To what extent will human behavior affect mortality projections

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

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ORIGINALLY PRESENTED AT THE 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
  - Smoking cigarettes
  - Obesity (underlying behaviors include nutrition, physical activity and time being sedentary)

Background: smoking

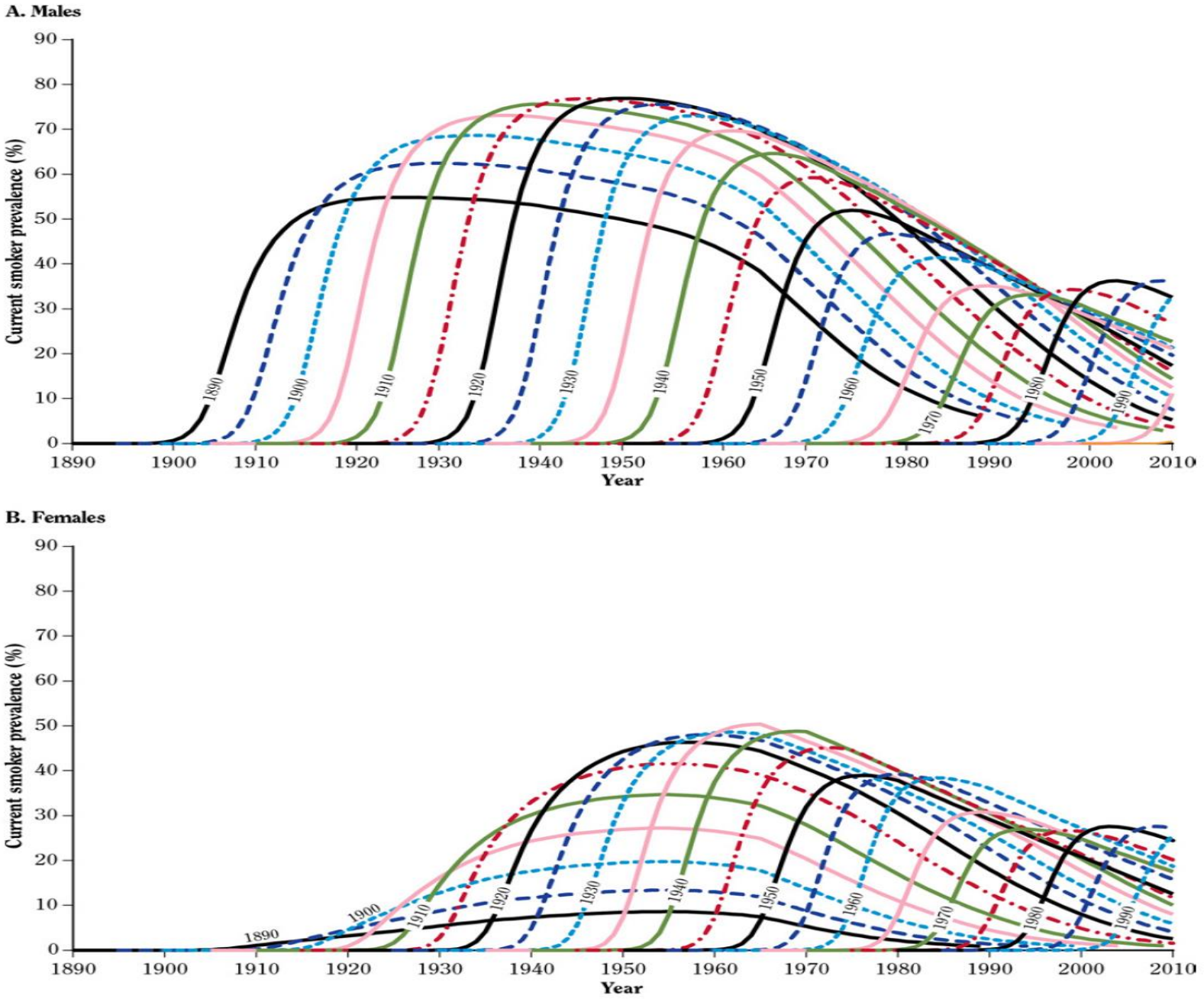
- Prevalence of smoking cigarettes in the United States, especially for males, was extremely high
  - Peaked at about 63% of male adults in the 1940s and 1950s and about 38% of female adults in the 1960s
- Has decreased for both genders since then
- Cigarettes smoked per smoker has also declined

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

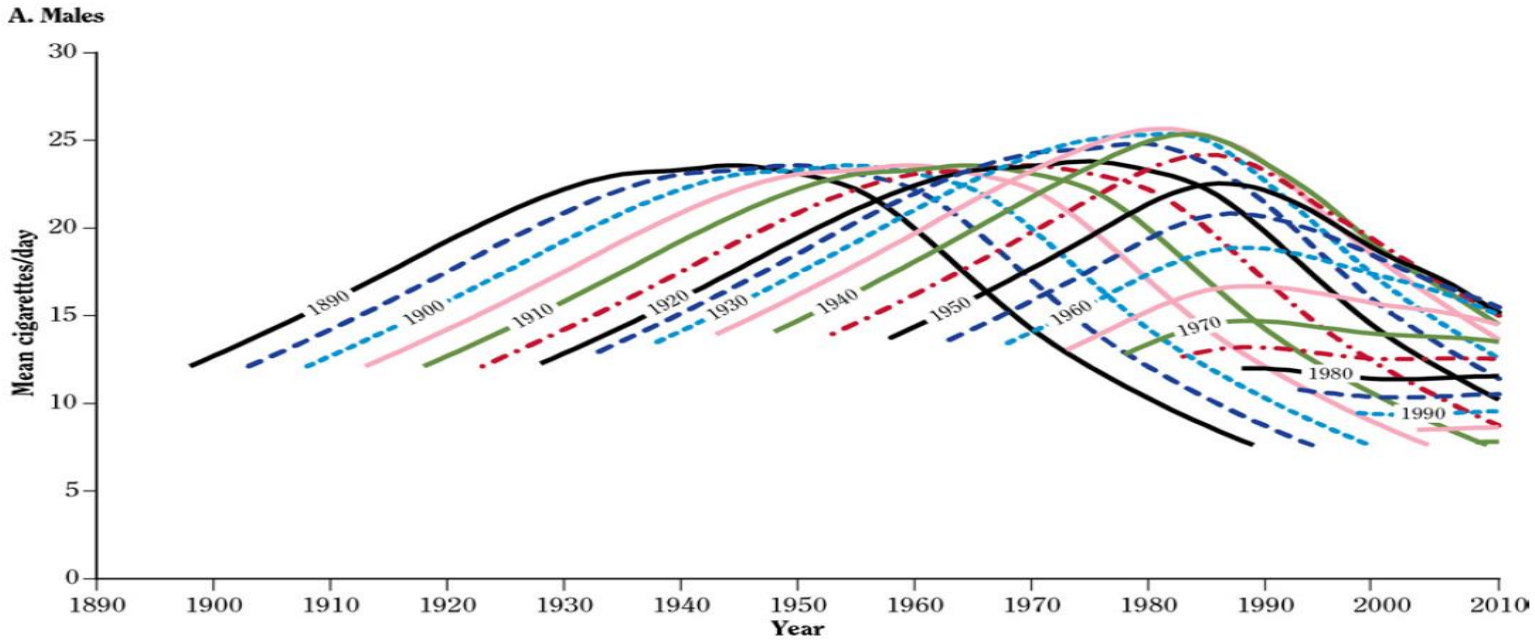
Source: CDC

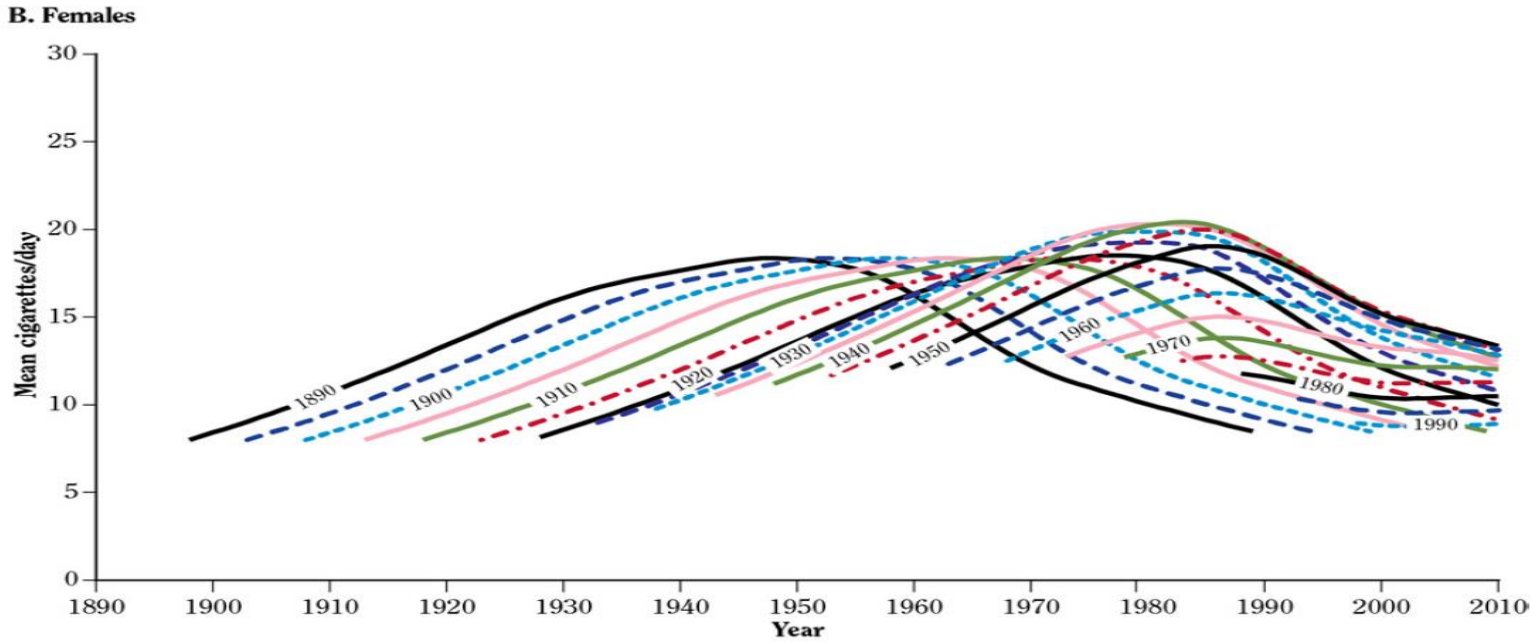
Smoking prevalence by birth cohort and gender



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

Average cigarette smoked per day by birth cohort and gender





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

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	1.0	2.8	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	7.6	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	19.9	47.7	91.7	162.7	248.9	369.9	448.9	485.0	517.8
2000-2004	0.5	1.1	3.0	7.0	18.4	49.4	98.8	176.9	275.9	420.9	571.5	659.4	738.4
2005-2009	0.4	1.3	3.8	9.6	18.1	43.2	92.9	174.6	285.5	437.3	594.2	733.5	873.1
2010-2014	0.4	1.0	3.7	11.4	22.3	41.0	83.9	170.5	280.8	432.1	605.5	768.0	939.6
Males													
1980-1984	0.4	1.2	3.4	11.1	29.3	64.7	132.6	253.9	392.2	543.4	661.3	664.8	663.7
1985-1989	0.5	1.1	3.5	10.0	28.4	68.7	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	134.9	234.7	392.8	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	643.2	925.8	1,141.3	1,369.0
2000-2004	0.4	1.3	3.6	9.0	22.1	56.9	116.2	230.0	388.9	625.3	943.2	1,261.6	1,537.4
2005-2009	0.3	1.2	4.0	10.2	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	24.6	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

- For two major causes of deaths resulting from smoking (lung cancer and other pulmonary diseases) for age categories 35-39 to 95-99
  - Age categories 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 the two resulting sets of percentages of future rates by age category and calendar period

Mortality projection: smoking methodology (2)

- Since these two aren't the only causes of death resulting from smoking
  - The total deaths from these two causes have been about 61% of male deaths and 47% of female deaths that are estimated to be due to smoking
  - Increased the percentage reduction from the prior step 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-year old and a 65-year old in 2015

Mortality projection: smoking methodology

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

	at age 35		at age 65	
Scenario:	Females	Males	Females	Males
2016 Trustees report	46.27	42.38	18.70	16.37
With expected reductions in smoking	47.23	43.37	19.31	16.98
Effect of reduction in smoking	+ 0.96	+ 0.99	+ 0.61	+ 0.61

- 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 effect will reduce and may reverse
  - One reason why female and male patterns of mortality have and will differ

Background: obesity prevalence

- The obesity epidemic in the United States began in the 1970s and has not yet stopped
  - Obesity determined 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 distribution shift

- BMI distribution has shifted to the right, i.e., average BMI for the obese is increasing faster than the median
- Transitions between BMI categories over ten year periods have been

BMI	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%)

Obesity hazard ratios

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

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

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 taken to correspond to current mortality; 2013-14 NHANES to correspond to mortality in 30 years
- Approximate 110% and 120% scenario distributions developed by judgment

BMI category	1988-94 NHANES scenario 1		2013-14 NHANES						Hazard Ratios from slide 15	
			100% - scenario 2		110% - scenario 3		120% - scenario 4			
	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

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)

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
    - 1986-90 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
    - Males: 1.166, 1.202 and 1.235
    - Females: 1.118, 1.150 and 1.180
- Obesity mortality hazard ratios
  - Based on BMI Collaborative Study (2016) values by gender and BMI category (slide 15, columns 3 and 4)

Projection: effects of obesity

- U.S. cohort life expectancy for a 35-year old and a 65-year old in 2015

Age in 2015:	age 35		age 65	
Life expectancy in the NHANES scenario:	Females	Males	Females	Males
1988-94	46.27	42.38	18.70	16.37
low 2013-14	45.32	41.04	18.17	15.70
mid 2013-14	45.08	40.77	18.03	15.58
high 2013-14	44.86	40.54	17.92	15.47
Effect of increases in obesity from 1988-94 NHANES:				
low 2013-14	- 0.95	- 1.34	- 0.53	- 0.67
mid 2013-14	- 1.19	- 1.61	- 0.63	- 0.79
high 2013-14	- 1.41	- 1.84	- 0.78	- 0.90

Effect of smoking and obesity

- Estimated net effect on cohort life expectancy of a 35-year old in 2015 is a net reduction of about 0.61 years and of a 65-year old is about 0.02 years for a female and 0.18 for a male

Effect of changes in behavior	Age in 2015	Low		Intermediate		High	
		Females	Males	Females	Males	Females	Males
Smoking	35			0.96	0.99		
Obesity	35	- 0.95	- 1.34	- 1.19	- 1.61	- 1.41	- 1.84
Net	35			- 0.23	- 0.62		
Smoking	65			0.61	0.61		
Obesity	65	- 0.53	- 0.67	- 0.63	- 0.79	- 0.78	- 0.90
Net	65			- 0.02	- 0.18		

Limitations

- Projection methodology heavily reliant on judgment – key assumptions:
  - Rate of decline in mortality due to lower prevalence of smokers
  - Period of decline and ultimate value of mortality due to smokers
  - Future prevalence and distribution of obesity
  - Period to which ultimate hazard ratios for obesity apply
  - BMI Collaborative 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