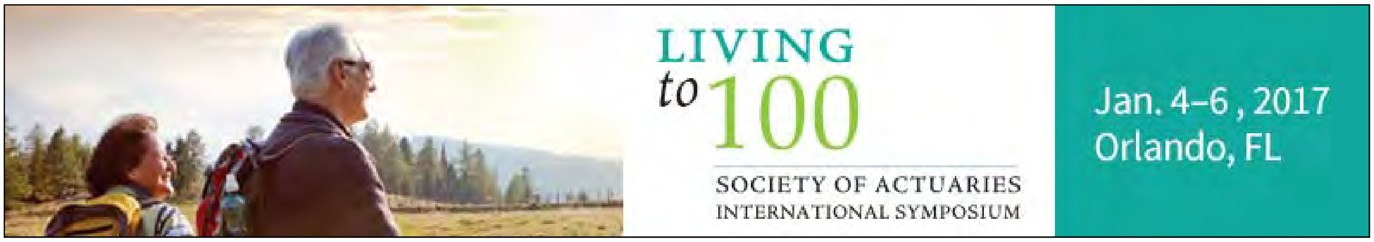

Session 3A, Mortality Inequality: Impact of Socioeconomic Factors

Moderator:
Timothy F. Harris, FSA, MAAA

Presenters:
Sam Gutterman, FSA, CERA, FCA, FCAS, HONFIA, MAAA
Severine Arnold
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Causal Mortality by Socioeconomic Circumstances: A Model to Assess the Impact of Policy Options on Inequalities in Life Expectancy

Séverine Arnold
(joint work with Daniel Alai, Madhavi Bajekal and Andrés Villegas)

Living to 100
January 5, 2017

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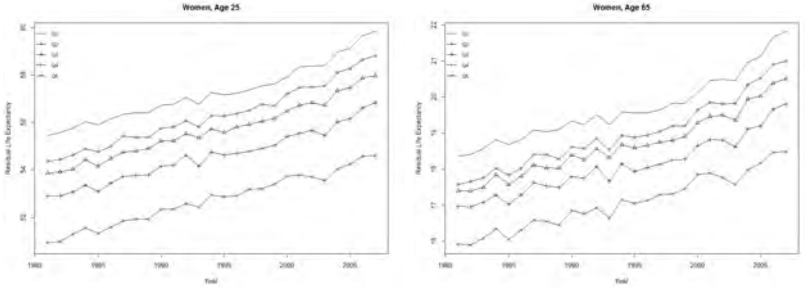
Recent observations

Differences in life expectancy between the lowest and the highest socioeconomic categories have widened over past decades in several countries (Brønnum-Hansen and Baadsgaard [2012]).

Recent observations

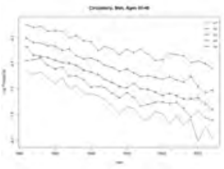


(a) Age 25

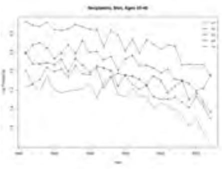
(b) Age 65

Figure: Life expectancy, England, females

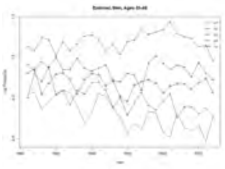
Recent observations



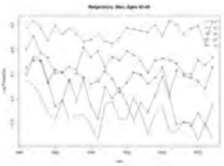
(a) Circulatory system



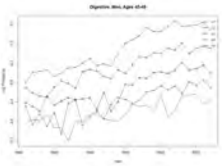
(b) Neoplasms



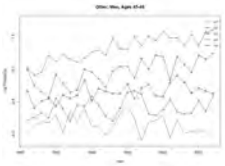
(c) External



(d) Respiratory



(e) Digestive



(f) Other

Figure: Log-mortality over time, England, males

Aim

What? Develop a tool that would help policy decisions aiming at reducing differences in life expectancy between socioeconomic categories.

How? By developing a model which takes into account the main causes of death for each socioeconomic category.

Key questions:

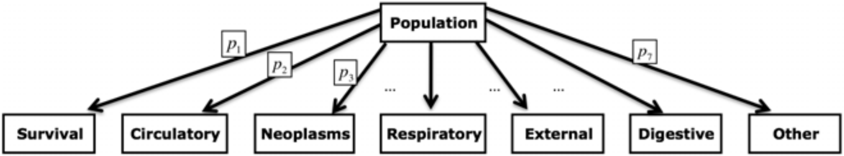
→ Which scenario of cause-elimination would help to reduce the gap?

→ Which scenario of cause-elimination would help to close the life expectancy gap while achieving the highest overall increase in life expectancy across the society?

Data

- 1981-2007, England by socioeconomic circumstances (SEC) quintiles.
  → Mortality counts from ONS.
  → Population estimates from Dr Paul Norman, Leeds University.
- Inequalities by SEC: census areas grouped into quintiles by increasing deprivation (IMD 2007)
  → Q1 = least deprived.
  → Q5 = most deprived.
- Causes-of-Death (CoD) - adjusted for ICD change using ONS bridge coded dataset 1999: diseases of the circulatory system; neoplasms; diseases of the respiratory system; external causes; digestive causes; other.

Multinomial logit models



- Typically used for a response with several unordered categories (Alai et al. [2015]).

Multinomial logit models

$$
\begin{aligned}
\log\left(\frac{q_1(x,t,g,s)}{p(x,t,g,s)}\right) &= a^{(1)}_{x,g,s} + b^{(1)}_{x,g}\cdot t + c^{(1)}_{x,g}\cdot t^2 + e^{(1)}_{g,s}\cdot t + f^{(1)}_{g,s}\cdot t^2 \\
&= Y^{(1)}(x,t,g,s) \\
\log\left(\frac{q_2(x,t,g,s)}{p(x,t,g,s)}\right) &= a^{(2)}_{x,g,s} + b^{(2)}_{x,g}\cdot t + c^{(2)}_{x,g}\cdot t^2 + e^{(2)}_{g,s}\cdot t + f^{(2)}_{g,s}\cdot t^2 \\
&= Y^{(2)}(x,t,g,s) \\
\ldots \\
\log\left(\frac{q_6(x,t,g,s)}{p(x,t,g,s)}\right) &= a^{(6)}_{x,g,s} + b^{(6)}_{x,g}\cdot t + c^{(6)}_{x,g}\cdot t^2 + e^{(6)}_{g,s}\cdot t + f^{(6)}_{g,s}\cdot t^2 \\
&= Y^{(6)}(x,t,g,s)
\end{aligned}
$$

The *logit* probabilities depend on a set of factors: the age, the gender, the SEC and a period effect.

Multinomial logit models

By definition of the logit function, we have

$$\begin{aligned} q_i(x,t,g,s) &= \frac{\exp\{Y^{(i)}(x,t,g,s)\}}{1+\sum_k \exp\{Y^{(k)}(x,t,g,s)\}}, \quad i = 1,\ldots,n \\ p(x,t,g,s) &= \frac{1}{1+\sum_k \exp\{Y^{(k)}(x,t,g,s)\}}. \end{aligned}$$

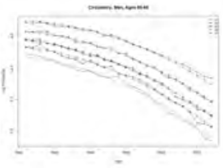
Shocks in the multinomial model

$$
\begin{aligned}
q_i(x,t,g,s) &= \frac{\rho_i \exp\{Y^{(i)}(x,t,g,s)\}}{1+\sum_k \rho_k \exp\{Y^{(k)}(x,t,g,s)\}}, \quad i=1,\ldots,n \\
p(x,t,g,s) &= \frac{1}{1+\sum_k \rho_k \exp\{Y^{(k)}(x,t,g,s)\}},
\end{aligned}
$$

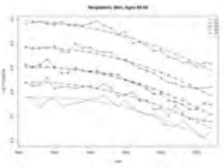
with $\rho_i \geq 0$, a shock applied to cause i.

→ Assume independence

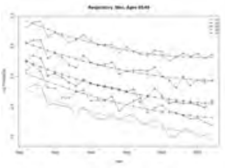
Do we have a good fit?



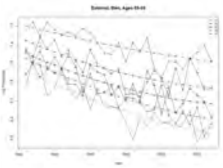
(a) Circulatory system



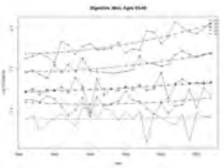
(b) Neoplasms



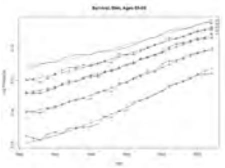
(c) Respiratory



(d) External



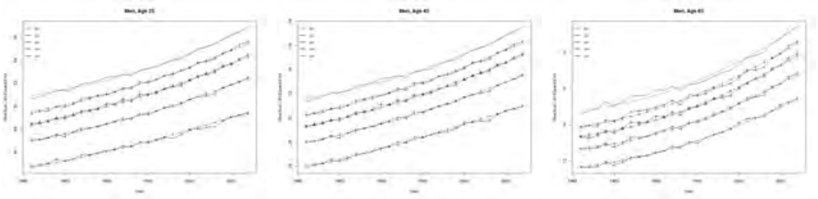
(e) Digestive



(f) Survival

Figure: Observed and fitted values of mortality rates, age-group 65-69, England, males

Do we have a good fit?



(a) Age 25 (b) Age 45 (c) Age 65

Figure: Observed and fitted life expectancies, England, males

Which scenario of cause-elimination would help to reduce the gap?

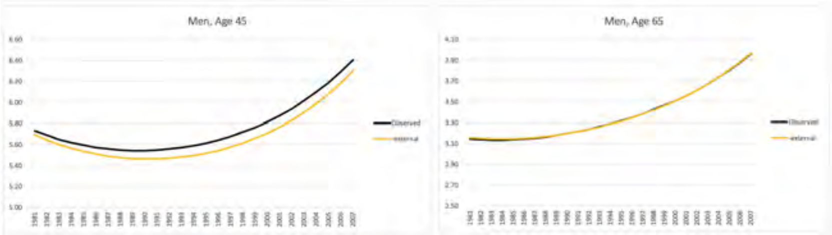


Figure: Gaps in life expectancy between the highest and lowest socio-economic categories, England, males, ages 45 and 65

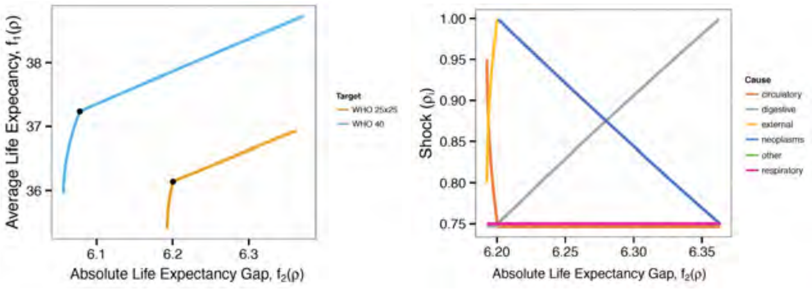
Which scenario of cause-elimination would help to close the life expectancy gap while achieving the highest overall increase in life expectancy across the society?

WHO NCD Global Monitoring Framework 2025 target: Overall reduction in premature mortality by 25%, from cardiovascular disease, chronic respiratory disease, diabetes and neoplasms.

→ Is it the optimal strategy?

→ Multi-objective optimisation approach

Which scenario of cause-elimination would help to close the life expectancy gap while achieving the highest overall increase in life expectancy across the society?



(a) Pareto Front (b) Optimal policies WHO 25x25

Figure: Optimal strategies for males age 45

Concluding remarks

- We provide a basis to assist government bodies in implementing well-informed strategies aimed at reducing social inequalities.

  → Use cause-specific mortality data by deprivation categories.

  → Use the multinomial logit model developed by Alai et al. [2015] → extend it to allow for socio-economic covariates. AND an optimisation procedure → simultaneously maximises overall gain in life expectancy whilst minimising social inequalities.

Concluding remarks

Key findings:

- Decline in heart disease mortality:
  → Major contributor to increases in life expectancy
  → BUT also increases inequalities.
- The optimal cause-of-death to target in order to reduce life expectancy gaps changes over time.
  → Crucial to take into account the latest time trends.
- To reduce inequalities, respiratory diseases need to be targeted as a priority.
- WHO target increases inequalities for men
  → A more optimal solution would be to target digestive diseases instead of neoplasms.

Next step: Include a budget constraint.

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Thank you very much for your attention!

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Improvement in late-life mortality and its impact on the increase in the number of Centenarians in Quebec (Canada)

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Melissa Beaudry-Godin
Bertrand Desjardins

Department of Demography, Université de Montréal

SOA 2017 Living to 100 Symposium
Orlando, USA
January 4-6, 2017

Université de Montréal

Outline of the presentation

- Background: Increase in the number of centenarians
- Indicators of the importance of centenarians
- Quebec Data and Methods
- Estimation of centenarians in Quebec
- Factors responsible for the increase in numbers of centenarians
- Conclusion : Challenges

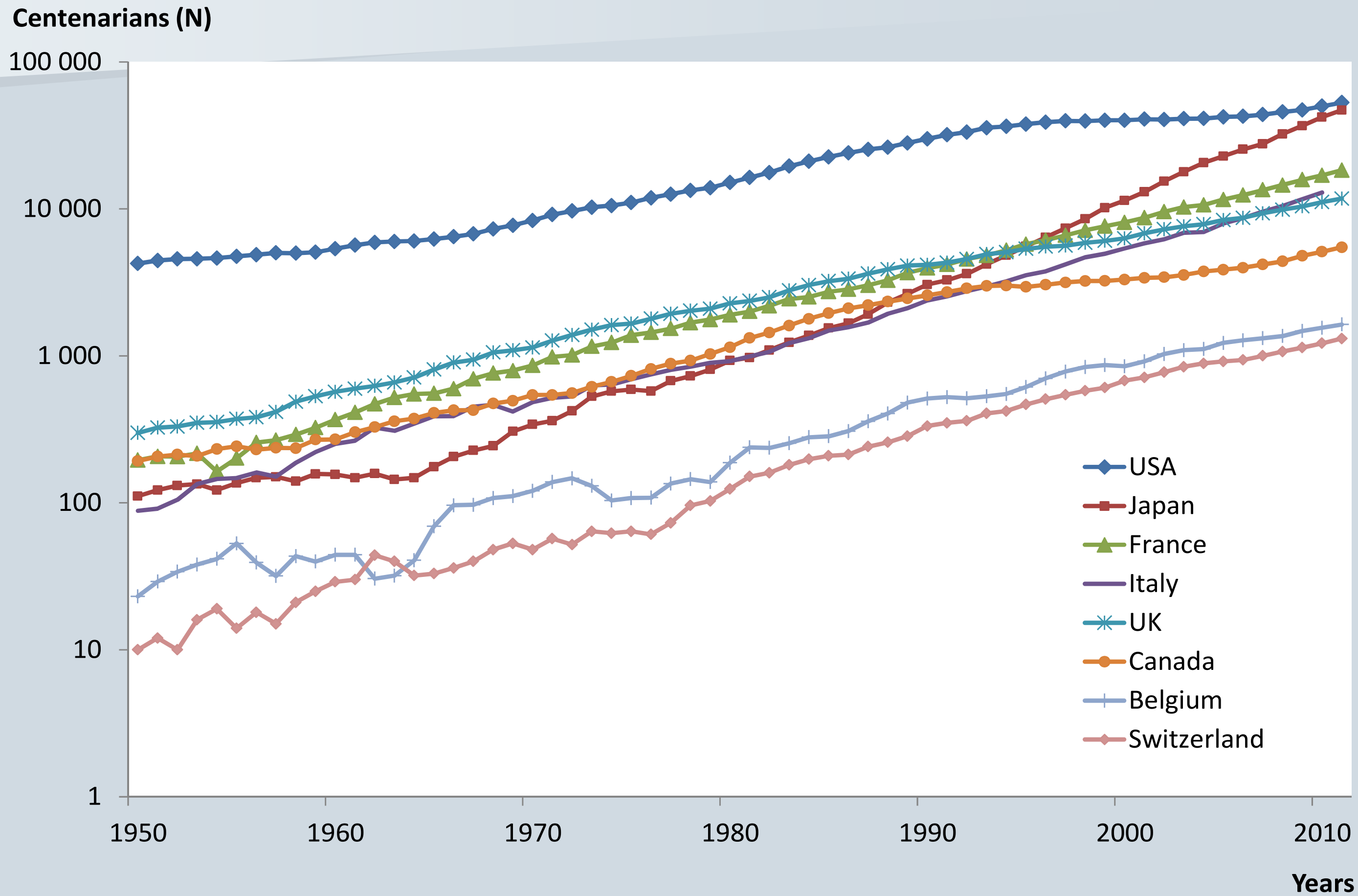
The 21st century – the century of centenarians

Published on N-IUSSP.ORG November 21, 2016

George W Leeson

"The emergence of large numbers of centenarians has accompanied the ageing of our populations. The number of people aged 100 years and over in England and Wales, for example, increased from less than 200 in 1922 to 570 in 1961. By 1981 it had climbed to 2,418 and to 12,318 in 2012…."

Evolution of numbers of centenarians, selected countries, 1950-2011



Source : HMD

Number of centenarians and sex ratio of centenarians in selected countries, 1 January 2011

Countries	Men	Women	Total	Centenarians per 10 000 persons	Ratio Women/Men
USA	8 181	44 742	52 923	1.7	5.5
Japan	6 093	40 914	47 007	**3.7**	6.7
France	2 192	15 968	18 160	2.9	**7.2**
Italy	2 224	11 934	14 158	2.3	**5.3**
UK	1 596	10 154	11 750	1.9	6.4
Canada	844	4 638	5 482	1.6	5.5
Belgium	206	1 428	1 634	**1.5**	6.9
Switzerland	200	1 111	1 312	1.7	5.6

Source : HMD

Comparison of ratio of centenarian (RC_{60}), selected countries, 1961 to 2011

	Japan	France	Canada	**Québec**	USA	Italy	Switzerland	UK	Belgium
1961		5.4	24.0			3.9	3.1	8.0*	3.7
1971		11.4	34.0			7.7	7.3	14.7	9.3
1981		22.6	62.8		59.8	14.7	19.9	21.6	13.8
1991	29.2	43.4	99.4		91.3	28.2	35.9	34.6	25.6
2001	81.8	72.0	105.2		103.8	51.1	57.9	48.9	37.7
2011	227.9	135.3	135.0		111.0	91.4	87.4	72.8	63.2

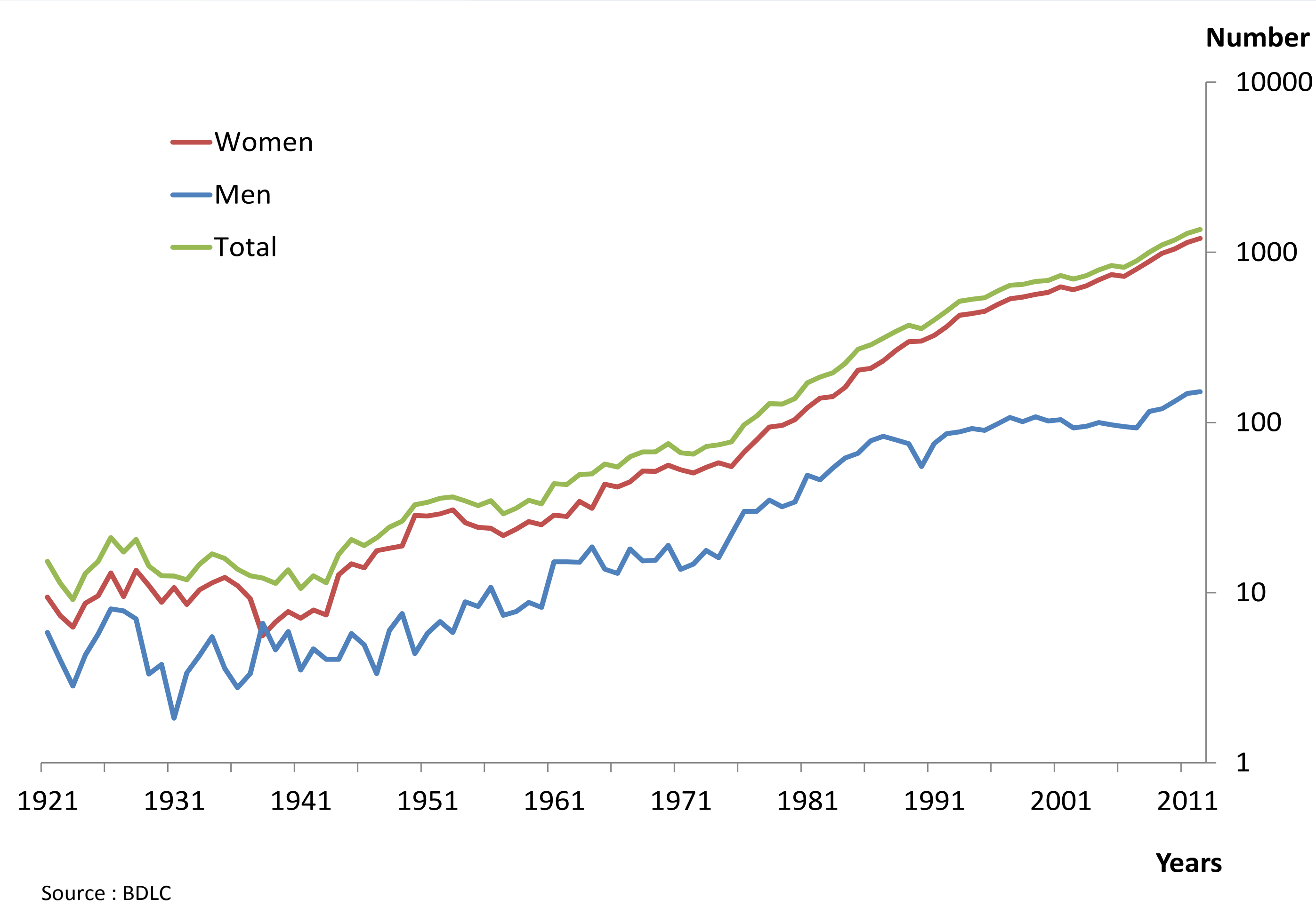
Source: HMD and CHMD

$$RC_{[60]} = \frac{P(100)^{t}}{P(60)^{t-40}} * 10\,000$$

The case of Quebec (Canada)
Data

- **Canadian Censuses**: good quality on population counts up to 100 years old; 100 + had problems (overestimation). Corrections have been implemented recently to population estimates by Statistics Canada
- **Canadian vital statistics** (deaths): superior quality compared to population data. Systematic control measures (matching with others sources) in Quebec since 1986
- **Reconstituted populations**: extinct generation and survivor ratio methods based on deaths data
- **Indicator:** $RC_{(60)}$ appropriate for Quebec given the migration context of this region in the 19^{th} and 20^{th} centuries where migration after age 80 is negligible and quite rare after age 60

Evolution of numbers of centenarians by sex, Quebec, 1921-2012



Ratio of centenarians per 10,000 individuals aged 60 forty years earlier (RC_{60}), Quebec, 1961 to 2011

Year	Men	Women	Total
1961	11.6	19.4	**15.5**
1971	6.3	29.0	**17.4**
1981	21.5	55.4	**37.9**
1991	29.4	104.7	**66.6**
2001	31.2	147.7	**90.3**
2011	34.7	196.4	**118.3**

$$RC_{[60]} = \frac{P(100)^{t}}{P(60)^{t-40}} * 10\,000$$

Comparison of centenarian ratio (RC_{60}), selected countries, 1961 to 2011

	Japan	France	Canada	**Québec**	USA	Italy	Switzerland	UK	Belgium
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1991	29.2	43.4	99.4	**66.6**	91.3	28.2	35.9	34.6	25.6
2001	81.8	72.0	105.2	**90.3**	103.8	51.1	57.9	48.9	37.7
2011	227.9	135.3	135.0	**118.3**	111.0	91.4	87.4	72.8	63.2

Source: HMD and CHMD

$$RC_{[60]} = \frac{P(100)^{t}}{P(60)^{t-40}} * 10\,000$$

Factors responsible for the increase in numbers of centenarians in Quebec

- **Birth cohorts**: 1871 to 1901 (more detailed results in Appendix II of the paper)
- **Increased cohort size**
- **Migration : estimation and correction for this factor**
- **Increase in the probability of survival from birth to age 80**
- **Increased probability of surviving from age 80 to 100**

Factors responsible for the increase in numbers of centenarians (Method)

- **Increased cohort size**
  - The numbers of births by sex: from the Canadian census for the 1871 and 1881 birth cohorts.
  - For the births of the 1901 cohort, estimation proposed by the Institut de la Statistique du Québec.
  - Births of the 1891 cohort : linear interpolation between the years 1881 and 1901
- **Increase in the probability of survival from birth to age 80**
  - Numbers of survivors at the exact age of 80 obtained by adding the population aged 80 in year x (total numbers on January 1st) to the deaths taking place at 80 years of age in the lower triangle of the year x-1.
  - Numbers corrected to exclude immigrants from the analysis.
  - No correction for emigration (slight underestimation of the probabilities of survival)
- **Increased probability of surviving from age 80 to age 100**
  - Survivors to 100 years of age were also obtained by adding population estimates on January 1st published by the CHMD to the deaths in the corresponding birth cohorts.
  - Adjustment to retain only survivors born in Quebec.

Factors responsible for the rise in numbers of centenarians, Quebec, birth cohorts of 1871 and 1901 (Results)

Factors involved in increase	Numbers (Sx)			Probability of surviving	
	Age 0	Age 80	Age 100	${}_{80}p_0$	${}_{20}p_{80}$
MEN					
1871 cohort	23741	2070	8	0.0872	0.0040
1901 cohort	31882	4372	46	0.1371	0.0105
Growth coefficient	**1.34**	**2.11**	**5.55**	**1.57**	**2.64**
WOMEN					
1871 cohort	22490	2398	21	0.10166	0.0088
1901 cohort	30363	7089	201	0.233504	0.0283
Growth coefficient	**1.35**	**2.96**	**9.46**	**2.19**	**3.20**
TOTAL					
1871 cohort	46231	4469	28	0.0967	0.0066
1901 cohort	62245	11461	255	0.1841	0.0213
Growth coefficient	**1.35**	**2.56**	**8.30**	**1.90**	**3.23**

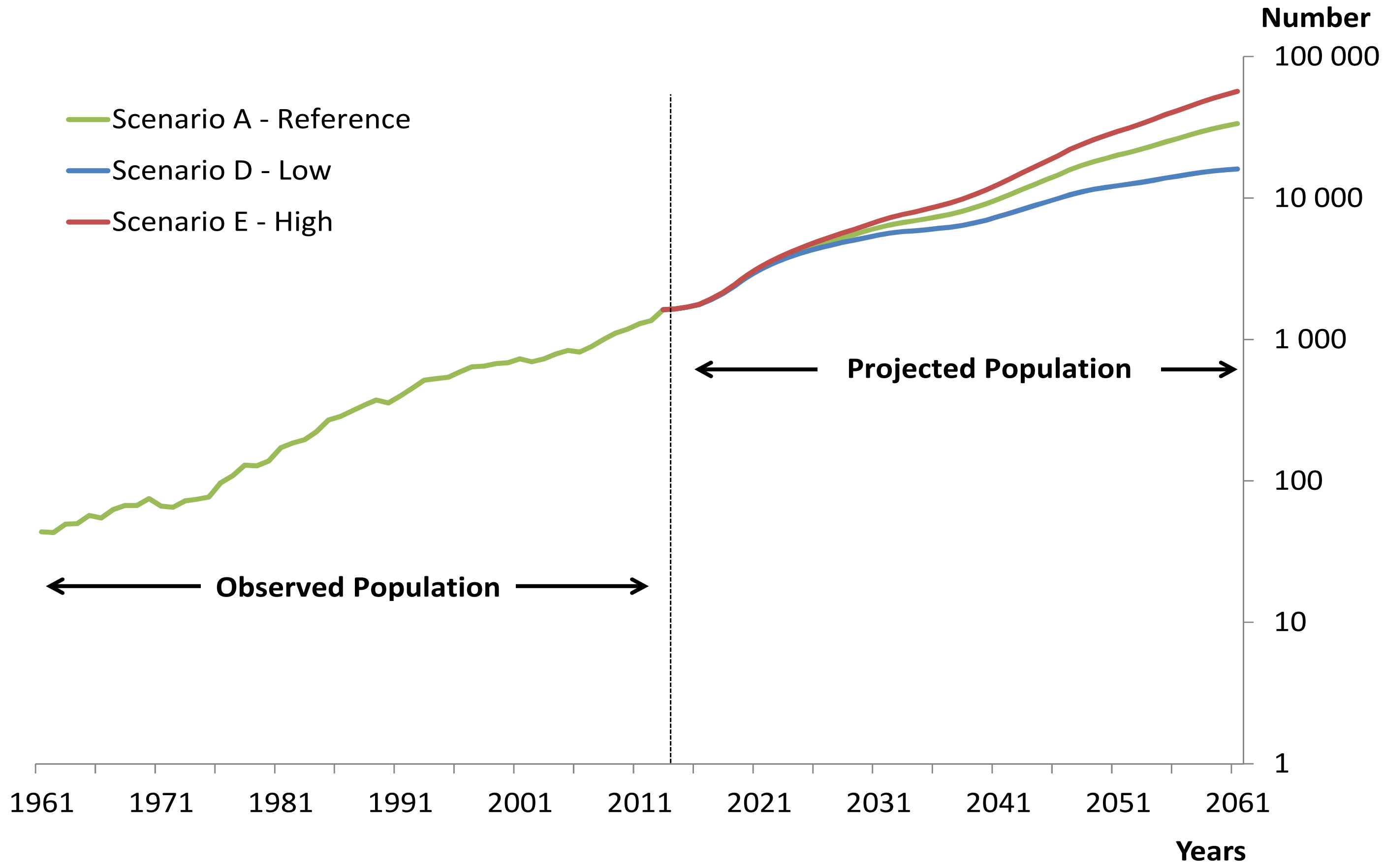
The growth rate in the probability of surviving from age 80 to age 100 is notably higher than for the probability of surviving to age 80, doubling for men and tripling for women over the space of 30 years.

Factors responsible for the rise in numbers of centenarians, Switzerland, England and Wales and Quebec

Factors involved in increase	Numbers (Sx)			Probability of surviving	
	Age 0	Age 80	Age 100	${}_{80}p_0$	${}_{20}p_{80}$
TOTAL SWITZERLAND					
1870 cohort	79208	10267	29.5	0.1296	0.0029
1900 cohort	94316	26361	346.5	0.2795	0.0131
Growth coefficient (1870 – 1900)	**1.19**	**2.57**	**11.74**	**2.16**	**4.57**
TOTAL ENGLAND AND WALES					
1850 cohort					
1895 Cohort					
Growth coefficient (1850-1895)	**1.55**		**15.41**	**2.08**	**4.78**
TOTAL QUEBEC					
1871 cohort	46231	4469	28	0.0967	0.0066
1901 cohort	62245	11461	255	0.1841	0.0213
Growth coefficient (1871-1901)	**1.35**	**2.56**	**8.30**	**1.90**	**3.23**

Source: Robine, J.M. and Paccaud, F. (2004). La démographie des nonagénaires et des centenaires en Suisse, **Cahiers québécois de démographie**, 33 (1), 51-81.
Thatcher, R. (1999). The demography of centenairians in England and wales, **Population Trends**, Office for National Statistics, p. 5-12.

Observed and projected centenarian population, three scenarios, Quebec, 1961-2061



Source : BDLC and Institut de la statistique du Québec, Perspectives démographiques du Québec et des régions, 2011-2061.

Conclusion

- This study confirms that the decrease in old-age mortality has largely contributed to raising the number of persons reaching 100 years old.

- What will happen after age 100 is under investigation and will determine whether the scenario of compression of mortality will occur (with a maximum age at death already attained?) or the shifting mortality scenario will remain a realistic description of the current situation (with a maximum age at death still in progression).

Challenges

- The century of centenarians : a challenge in both developed and emerging countries
- This trend has important consequences for the way in which individuals live these extending lives:
  - Delay in life course transitions (retirement and old age)
  - Rethinking of the concept of age
- Intergenerational families and caregiving
- Adjusting to the needs of extreme-aged populations:
  - Public infrastructures (education, workplace, housing, transport, health and social care)

Acknowledgements

- Data on Centenarians:

  Statistics Canada

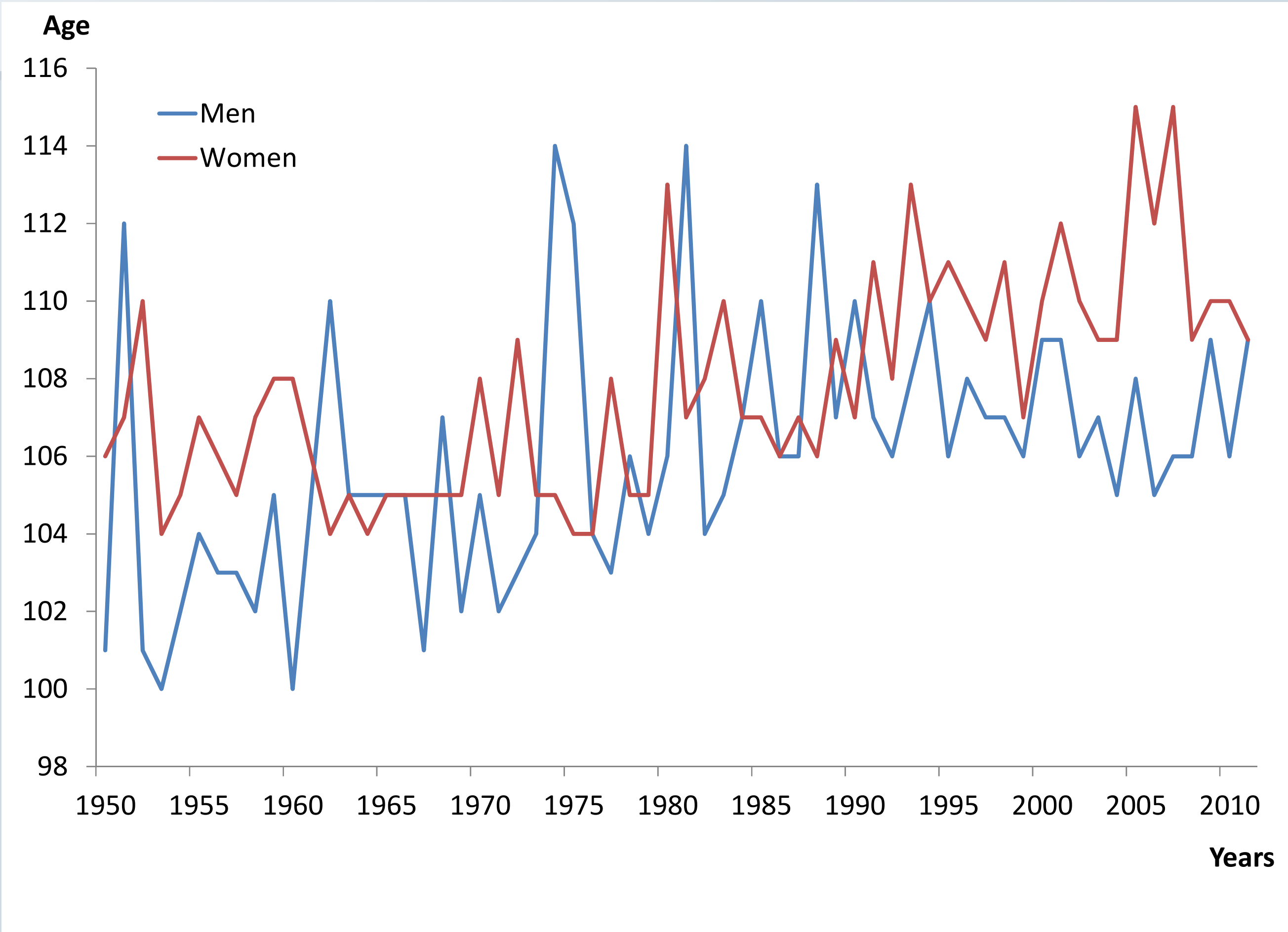
  HMD and CHMD

- Financial support:

  Social Sciences and Humanities Research Council of Canada

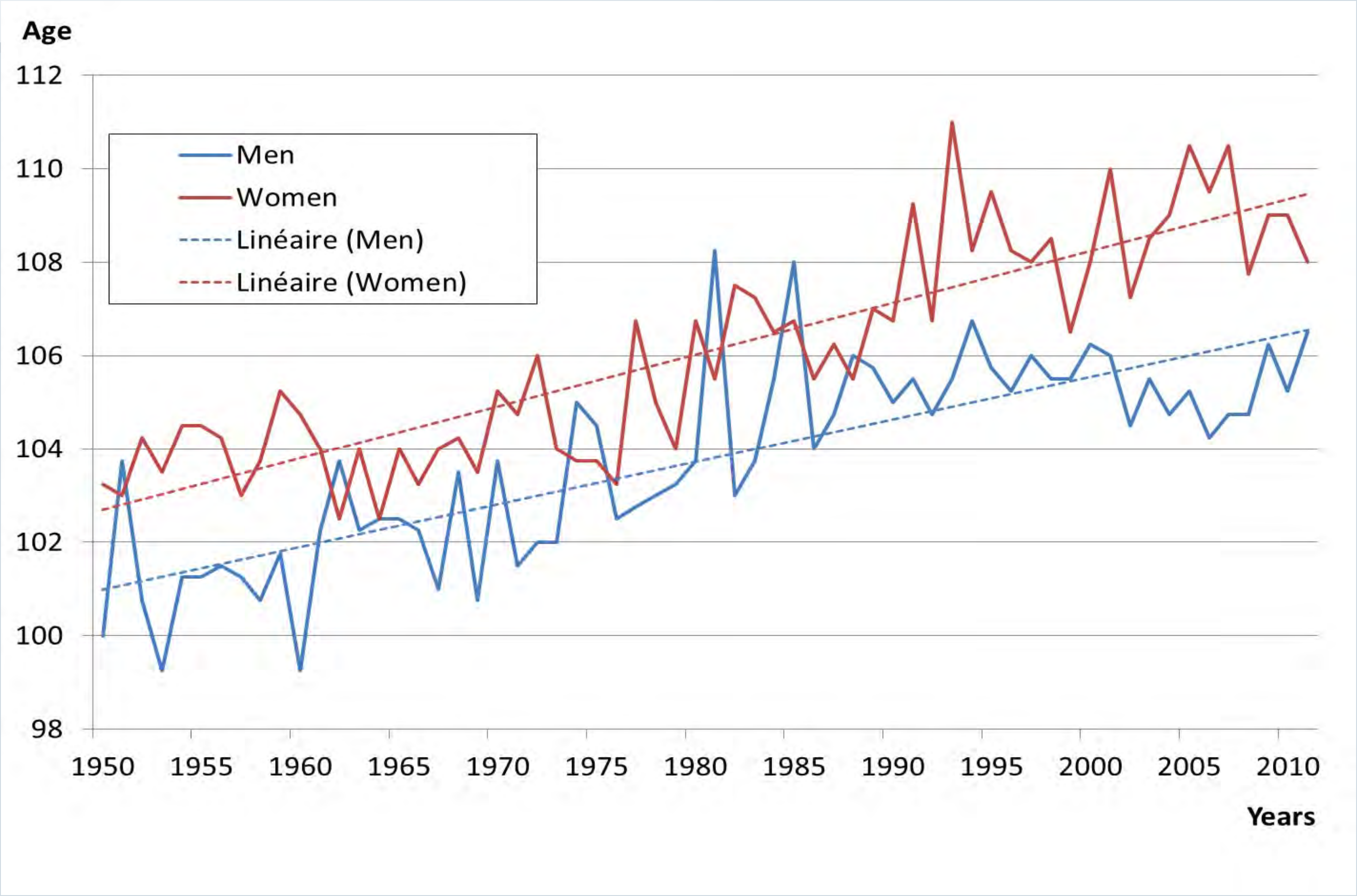
Supplementary figures

Evolution of maximum age at death, Quebec, 1950-2011



Source : CHMD and Institut de la statistique du Québec (unpublished data)

Evolution of mean maximum age at death, Quebec, 1950-2011



Source : CHMD and Institut de la statistique du Québec (unpublished data)

To what extent will human behavior affect mortality projections

Sam Gutterman, FSA, FCAS, MAAA, CERA, HonFIA

2017 LIVING TO 100 SYMPOSIUM

Agenda

- Why human behavior
- Background and projected effects of
  - Smoking
  - Obesity
- Limitations

Why human behavior

- Controllable – to some extent
- Significant
- Underlying drivers of mortality
- Two human behaviors with large effects on mortality were selected to study here
  - Smoking cigarettes
  - Obesity (underlying behaviors include nutrition, physical activity and time being sedentary)

Background: smoking

- Prevalence of smoking cigarettes in the United States, especially for males, was extremely high
  - Peaked at about 63% of male adults in the 1940s and 1950s and about 38% of female adults in the 1960s
- Has decreased for both genders since then
- Cigarettes smoked per smoker has also declined

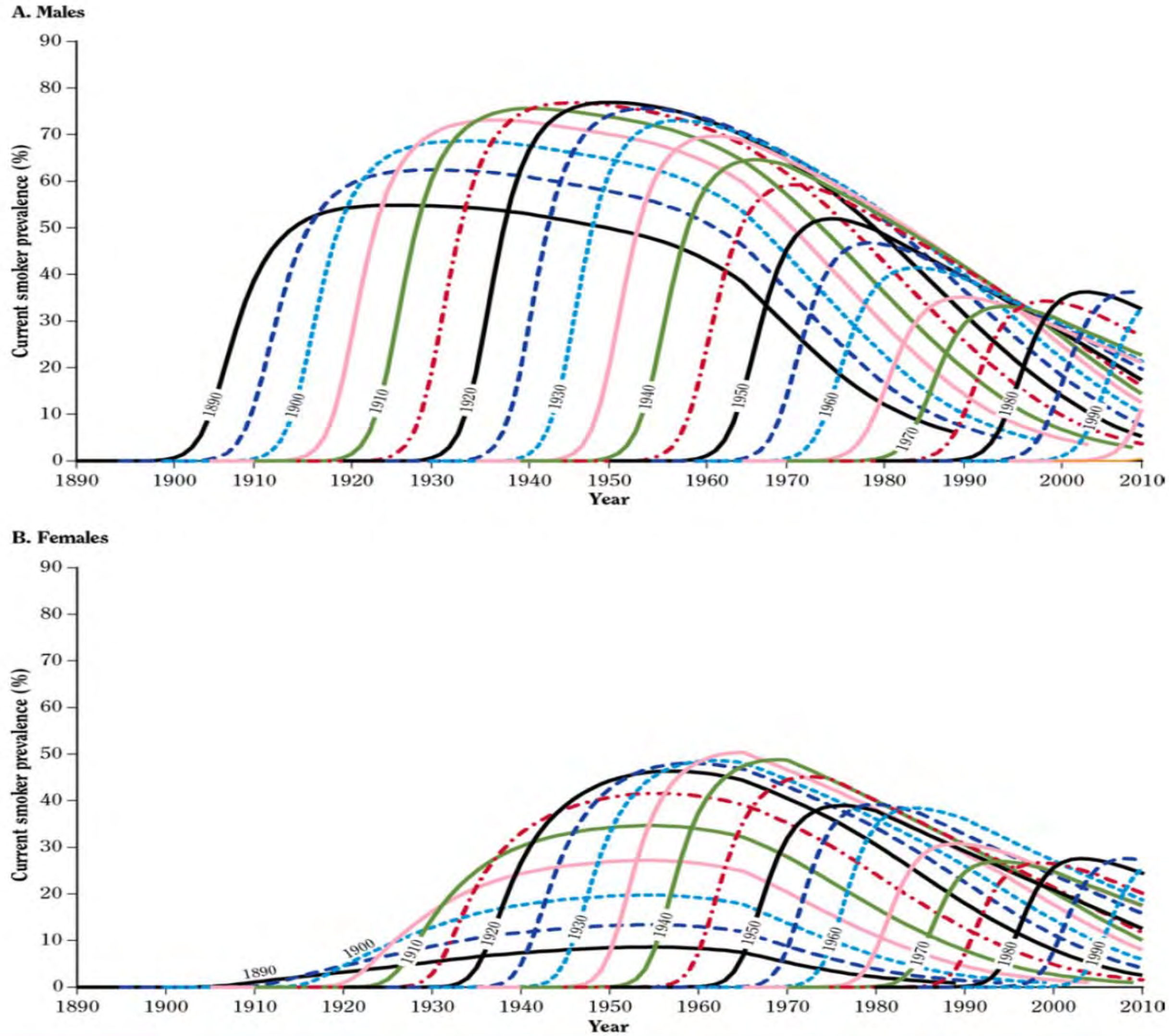
Smoking prevalence for American adults

Gender	Males		Females		Total	
Age/year	2005	2014	2005	2014	2005	2014
18 – 24	28.0%	18.5%	20.7%	14.8%	24.4%	16.7%
24 - 44	26.8	22.9	21.4	17.2	24.1	20.0
45 – 64	25.2	19.4	18.8	16.8	21.9	18.0
65 +	8.9	9.8	8.3	7.5	8.6	8.5
Total	23.9	18.8	18.1	14.8	20.9	16.8

Source: CDC

Smoking prevalence by birth cohort and gender

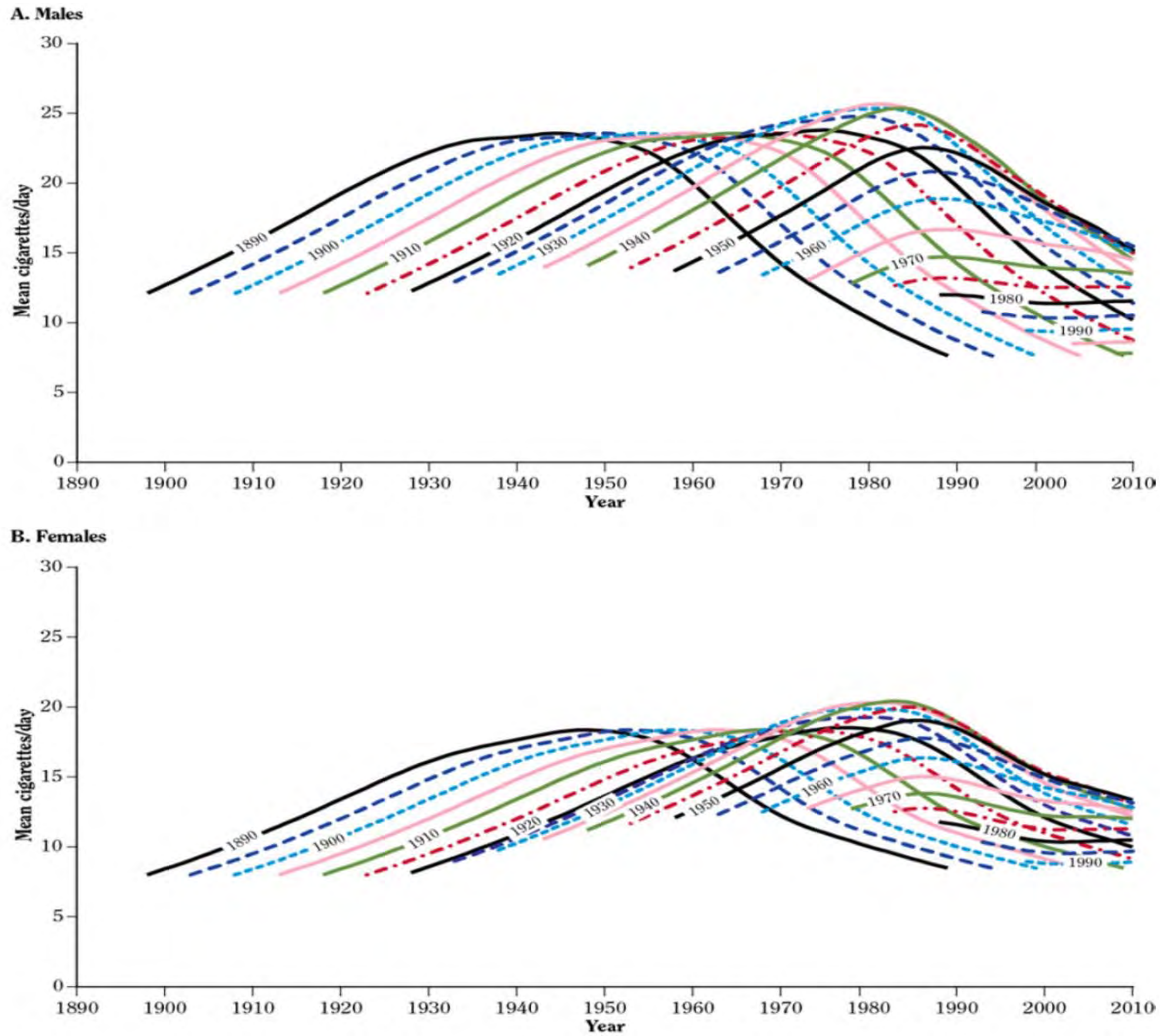
Cohort with maximum prevalence of about 80% smokers of adult males and 50% of adult females



Source: U.S. Surgeon General’s report (2014)

Average cigarette smoked per day by birth cohort and gender

Cohort with maximum of about 25 cigarettes / day for adult males and 20 for females



Source: U.S. Surgeon General's report (2014)

Mortality projection: smoking methodology

- For two major causes of deaths resulting from smoking (lung cancer and other pulmonary diseases) for age categories 35-39 to 95-99 – selected because of high percentage of each due to smoking
  - Reviewed past reductions in percent of deaths from cause by period for each gender and age category measured from peak year
  - Estimated future reductions in percentage of total mortality, measured from peak calendar period
  - Estimated ultimate percent, assumed to be met after 30 years (after that a steady state level of smoking is assumed)
    - Between 25% and 75% for lung cancer and 65% and 80% for other pulmonary diseases (higher for the latter because longer lag time and higher rates in pre-heavy smoking period)
- Added two resulting sets of percentages of future rates by age category and calendar period
- Since these two aren't the only causes of death resulting from smoking
  - 47% of male deaths and 61% of female deaths due to smoking were attributed to these two causes
  - Increased the percentage reduction accordingly
- Applied resulting percentages to Social Security (US) projected mortality rates by gender, age and period
- Calculated resulting difference in cohort life expectancy for a 35 and 65 year old in 2015

U.S. Lung cancer mortality rates as a percent of total mortality rates

Females	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
1970-1974	1.48%	3.02%	4.28%	4.75%	5.05%	4.05%	2.95%	1.97%	1.27%	0.77%	0.51%	0.35%	0.17%
1975-1979	1.70%	4.13%	5.76%	7.11%	6.93%	6.65%	5.32%	3.43%	2.12%	1.25%	0.71%	0.48%	0.32%
1980-1984	1.72%	3.93%	6.91%	8.97%	9.68%	8.77%	7.57%	5.62%	3.36%	1.84%	1.04%	0.59%	0.40%
1985-1989	1.56%	3.82%	7.32%	10.04%	10.69%	10.91%	9.35%	7.67%	4.99%	2.71%	1.33%	0.72%	0.44%
1990-1994	1.71%	3.41%	6.50%	9.65%	11.62%	12.19%	11.61%	9.61%	6.91%	4.05%	2.03%	0.96%	0.54%
1995-1999	1.66%	3.63%	5.45%	8.61%	11.36%	12.23%	12.16%	10.71%	7.75%	4.99%	2.53%	1.23%	0.54%
2000-2004	1.51%	3.25%	5.87%	7.63%	10.05%	12.20%	12.48%	11.40%	8.94%	5.59%	2.93%	1.41%	0.65%
2005-2009	1.17%	2.69%	5.54%	7.80%	9.17%	11.04%	12.73%	11.94%	9.78%	6.45%	3.49%	1.64%	0.82%
2010-2014	0.94%	1.84%	4.13%	7.30%	9.43%	10.02%	10.99%	11.62%	9.49%	6.71%	3.77%	1.77%	0.86%
Males													
1970-1974	1.82%	4.10%	6.12%	7.47%	8.70%	8.80%	8.44%	7.07%	5.27%	3.39%	1.81%	0.92%	0.57%
1975-1979	1.61%	4.12%	6.82%	9.38%	10.59%	10.90%	10.26%	8.87%	6.69%	4.46%	2.60%	1.29%	0.82%
1980-1984	1.29%	3.93%	7.11%	10.25%	12.06%	12.64%	11.84%	10.27%	8.09%	5.46%	3.36%	1.73%	1.05%
1985-1989	1.10%	3.26%	6.64%	10.35%	12.63%	13.93%	13.04%	11.39%	8.97%	6.17%	3.86%	2.14%	1.13%
1990-1994	0.91%	2.28%	5.21%	9.34%	12.50%	14.18%	14.21%	12.58%	9.86%	7.01%	4.45%	2.49%	1.32%
1995-1999	0.94%	2.49%	4.48%	7.61%	11.03%	13.25%	13.75%	12.87%	10.00%	7.14%	4.56%	2.53%	1.48%
2000-2004	0.80%	2.16%	4.56%	6.59%	9.63%	12.41%	13.29%	12.99%	10.71%	7.50%	4.59%	2.52%	1.45%
2005-2009	0.76%	1.58%	3.81%	6.05%	8.19%	10.79%	12.84%	12.89%	10.85%	8.15%	5.04%	2.75%	1.48%
2010-2014	0.59%	1.34%	2.87%	5.16%	7.72%	9.30%	11.00%	11.49%	10.14%	7.69%	5.06%	2.69%	1.38%

Source: Human mortality data base by cause

U.S. Lung cancer mortality rates per 100,000

Females	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
1970-1974	2.5	8.1	17.4	28.0	44.3	51.9	56.9	62.5	65.4	64.7	70.7	74.4	53.1
1975-1979	2.3	9.1	19.9	37.3	53.5	78.2	89.7	94.8	92.4	91.4	85.8	90.2	89.1
1980-1984	2.0	7.3	21.0	43.3	71.7	98.9	127.6	146.6	137.1	128.2	119.1	108.3	109.5
1985-1989	1.8	6.5	20.3	45.6	75.9	121.2	154.8	196.6	199.5	182.4	150.6	132.4	124.5
1990-1994	2.0	5.7	16.9	40.2	77.8	127.9	184.4	234.1	261.4	259.1	216.8	169.2	147.5
1995-1999	2.0	6.2	13.6	33.5	71.1	123.0	186.8	257.3	289.7	322.5	277.5	225.8	157.4
2000-2004	1.7	5.8	15.3	28.8	58.7	113.5	180.3	259.2	326.4	355.2	325.2	266.5	197.7
2005-2009	1.3	4.6	14.5	29.4	49.3	91.8	163.2	243.7	324.9	370.0	356.0	292.1	238.7
2010-2014	1.0	2.9	10.2	27.5	50.5	77.5	129.7	217.5	292.6	354.5	359.2	299.1	240.9
Males													
1970-1974	5.5	18.9	45.1	84.2	155.1	236.9	333.4	413.9	447.5	419.3	329.0	238.2	198.8
1975-1979	4.2	16.1	43.1	94.2	161.3	261.0	357.5	471.9	507.9	510.2	435.7	310.8	271.4
1980-1984	3.0	13.3	38.9	91.6	170.0	271.0	384.7	504.7	585.6	605.8	551.3	409.7	350.3
1985-1989	2.9	10.9	33.4	83.5	163.6	282.0	392.9	530.8	622.5	667.9	629.3	514.7	386.0
1990-1994	2.6	8.2	25.4	68.2	145.0	260.2	395.0	522.9	622.0	713.7	692.7	581.8	453.7
1995-1999	2.2	8.2	20.7	50.2	114.2	219.1	347.4	502.1	589.3	701.4	713.1	610.5	525.9
2000-2004	1.6	6.6	20.7	42.8	91.4	181.9	297.1	450.9	581.8	677.2	689.8	608.4	530.7
2005-2009	1.4	4.4	16.3	39.2	74.9	142.8	251.4	387.2	517.5	645.3	673.4	615.8	517.4
2010-2014	1.1	3.3	11.2	31.6	70.4	119.3	199.5	316.9	441.8	554.3	618.8	559.4	454.9

Source: Human mortality data base by cause

U.S. Other Pulmonary (mostly COPD) mortality rates as a percent of total mortality rates

Females	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
1980-1984	0.20%	0.55%	0.93%	1.45%	2.11%	2.76%	3.35%	3.36%	2.67%	1.91%	1.25%	0.86%	0.59%
1985-1989	0.20%	0.30%	0.92%	1.67%	2.72%	3.63%	4.24%	4.66%	4.25%	3.10%	2.01%	1.30%	0.93%
1990-1994	0.18%	0.33%	0.70%	1.70%	2.84%	4.28%	5.32%	5.68%	5.78%	4.50%	3.06%	1.94%	1.29%
1995-1999	0.19%	0.45%	0.84%	1.76%	3.18%	4.75%	5.97%	6.77%	6.65%	5.72%	4.09%	2.64%	1.78%
2000-2004	0.44%	0.59%	1.16%	1.86%	3.14%	5.32%	6.84%	7.78%	7.56%	6.63%	5.15%	3.48%	2.43%
2005-2009	0.33%	0.75%	1.46%	2.54%	3.37%	5.19%	7.24%	8.56%	8.59%	7.63%	5.83%	4.11%	3.01%
2010-2014	0.36%	0.66%	1.49%	3.02%	4.16%	5.30%	7.11%	9.11%	9.10%	8.18%	6.35%	4.54%	3.37%
Males													
1980-1984	0.16%	0.37%	0.62%	1.24%	2.08%	3.02%	4.08%	5.17%	5.42%	4.90%	4.02%	2.81%	1.99%
1985-1989	0.18%	0.33%	0.69%	1.23%	2.19%	3.39%	4.47%	5.43%	5.97%	5.69%	4.92%	3.51%	2.65%
1990-1994	0.12%	0.30%	0.54%	1.23%	2.22%	3.37%	4.86%	5.64%	6.23%	6.11%	5.38%	4.13%	3.39%
1995-1999	0.13%	0.33%	0.63%	1.30%	2.37%	3.59%	4.90%	6.22%	6.62%	6.54%	5.92%	4.73%	3.86%
2000-2004	0.17%	0.42%	0.80%	1.38%	2.33%	3.88%	5.20%	6.63%	7.16%	6.92%	6.28%	5.22%	4.20%
2005-2009	0.17%	0.42%	0.93%	1.58%	2.49%	3.83%	5.55%	6.91%	7.58%	7.45%	6.40%	5.22%	4.26%
2010-2014	0.14%	0.45%	0.77%	1.63%	2.69%	3.86%	5.38%	7.28%	7.59%	7.49%	6.70%	5.31%	4.58%

Source: Human mortality data base by cause

U.S. other pulmonary (mostly COPD) mortality rates per 100,000

Females	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**	**60-64**	**65-69**	**70-74**	**75-79**	**80-84**	**85-89**	**90-94**	**95-99**
1980-1984	**0.2**	**<u>1.0</u>**	**<u>2.8</u>**	**7.0**	**15.6**	**31.1**	**56.5**	**87.7**	**109.1**	**133.0**	**144.0**	**157.8**	**161.2**
1985-1989	**0.2**	**0.5**	**2.6**	**<u>7.6</u>**	**19.4**	**40.4**	**70.3**	**119.5**	**169.9**	**208.5**	**227.6**	**239.3**	**262.8**
1990-1994	**0.2**	**0.6**	**1.8**	**7.1**	**19.0**	**44.9**	**84.5**	**138.5**	**218.5**	**287.6**	**325.9**	**341.2**	**353.3**
1995-1999	**0.2**	**0.8**	**2.1**	**6.8**	**<u>19.9</u>**	**47.7**	**91.7**	**162.7**	**248.9**	**369.9**	**448.9**	**485.0**	**517.8**
2000-2004	**<u>0.5</u>**	**1.1**	**3.0**	**7.0**	**18.4**	**<u>49.4</u>**	**<u>98.8</u>**	**<u>176.9</u>**	**275.9**	**420.9**	**571.5**	**659.4**	**738.4**
2005-2009	**0.4**	**<u>1.3</u>**	**<u>3.8</u>**	**9.6**	**18.1**	**43.2**	**92.9**	**174.6**	**<u>285.5</u>**	**<u>437.3</u>**	**594.2**	**733.5**	**873.1**
2010-2014	**0.4**	**1.0**	**3.7**	**<u>11.4</u>**	**<u>22.3</u>**	**41.0**	**83.9**	**170.5**	**280.8**	**432.1**	**<u>605.5</u>**	**<u>768.0</u>**	**<u>939.6</u>**
Males													
1980-1984	**0.4**	**<u>1.2</u>**	**3.4**	**<u>11.1</u>**	**<u>29.3</u>**	**64.7**	**132.6**	**<u>253.9</u>**	**392.2**	**543.4**	**661.3**	**664.8**	**663.7**
1985-1989	**0.5**	**1.1**	**<u>3.5</u>**	**10.0**	**28.4**	**<u>68.7</u>**	**134.8**	**253.1**	**414.3**	**615.8**	**801.3**	**844.7**	**909.6**
1990-1994	**0.4**	**1.1**	**2.6**	**9.0**	**25.8**	**61.8**	**<u>134.9</u>**	**234.7**	**<u>392.8</u>**	**622.9**	**838.2**	**966.4**	**1,164.4**
1995-1999	**0.3**	**1.1**	**2.9**	**8.6**	**24.5**	**59.3**	**123.8**	**242.8**	**390.0**	**<u>643.2</u>**	**925.8**	**1,141.3**	**1,369.0**
2000-2004	**<u>0.4</u>**	**<u>1.3</u>**	**3.6**	**9.0**	**22.1**	**56.9**	**116.2**	**230.0**	**388.9**	**625.3**	**<u>943.2</u>**	**<u>1,261.6</u>**	**<u>1,537.4</u>**
2005-2009	**0.3**	**1.2**	**<u>4.0</u>**	**<u>10.2</u>**	**22.8**	**50.7**	**108.6**	**207.6**	**361.5**	**589.6**	**855.7**	**1,169.3**	**1,489.3**
2010-2014	**0.3**	**1.1**	**3.0**	**9.9**	**<u>24.6</u>**	**49.4**	**97.5**	**200.8**	**330.6**	**540.1**	**819.3**	**1,103.1**	**1,511.2**

Source: Human mortality data base by cause

Mortality projection: smoking methodology

- Resulting estimated difference in cohort life expectancy at age 35 and 65 in 2015 by gender

	Age 35		Age 65	
Scenario	**Females**	**Males**	**Females**	**Males**
2016 Trustees report	46.27	42.38	18.70	16.37
With expected reductions in smoking	47.02	43.66	19.18	17.16
Effect of reduction	0.75	1.28	0.48	0.79

- Reduction in prevalence and effect of smoking cessation for males is one reason why life expectancy differences between gender decreased over the last few decades
  - This difference will continue to reduce somewhat in the future and then may increase again
  - One reason why female and male patterns of mortality have and will differ

Background: obesity

- The obesity epidemic in the United States began in the 1970s and has not yet stopped
  - Obesity is determined here on the basis of a body mass index (BMI) of 30.0 and greater
  - From 15% in the late 1970s to the high 30s now

NHANES Years / Ages	Males				Females			
	20-39	40-59	60 +	All	20-39	40-59	60 +	All
1988-1994	14.8%	25.4%	21.2%	20.2%	20.7%	30.3%	25.6%	25.4%
1999-2002	23.0	30.5	30.8	27.6	29.1	36.7	35.0	33.3
2003-2006	28.0	37.2	31.3	32.2	29.7	39.9	33.0	34.2
2007-2010	30.3	35.7	36.8	33.9	32.9	37.0	37.9	35.6
2011-2014	30.3	38.3	34.8	34.3	34.4	42.1	38.8	38.3
2013-2014	31.6	37.2	37.5	35.2	37.0	44.6	39.4	40.5
2013-2014: class 3+ obese	6.0	5.2	5.0	5.5	10.1	11.9	6.4	9.7

Sources: National Health And Nutrition Expenditure Surveys (NHANES), for adults aged 20+, Flegal et al. (2016), Fryar et al. (2016)
Notes: All age totals are age-adjusted; four year values are equal to the average of the two sets of two year survey results.

Background: obesity

- BMI distribution has shifted to the right
  - In other words, average BMI for the obese has increased faster than the median

- Transitions between BMI categories over ten year periods have been

BMI: from/to	Gender	Normal	Overweight	Class 1 Obese	Class 2+ Obese
Normal	Both	62%	34%	4%	0%
Overweight	Males	13	53	27	7
	Females	7	44	37	31
Obese 1	Males	2	23	44	31
	Females	2	16	41	40
Obese 2+	Both	0	5	25	70

Source: based on Preston et al. (2014), between decadal NHANES; underweight not reflected due to its relatively small prevalence

- It is unlikely that these transitions will continue for a long time.
  - Estimated ultimate rate of obesity as about 110% of 2013-14 NHANES level (range: 100 and 120%)

Mortality projection: obesity methodology

Approach:

1. For each scenario, weight the selected hazard ratios for each BMI category by the assumed distribution of number of individuals corresponding to those BMI categories
2. Divide the weighted hazard ratio corresponding to the ultimate scenario (30 years hence) to the hazard ratio for the current scenario
3. Solve for the annual rate of change in mortality between 2015 and 2045 corresponding to (2)
4. Determine the equivalent life expectancy for cohort mortality for a 35 year old in 2015 for the high, mid and low point in the range (used Social Security Trustees' 2016 mortality projections as a base)

Effects of obesity on hazard ratios

- Mortality hazard ratios by BMI category, gender and time of measurement
- Due to decrease in cardiovascular diseases caused in part by obesity, hazard ratios have decreased recently

<table>
<tr><th>BMI category</th><th>Total</th><th>Males</th><th>Females</th><th>Measured
< 1990</th><th>Measured
≥ 1990</th></tr>
<tr><td>15.0 – 18.4</td><td>1.51</td><td>1.83</td><td>1.53</td><td>1.43</td><td>1.53</td></tr>
<tr><td>18.5 – 19.9</td><td>1.33</td><td rowspan="3">1.00</td><td rowspan="3">1.00</td><td rowspan="3">1.00</td><td rowspan="3">1.00</td></tr>
<tr><td>20.0 – 22.4</td><td>1.00</td></tr>
<tr><td>22.5 – 24.9</td><td>1.00</td></tr>
<tr><td>25.0 – 27.4</td><td>1.07</td><td rowspan="2">1.12</td><td rowspan="2">1.08</td><td rowspan="2">1.14</td><td rowspan="2">1.05</td></tr>
<tr><td>27.5 – 29.9</td><td>1.20</td></tr>
<tr><td>30.0 – 34.9</td><td>1.45</td><td>1.70</td><td>1.37</td><td>1.58</td><td>1.31</td></tr>
<tr><td>35.0 – 39.9</td><td>1.94</td><td>2.68</td><td>1.86</td><td>2.10</td><td>1.76</td></tr>
<tr><td>40.0 +</td><td>2.76</td><td>4.24</td><td>2.71</td><td>2.88</td><td>2.49</td></tr>
</table>

Source: Global BMI Mortality Collaboration (2016)
Notes: “Total” and other columnar breakdowns come from different combinations of studies and may be inconsistent

Distribution of BMI by scenario

- Distribution by BMI category, gender and period of NHANES
  - 1988-94 NHANES assumed to correspond to current mortality
  - 2013-14 NHANES assumed to correspond to mortality in 30 years
- Approximate 110% and 120% scenario distribution by BMI category developed by judgment

BMI category	1988-94 NHANES scenario 1		2013-14 NHANES 100% - scenario 2		2013-14 NHANES 110% - scenario 3		2013-14 NHANES 120% - scenario 4		Hazard Ratios from slide 15	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Underweight	4%	4%	2%	2%	2%	2%	2%	2%	1.83	1.53
Normal	35.1	44.7	24.3	31.1	21.8	27.1	19.8	23.5	1.00	1.00
Overweight	40.7	25.9	38.7	26.5	38.7	26.5	38.7	26.5	1.12	1.08
Obese 1	12.0	12.0	19.0	17.0	20.0	18.5	20.5	19.1	1.70	1.37
Obese 2	6.5	9.5	10.5	13.5	11.0	14.5	11.5	16.5	2.68	1.86
Obese 3	1.7	3.9	5.5	9.9	6.5	11.4	7.5	12.4	4.24	2.71

Source: NHANES

Mortality projection: obesity methodology (2)

Components

- Obesity prevalence (underweight, normal, overweight, class 1, class 2 and class 3 obese)
  - Because of the lag between obesity and premature death
    - 1988-94 NHANES prevalence assumed to correspond to current mortality experience
    - 2013-14 NHANES corresponding to assumed prevalence in 30 years, with linear changes in between
      - 100%, 110% and 120% of additional percentage of deaths represent range, corresponding to an estimated range based on (2013/14) NHANES prevalence distribution, with higher obesity categories assumed to increase proportionally more
- Obesity mortality hazard ratios
  - Based on BMI Collaborative Study (2016) values by gender and BMI category (slide 15, columns 3 and 4)

Resulting mortality ratios

- Males: 1.166, 1.202 and 1.235
- Females: 1.118, 1.150 and 1.180

Projection: effects of obesity

- U.S. cohort life expectancy for a 35 year old and a 65 year old in 2035

	Age 35		Age 65	
Scenario	Females	Males	Females	Males
2016 Trustees report	46.27	42.38	18.70	16.37
100% (2013-14 NHANES BMI distribution)	45.32	41.04	18.17	15.70
110% (2013-14 NHANES BMI distribution)	45.08	40.77	18.03	15.58
120% (2013-14 NHANES BMI distribution)	44.86	40.54	17.92	15.47
100% scenario – decrease in life expectancy	0.95	1.34	0.53	0.67
110% scenario – decrease in life expectancy	1.19	1.61	0.63	0.79
120% scenario – decrease in life expectancy	1.41	1.84	0.78	0.90

Effect of smoking and obesity

- Net effect on life expectancy of 35 year old in 2015 is a net reduction of about 0.34 years for females and 0.33 for males
  - For a 65 year old in 2015 – a net reduction of about 0.15 years for females and no change for males

Effect of behavior / scenario – Age 35	2		Intermediate		4	
	Females	Males	Females	Males	Females	Males
Decrease in Smoking			0.75	1.28		
Incease in Obesity	- 0.95	- 1.34	- 1.19	- 1.61	- 1.41	- 1.84
net			- 0.34	- 0.33		
Age 65						
Decrease in Smoking			0.48	0.79		
Incease in Obesity	- 0.53	- 0.67	- 0.63	- 0.79	- 0.78	- 0.90
net			- 0.15	0.00		

Limitations

- Projection methodology heavily reliant on judgment – key assumptions:
  - Rate of decline in mortality by cause of death / age category due to lower prevalence of smokers
  - Period of decline and ultimate value of mortality by cause of death / age category due to smokers
  - Future prevalence and distribution of obesity by category
  - Period to which ultimate hazard ratios for obesity apply
  - BMI Collaborative study's hazard ratios for obesity will correspond to ultimate values
    - Effect of (1) disease mix and (2) older age mortality may make findings conservative
- Does not directly reflect relations between smoking and obesity
  - Those who quit smoking tend to gain weight
  - Effect of those who both smoke and are obese – more than additive effect
  - Their opposite effect in the aggregate should reduce, but not eliminate, the effect of aging of those affected
- Some of the effects noted is applied to the very oldest ages (e.g., the 90s), which should not be considered "premature" deaths