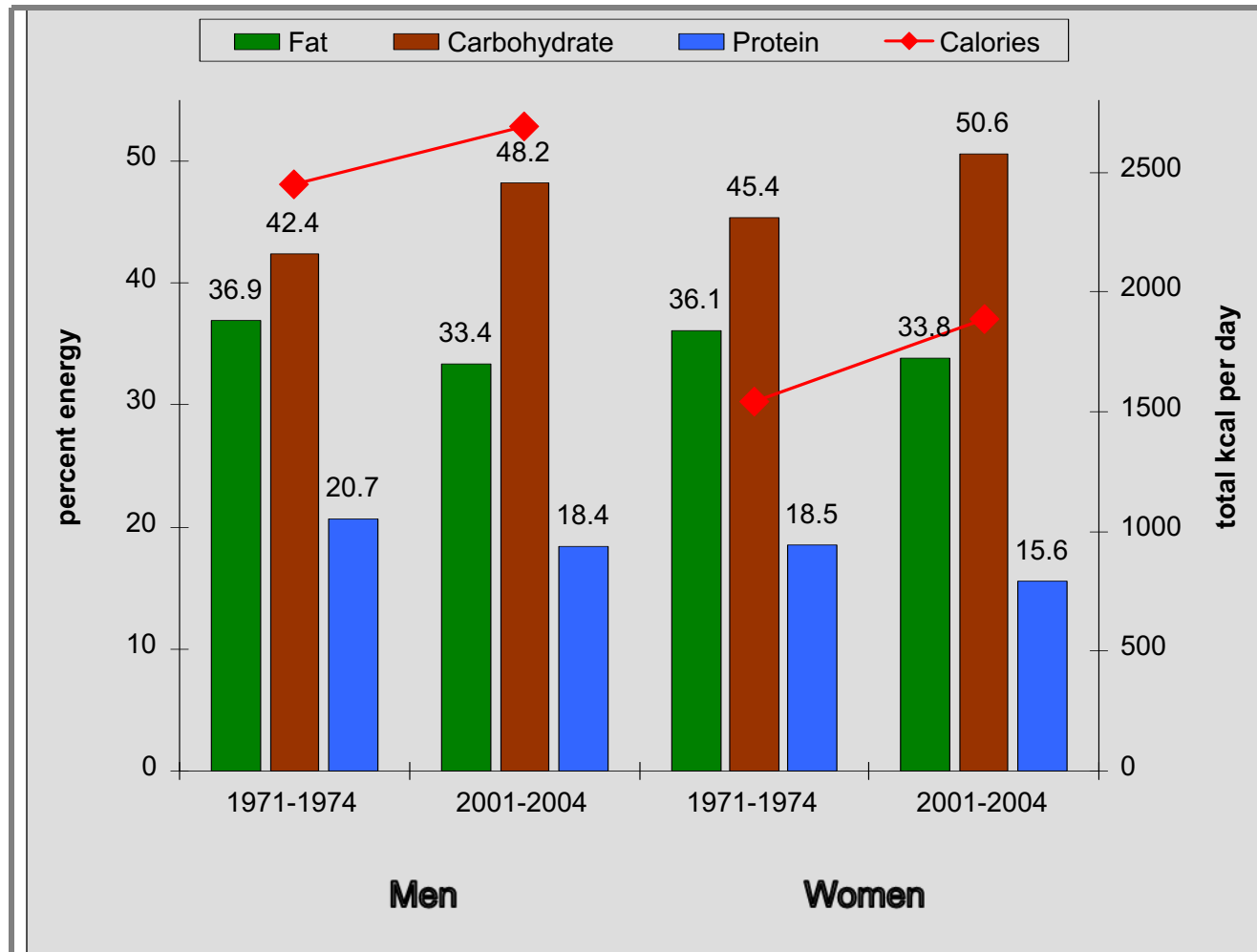
Age-Adjusted Trends in Macronutrients and Total Calories Consumed by U.S. Adults (20-74 years), 1971-2004.

Source: National Center for Health Statistics. *Health, United States 2008, With Special Focus on Young Adults.* NCHS; 2009

Risk of Flu and Pandemics

- **Olshansky SJ, Ault, A.B. The Fourth Stage of the Epidemiologic Transition: The Age of Delayed Degenerative Diseases. The Milbank Quarterly, Vol. 64, No. 3 (1986), pp. 355-391.**

- **Olshansky SJ, Carnes BA, Rogers RG, Smith L. Emerging infectious diseases: the fifth stage of the epidemiological transition? World Health Statistics Quarterly 1998;51:207-17.**

- **Barrett R, Kuzawa CW, McDade T, Armelagos GJ. Emerging and re-emerging infectious diseases: the third epidemiologic transition. Annual Review of Anthropology 1998;27:247-71.1**
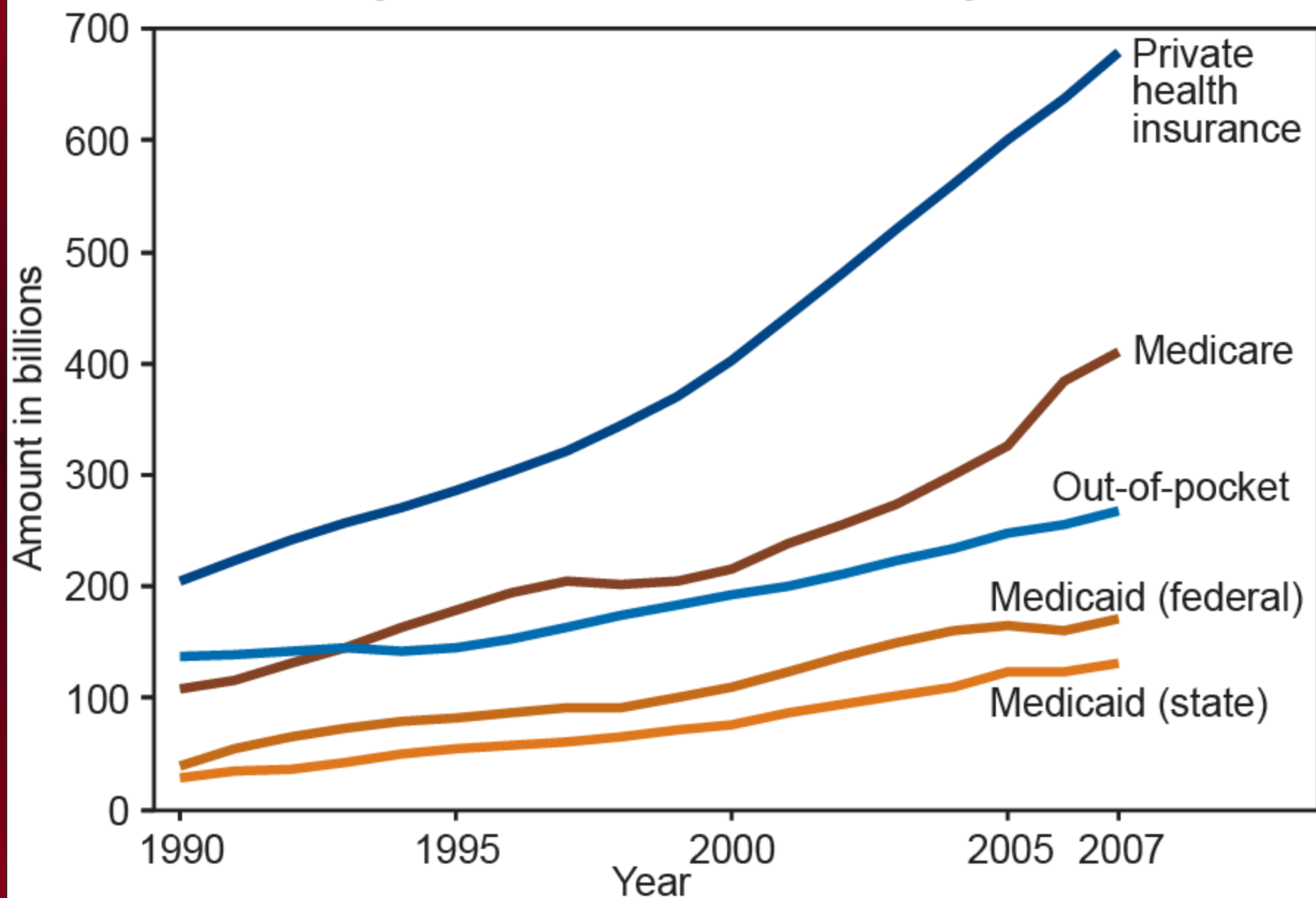
Influenza and pneumococcal vaccination
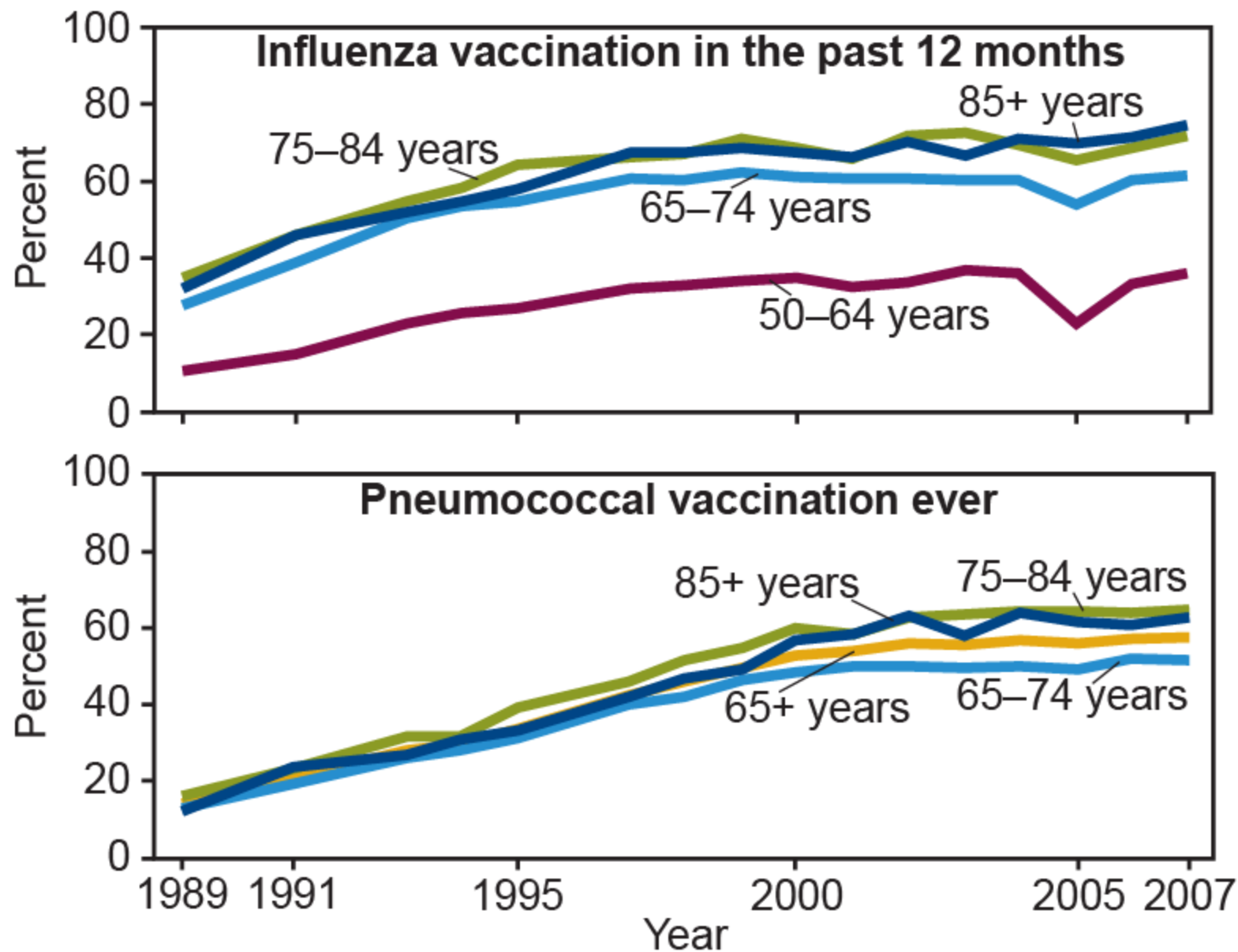
SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 9. Data from the National Health Interview Survey.
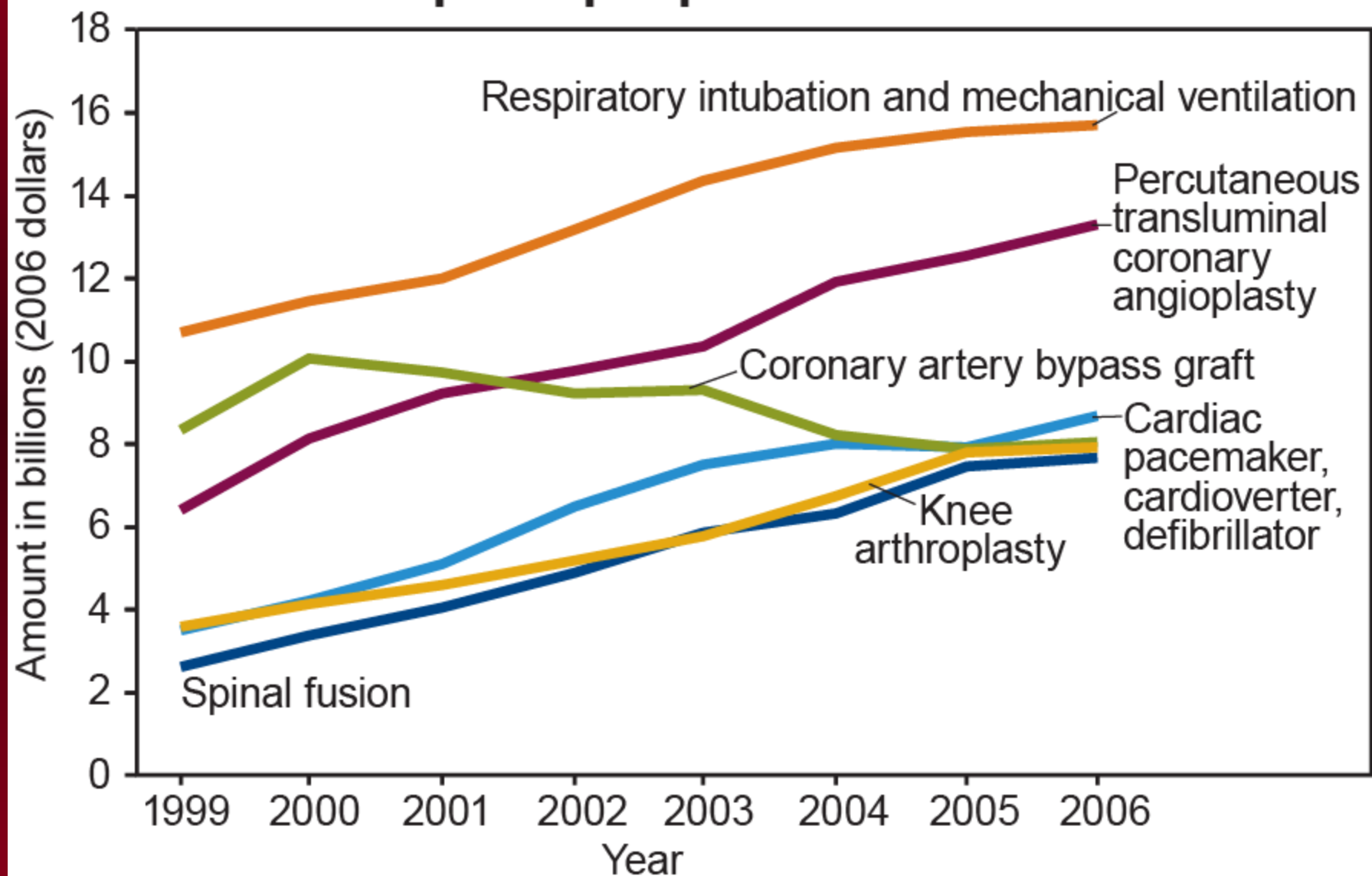
Growth of Health Care Costs

- **May decrease usage of health care**

Growth in personal health care expenditures

SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 22. Data from the Centers for Medicare & Medicaid Services.

Costs for hospital stays with the six most expensive principal procedures

SOURCE: CDC/NCHS, *Health, United States, 2009*, Figure 36. Data from the Agency for Healthcare Research and Quality.

Current trend

Widening socioeconomic inequalities in mortality

"In most [studied] countries, mortality from cardiovascular diseases declined proportionally faster in the upper socioeconomic groups." (Mackenbach et al., 2003)

Current view

- "…mortality improvement rates for UK adults across all ages have reached more than 2% a year - mainly driven by a decrease in the number of people smoking and the healthcare industry's effectiveness in reducing premature deaths, particularly from heart disease.

- However, …both of these trends have diminishing returns in improving mortality, as smoking rates have already dropped to low proportions and the decline in premature deaths related to cardiovascular disease treatments is slowing down."

Risk Management Solutions (Global Pensions - 12 Jul 2010)

We considered factors affecting gradual changes in life expectancy after age 50

What about the opportunity of radical increase in survival?

Longevity Revolution through Biotechnology and genetic engineering
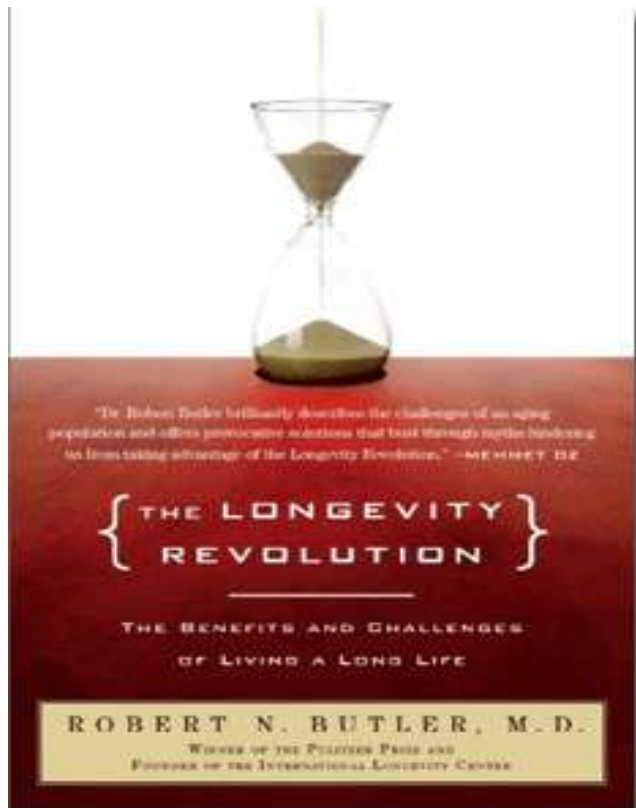
- *"... it may soon be possible to delay both aging and age-related disease in humans."* (p. 162)

The Longevity Revolution: The Benefits and Challenges of Living a Long Life. By Robert N. Butler. 553 pp. New York, PublicAffairs, 2008

Longevity Revolution (2)

- *"The present level of development of aging and longevity research justifies an Apollo-type effort to control aging …"* (p. 187)
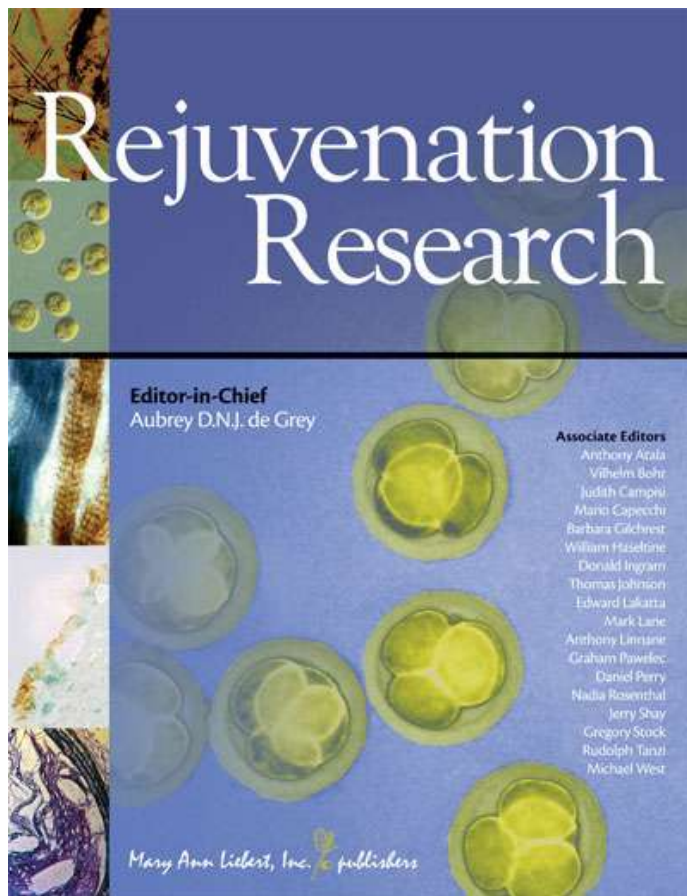
Longevity Revolution (3)

- *"Enthusiasts over the future of cell, tissue, and organ replacement imagine successive, comprehensive reconstitutions of the body. Replacement or regenerative medicine would push death back, presumably indefinitely."* (p. 401)

Longevity Revolution (4)

■ *" "Indeed, some believe that humans can master their evolution. Among them is Aubrey de Grey of Cambridge University, who suggests a life expectancy of five thousand years by 2100 [17]."* **(pp. 13-14)**

New academic journal on life-extension and rejuvenation

- **Fully indexed by MEDLINE**

- **Latest Impact Factor* is 4.138**

Why Longevity Revolution may be delayed?

Because it requires serious funding

and commitment:

- *"It is sheer foolishness to imagine that we can extend life … without substantial governmental participation"* (p. 11)

- *"… in 2007 only about 15 to 20 percent of approved grants were funded, depending on the institute.   I believe that at least 30 percent of approved grants (if not more) should be funded. … When funds are tight, review committees act too cautiously and conservatively. Funds should be available to support risky research."* (p.106)

Why Longevity Revolution may be delayed? (2)

- *"Today less than 1 percent of the entire federal budget is spent on medical research. Both to improve health and control costs, I propose that 3 percent of the nation's overall health bill ($1.8 trillion projected as 2005) or $54 billion be available to NIH for medical research from federal revenues. I also propose that of Medicare expenditures, 1 percent (or $3 billion) be devoted to the National Institute on Aging.* (p.110)

Why Longevity Revolution may be delayed? (3)

- *"While the numbers I am suggesting may seem extraordinary, I believe the level of scientific progress in the field since the 1950s justifies such a program, which could be dubbed the Apollo Program for Aging and Longevity Science."* (p.110)

- *"An orbital jump in financing of science is required to advance longevity and health as well as national wealth."* (p. 118 - 119)

Reference: The Longevity Revolution: The Benefits and Challenges of Living a Long Life. By Robert N. Butler. 553 pp. New York, PublicAffairs, 2008

General Prediction

Effective life-extending technologies may appear within our lifetime

However they will be initially expensive and not readily available

Therefore, 'longevity risk' will be particularly high for persons who are HEWM:

- Healthy (at baseline)
- Educated
- Wealthy
- Motivated

It is conceivable that such HEWM people may reach life expectancy of about 120 years in a foreseeable future.

Acknowledgments

This study was made possible thanks to:

**For More Information and Updates
Please Visit Our
Scientific and Educational Website
on Human Longevity:**

- **http://longevity-science.org**

**And Please Post Your Comments at
our Scientific Discussion Blog:**

- **http://longevity-science.blogspot.com/**

How can we improve the actuarial forecasts of mortality and longevity ?

By taking into account the <u>mortality laws</u> summarizing prior experience in mortality changes over age and time:

⑩ **Although age-specific mortality profiles for separate causes of death are complex mortality from all causes demonstrates rather simple behavior**

The Gompertz-Makeham Law

Death rate is a sum of age-independent component (Makeham term) and age-dependent component (Gompertz function), which increases exponentially with age.

$$\mu(x) = A + R\, e^{\,ax}$$

risk of death

A – Makeham term or background mortality

$R\, e^{\,ax}$ – age-dependent mortality; x - age

Gompertz-Makeham Law of Mortality in Italian Women
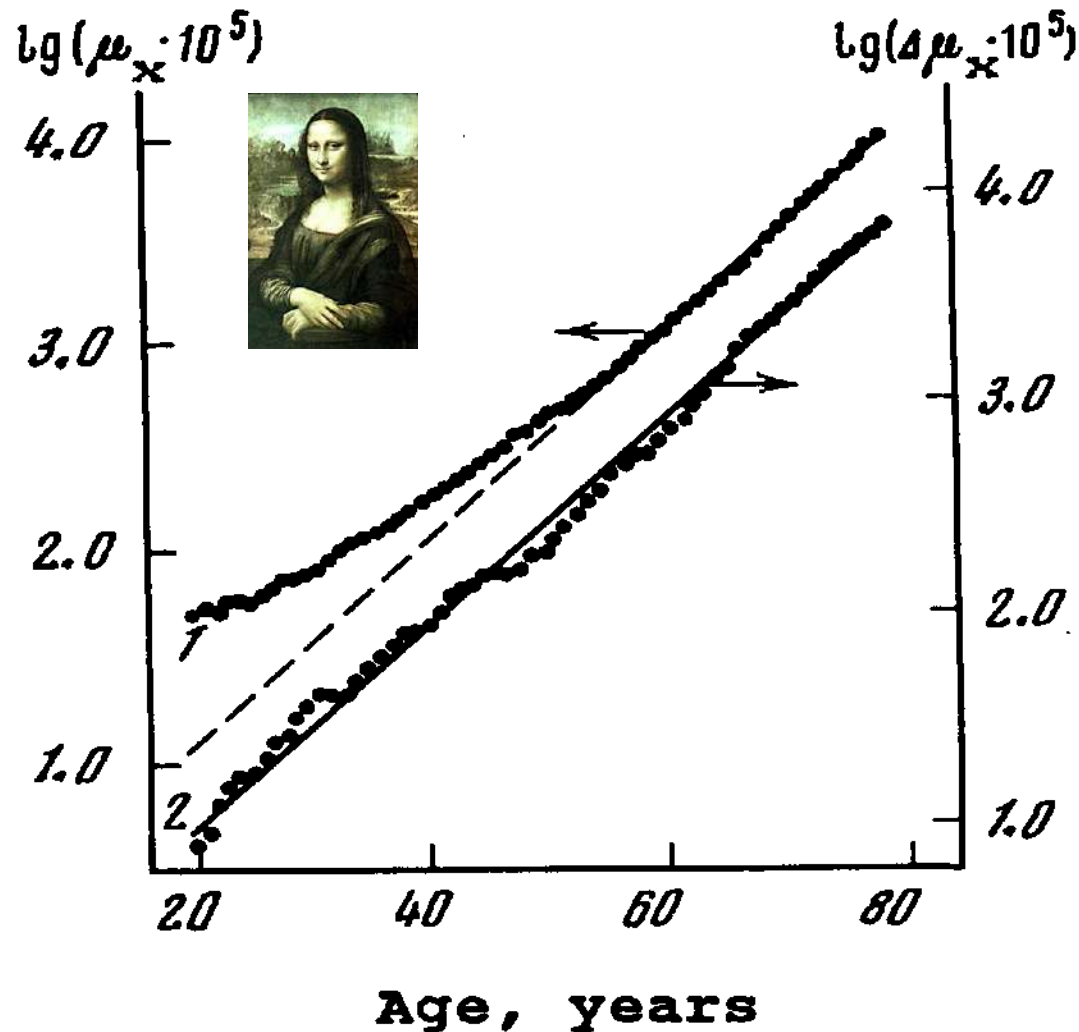
Based on the official Italian period life table for 1964-1967.

Source: Gavrilov, Gavrilova, "*The Biology of Life Span*" 1991
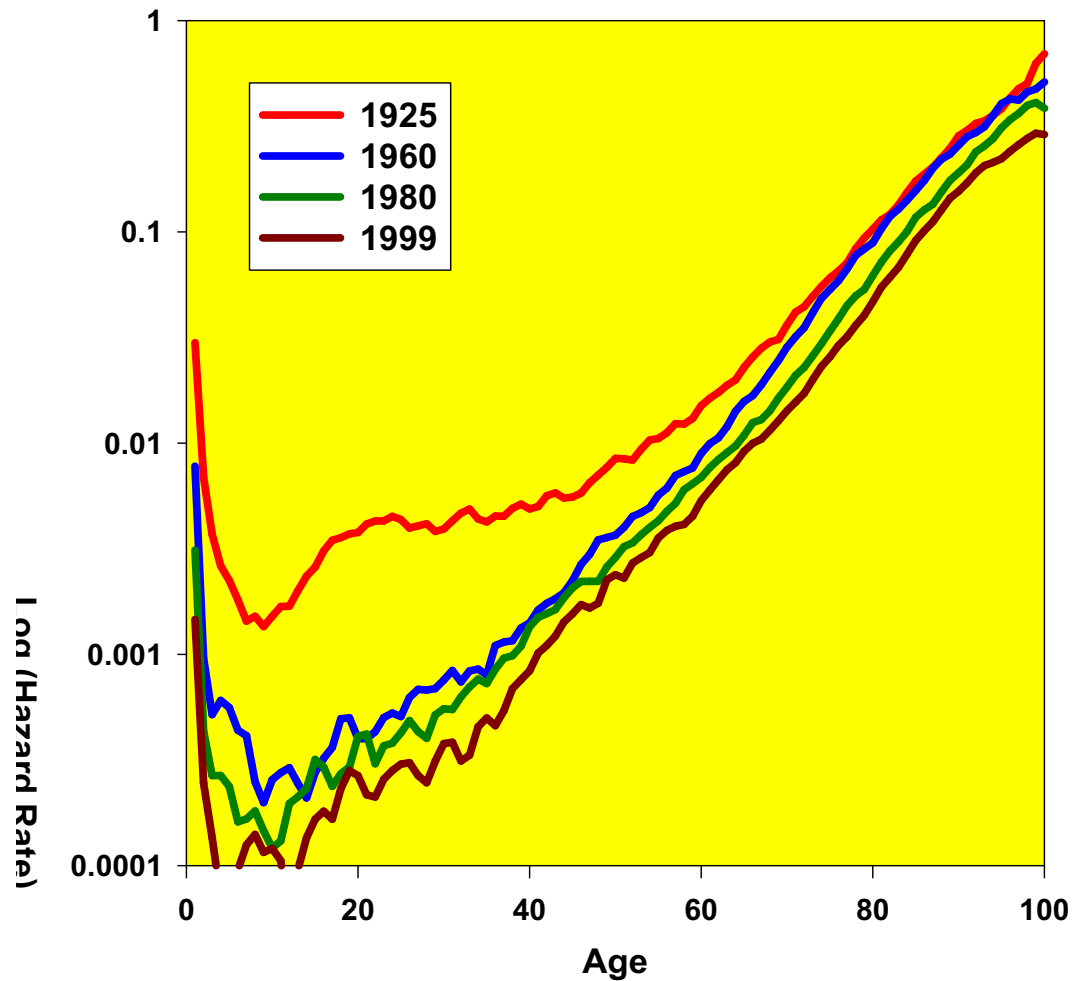
How can the Gompertz-Makeham law be used?

By studying the historical dynamics of the mortality components in this law:

$$\mu(x) = A + R\,e^{ax}$$

Makeham component

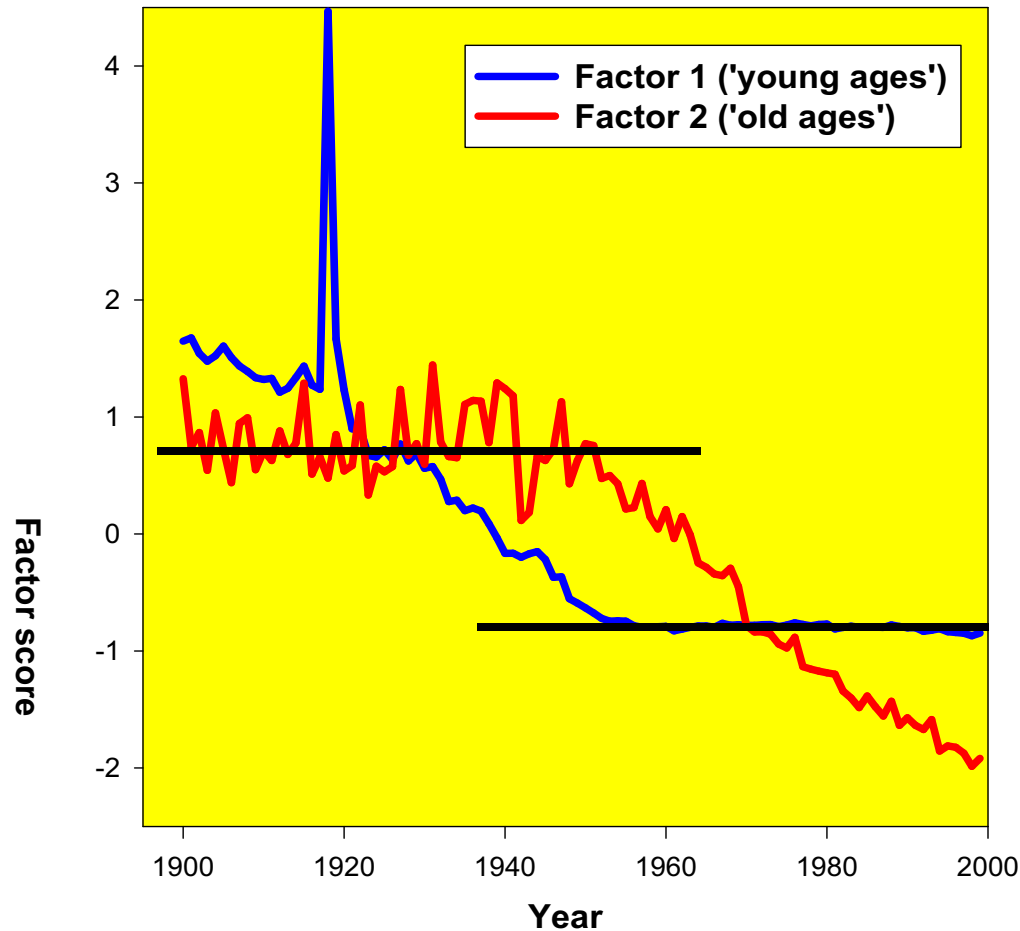Gompertz component

Historical Changes in Mortality
Swedish Females

Data source: Human Mortality Database

Extension of the Gompertz-Makeham Model Through the Factor Analysis of Mortality Trends

Mortality force (age, time) =

$$= a_0(age) + a_1(age) \times F_1(time) + a_2(age) \times F_2(time)$$

Factor Analysis of Mortality Swedish Females

Data source: Human Mortality Database

Implications

- **Mortality trends before the 1950s are useless or even misleading for current forecasts because all the "rules of the game" has been changed**

Preliminary Conclusions

- **There was some evidence for ' biological' mortality limits in the past, but these 'limits' proved to be responsive to the recent technological and medical progress.**

- **Thus, there is no convincing evidence for absolute 'biological' mortality limits now.**

- **<u>Analogy for illustration and clarification:</u> There was a limit to the speed of airplane flight in the past ('sound' barrier), but it was overcome by further technological progress. Similar observations seems to be applicable to current human mortality decline.**

The Biology of Life Span: A Quantitative Approach

L. A. Gavrilov and N. S. Gavrilova

Edited by
V. P. Skulachev
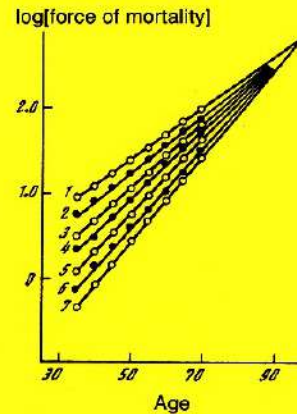
Gavrilov, L., Gavrilova, N. Reliability theory of aging and longevity. In: *Handbook of the Biology of Aging.* **Academic Press, 6ᵗʰ edition (published recently).**