Body Weight and Survival: Recent Trends in the US*

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Abstract

Continued mortality improvement in the last decades has been accompanied by a large increase in body weight. Today, the majority of the US population is considered overweight or obese, and it has been suggested that if the current trend in body weight continues, the continuing rise in life expectancy would stop. Empirical evidence, however, is limited. Using data from the Second and Third National Health and Nutrition Examination Survey (respective baseline at 1976-80 and 1988-92), this study will accomplish two tasks. First, it examines whether the weight/mortality associations have varied over time. Second, it estimates life expectancy at age 20 for the two periods, and quantifies the respective roles in expectancy changes of a changing population weight distribution, and changing weight/mortality associations, using a standard decomposition procedure. All estimates are standardized by a standard smoking distribution to account for well-documented changes in smoking behavior.

1 Background

People are living longer. Life expectancy at birth in the US has increased from about 40 years at the turn of the 20th century to 77 years at its end, with about half of the rise achieved during the last three decades of the 20th century. Are people living a healthier life as well? The overall picture is positive. Compared with those living at the turn of the 20th century, people are less likely to have chronic diseases or disabilities now (Costa 2002). A rise in the observed prevalence of disabilities, and greater proportion of life spent in ill health were detected from data in the 1960s and 1970s (Verbrugge 1984; Crimmins, Saito and Ingeneri 1989). This expansion of morbidity, however, seems to be temporary, as evidence for the 80s and 90s indicates either no clear trend or a decline in the levels of disability, especially for the elderly using common measures such as having difficulty or needing help with daily activities (Crimmins, Saito and Ingeneri 1997; Freedman et al. 2004). Cohort studies on the prevalence of disability and disease conditions have also found an overall pattern of improvement among the elderly (Manton, Stallard and Corder 1997; Reynolds, Crimmins and Saito 1998). But there is some evidence for a decline of health for younger adults, especially among the less educated subgroups (Lakdawalla, Bhattacharya and Goldman 2004; Reynolds et al. 1998).

Despite the overall optimism, health experts and the public have been alerted to the looming public health storm of obesity. Although the increase of body height and weight has been associated with factors responsible for the declines in mortality and morbidity (Fogel 1994), excess body mass is associated with a host of fatal diseases such as cardiovascular diseases, hypertension and stroke, cancer, Type II diabetes, gallbladder diseases, and with less life-threatening but debilitating conditions such as osteoarthritis and pulmonary diseases (WHO 2000). Since the 1960s, the mean weight of American adults aged 20-74 has increased by 11 kilograms (24 pounds); and the mean Body Mass Index (BMI, calculated as weight in kilograms divided by squared height in meters) has increased by 2.7 and 3.3 units to 27.8 and 28.2 for adult men and women, respectively (Ogden et al. 2004). Today, about two of every three American adults have a BMI greater than 25 and are considered overweight or obese (Flegal et al. 2002). This rapid rise in body mass has been observed of all ethnic groups and socio-economic strata. Although the prevalence of overweight and obesity has been higher in more disadvantaged sub-populations, the pace of rise in body weight has been faster among the traditionally less vulnerable groups.

What are the health implications of these trends in body weight? Olshansky et al. (2005) argued that obesity is responsible for a reduction of one third to three fourth of a year in period life expectancy at birth in the United States in 2000, and that the amount of life shortened would increase in the coming years because "the obese who are now at younger ages carry their elevated risk of death into middle and older ages." It has also been suggested that if the current trend in body weight continues, the continuing rise in life expectancy would stop (Olshansky et al. 2005), and recent gains in disability among older Americans would be wiped out (Sturm et al. 2004).

Empirical evidence, however, is limited regarding the role of body weight in recent mortality trends. The two studies that examined trends in mortality and body weight covered different time periods, and found opposite trends in how mortality varies by body weight. An increase from the end of the 19th century to early 1970's was observed when analyzing the Union Army Records and the 1971-75 National Health and Nutrition Examination Survey (NHANES I) (Su 2005), whereas a decline was reported in an analysis using the three NHANES data sets, with their respective baseline at 1971-75 (I), 1976-80 (II) and 1988-1992 (III), and the first two followed through 1992 and the last followed through 2000 for mortality (Flegal et al. 2005). The results in this second analysis have been questioned, on the grounds that the three datasets differ in length of mortality follow-up, and the excess mortality of excess weight may appear to be smaller with a shorter follow-up because a longer follow-up may allow the dying out of a subset of the reference normal-weight group who have been ill and lost weight, and who should elevate the level of reference mortality (Greenberg 2006). In addition, my own preliminary check of the NHANES II mortality data found that of the 3121 deaths through the year 1992 that were recorded by the National Center for Health Statistics in its 2005 restricted release, 976 deaths are short in the public release file that was based on a prior mortality linkage with the National Death Index, and used to obtain the results in Flegal et al. 2005. For these analytical and data quality concerns, it remains uncertain whether excess mortality associated with excess body weight has increased or declined in recent decades.

This study seeks to address the gaps, using data from the 1976-80 NHANES II and 1988-92 NHANES III, including the restricted file for NHANES II mortality and the recent public release of NHANES III mortality, and US national mortality for the corresponding years (1976-80 vs. 1988-92). It has two specific tasks. First, I examine changes in mortality differentials by body weight from the late 1970's to the early 90's. Second, I calculate life expectancy at age 20 for the two periods, and quantifies the respective roles in these period trends of a changing population weight distribution, and changing weight/mortality associations. The Gompertz model is used to analyze age-specific mortality and mortality differentials. Decomposition techniques (Das Gupta 1999) are used to partition temporal changes in expectancies into changes associated with population weight distribution (referred to as distribution component), and changes associated with weight/mortality associations (referred to as survival component).

The expectancy estimates are smoking-standardized by using a standard smoking distribution that is expressed in two groups (ever vs. never smokers), and analyzing the weight distribution and weight/mortality association conditional on smoking status. The health hazards of smoking and the secular trend in the past decades of smoking cessation and reduction are well-documented (CDC 2002). The weight/mortality association may also differ between smokers and nonsmokers (e.g., Breeze et al. 2006; Calle et al. 1999). With the use of a smoking standard, the expectancy estimates for the corresponding years would not match the actual numbers. The standardized estimates, however, help to focus on the changing relationship between body weight and population health that is not influenced by changing population composition in smoking.

There is immense uncertainty and interest in the future course of mortality. A focus on the trend of a risk factor such as excess weight that is experienced by a majority of the population helps to reduce uncertainty and to target public health interventions more effectively. A few studies have separately examined changes in population weight distribution (e.g., Arterburn, Crane and Sullivan 2004; Flegal et al. 1998; Flegal et al. 2002) and changes in health risks associated with body weight (e.g. Flegal et al. 2005; Su 2005), each presenting a more or less pessimistic view of the future. Combining the two approaches would bring a more balanced and more holistic view to the discussion.

2 Notation and Quantities

The analysis uses a mixture of statistical notation (for population risk factor distributions) and demographic life table notation. For 5-year age group x at time t, the following indices and quantities are used:

- Indices (See the data section for details about the definition of variables):
  - S: Smoking status, $s = 1$ (ever smokers), and 2 (never smokers)
  - W: Body weight status, $w = 1$ (lean), 2 (overweight), and 3 (obese)
- Distributions for risk factors:
  - $P_x^t(S)$: Smoking distribution.
  - $P_x^{t_0}(S)$: Standard smoking distribution.
  - $P_x^t(W|S)$: Weight distribution at each level of smoking status
- Smoking-standardized life table quantities:
  - Total mortality ${}_5M_x^{t,s}$, standardized by smoking (indicated by the right superscript s), which is a weighted average of smoking-weight-specific mortality ${}_5M_x^t(WS)$:

$$ {}_5M_x^{t,s} = \sum_s P_x^{t_0}(S) \sum_w P_x^t(W|S) \cdot {}_5M_x^t(WS) \tag{1} $$

  - Death probability from age x to $x+5$, assuming that deaths occur in the middle of the five-year age interval:

$$ {}_5q_x^{t,s} = \frac{5 \cdot {}_5M_x^{t,s}}{1 + 2.5 \cdot {}_5M_x^{t,s}} \tag{2} $$

  - Number of persons alive in the life table population:

$$ l_{x+5}^{t,s} = l_x^{t,s} \cdot (1 - {}_5q_x^{t,s}) \tag{3} $$

– Person-years lived between age x to $x+5$:

$$ {}_5L_x^{t,s} = 5 \cdot l_{x+5}^{t,s} + 2.5 \cdot (l_{x+5}^{t,s} - l_x^{t,s}) \tag{4} $$

– Life expectancy between age 20 with radix $l_{20} = 1$:

$$ e_{20}^{t,s} = \sum_{x=20} {}_5L_x^{t,s} \tag{5} $$

A decomposition procedure developed by Das Gupta (1999) is used to partition temporal changes in life expectancy (Δ^s) into two components: changes in population weight distribution (referred to as distribution component $\Delta^s(W)$), and changes in weight-specific survival (referred to as survival component $\Delta^s(M)$).

To show the logic of the decomposition procedure, I re-express life expectancy, using F to denote the function that transforms population risk factor distributions and mortality into life expectancy (that is, Eq. (1), Eq. (2), Eq. (3), Eq. (4) and Eq. (5)), and using underline for vectors of age-specific values:

$$ e_{20}^{t,s} = F[\underline{P^{t_0}(S)}, \underline{P^{t}(W|S)}, \underline{M^{t}(WS)}] \tag{6} $$

To obtain the distribution component, the procedure differences the expectancy estimates at two time points when the distribution factor is varied as it did, but the mortality factor is held constant by taking an average over two expectancies using mortality observed respectively at the two time points:

$$ \begin{aligned} &\Delta^s(W) = \\ &\frac{F[\underline{P^{t_0}(S)}, \underline{P^{t_2}(W|S)}, \underline{M^{t_2}(WS)}] + F[\underline{P^{t_0}(S)}, \underline{P^{t_2}(W|S)}, \underline{M^{t_1}(WS)}]}{2} - \\ &\frac{F[\underline{P^{t_0}(S)}, \underline{P^{t_1}(W|S)}, \underline{M^{t_2}(WS)}] + F[\underline{P^{t_0}(S)}, \underline{P^{t_1}(W|S)}, \underline{M^{t_1}(WS)}]}{2} \end{aligned} \tag{7} $$

Similarly, we obtain the survival component:

$$\Delta^s(M) = \\ \frac{F[\underline{P^{t_0}(S)}, \underline{P^{t_2}(W|S)}, \underline{M^{t_2}(WS)}] + F[\underline{P^{t_0}(S)}, \underline{P^{t_1}(W|S)}, \underline{M^{t_2}(WS)}]}{2} - \\ \frac{F[\underline{P^{t_0}(S)}, \underline{P^{t_1}(W|S)}, \underline{M^{t_1}(WS)}] + F[\underline{P^{t_0}(S)}, \underline{P^{t_2}(W|S)}, \underline{M^{t_1}(WS)}]}{2} \tag{8}$$

It can be shown that $\Delta^s = \Delta^s(W) + \Delta^s(M)$.

From Eq (7) and Eq (8) it can be told that when the population weight distribution shifts to the right, and survival by each weight status improves over time, the distribution component is most likely negative and the survival component, positive. It is less certain as to which component dominates. Actual life expectancy has been increasing continuously over the study period. Whether this is true for smoking-standardized estimates is not entirely clear. In an age-period-cohort analysis that specifies cohort proportion ever smoking as the cohort variable, declines in period mortality rates between age 50 and 85 have been found to be muted but not completely eliminated when smoking is accounted for in the model (Preston and Wang 2006). Suppose smoking-standardized expectancies are increasing, then obviously the survival component dominates the distribution component over time.

3 Data

Data come from the Second (1976-80) and Third (1988-92) National Health and Nutrition Examination Survey (NHANES) conducted by the National Center for Health Statistics. Each survey examined and interviewed a nationally representative sample of the US non-institutionalized population at the baseline, and followed through the year 2000 for subsequent mortality. NHANES II mortality was available in a restricted file provided by the NCHS, and NHANES III mortality has been released in a public file. I will also use US national mortality to estimate life expetancy, assuming that that body weight distributions and mortality ratios by weight are the same between the non-institutionalized and institutionalized population. Analysis would be done separately for men and women.

At each survey baseline, body weight and height were measured with standard procedures. Body mass Index (BMI) is calculated as weight in kilograms divided by squared height in meters. BMI would be divided into three groups, as done in Gregg et al. 2005:

- Lean (BMI < 25)
- Overweight ($25 \leq$ BMI< 30)
- Obese ($30 \leq$ BMI)

The lean category combines the underweight and normal-weight group in the World Health Organization (2000) guidelines, because of the small number of cases that are underweight. My preliminary analysis suggests higher underweight mortality than all other weight categories, but the main results are unlikely to differ due to the small number of underweight cases.

Smoking status is coded as ever smoker if the respondent reports having smoked at least 100 cigarettes in his/her entire life, and never smoker otherwise.

The two surveys cover a different age range. NHANES III has no upper limit, but codes everybody aged 90 and older as 90 in the public file. NHANES II limits to those aged 74 or younger. The analysis includes those aged 89 or younger, and will use extrapolation to estimate populaiton smoking and weight distribution at ages not covered in NHANES II.

The final NHANES II sample has 11765 cases, and the NHANES III sample, 16676 cases. The number of cases in the un-weighted sub-samples defined by broad age groups, smoking and BMI status are reported in Table 1 for men and women separately in each survey.

The graphs are all based on data using sample weights. Figure 1 shows sex-age-specific proportions of ever smokers. As expected, the smoking proportions have declined over time, more so for men. The NHANES III curves are higher at older ages, probably due to the survival improvement of more recent ever smokers.

Sex-age-specific proportions of the overweight or obese are shown in Figure 2. All curves rise and drop, as typically observed in the weight trajectories of cross-sectional populations. A recent longitudinal analysis has attributed these age patterns to birth cohort differences in body weight, and illness-related weight loss of the heavy weight at older ages (Barone et al. 2006). Women's curves generally peak 10 or 15 years later, and the drop is less strong than men's curves, suggesting sex differences in weight history. For both men and women, the proportions tend to be higher for never than ever smokers, and in NHANES III than NHANES II. Further logistic regression analysis will determine whether these differences are statistically significant at conventional levels.

Mortality conditional on weight and smoking status (${}_5M_x^t(WS)$) are calculated from all-cause US national mortality, and NHANES II and NHANES III. The survey data are used to derive mortality ratios by weight status relative to the lean category. For each five-year age group, let ${}_5M_x^t$ denote national mortality, ${}_5M_x^t(WS)$ weight-smoking-specific mortality, and ${}_5r_x^t(WS)$ weight-smoking-specific mortality ratios, using the mortality of the lean category as reference (${}_5r_x^t(W = w, S) = \frac{{}_5M_x^t(W=w,S)}{{}_5M_x^t(W=1,S)}$ for w=2, 3). The following two identities are used to derive smoking-weight-specific mortality ${}_5M_x^t(WS)$.

$$ {}_5M_x^t(WS) = {}_5r_x^t(WS) \cdot {}_5M_x^t(W = 1, S) \tag{9} $$

$$ {}_5M_x^t = \sum_s P_x^t(S) \sum_w P_x^t(W|S) \cdot {}_5M_x^t(WS) \tag{10} $$

Men's age-specific mortality ratios, based on three-year averaged mortality, are shown in Figure 3, separately for ever and never smokers in NHANES III. The mortality ratios of the overweight and obese seem to be higher for never- than ever-smoking men. Note the gap in the never-smoking curves results from no death in the reference lean group at the particular age points.

Women's ratio curves are shown in Figure 4. The age patterns look similar across smoking status. Visually it is difficult to determine whether the ratios are larger for never smokers because of big fluctuations in the ratio estimates. Using sampling weights tends to increase variations in estimates. In the un-weighted data (not shown here), the curves, with much less fluctuation, appear higher for never smokers.

I have not analyzed NHANES II's confidential mortality data, but the NCHS has approved my proposal to access the data. Further parametric survival analysis will focus on whether the BMI mortality differentials vary by smoking status and time periods. Also note that in Figure 3 and Figure 4, ratio estimates for the overweight are no less than those for the obese, whereas previous studies found no excess mortality of the overweight relative to the normal-weight. Mortality from NHANES II would allow me to investigate the changes, if any. The analysis will be finished at the end of this year.

References

[1] Arterburn, David E., Paul K. Crane, and Sean D. Sullivan. 2004. "The Coming Epidemic of Obesity in Elderly Americans." *Journal of the American Geriatrics Society* 52(11):1907-12.

[2] Barone, Bethany B., Jeanne M. Clark, Nae-Yuh Wang, Lucy A. Meoni, Michael J. Klag, and Frederick L. Brancati. 2006. "Lifetime Weight Patterns in Male Physicians: The Effects of Cohort and Selective Survival." *Obesity* 14(5):902-8.

[3] Breeze, Elizabeth, Robert Clarke, Martin J. Shipley, Michael G. Marmot, and Astrid E. Fletcher. 2006. "Cause-Specific Mortality in Old Age in Relation to Body Mass Index in Middle Age and in Old Age: Follow-Up of the Whitehall Cohort of Male Civil Servants." *International Journal of Epidemiology* 35(1):69-78.

[4] Calle, Eugenia E., Michael J. Thun, Jennifer M. Petrelli, Carmen Rodriguez, and Clark W. Heath. 1999. "Body-Mass Index and Mortality in a Prospective Cohort of U.S. Adults." *New England Journal of Medicine* 341(15):1097-105.

[5] Center for Disease Control and Prevention (CDC). 2002. "Number (in Millions) of Adults 18 Years and Older Who Were Current, Former, or Never Smokers, Overall and by Sex, Race, Hispanic Origin, Age, and Education, National Health Interview Surveys, Selected Years–United States, 1965-1995." `www.cdc.gov/Tobacco/Research_Data/Adults_Prev/Tab_3.Htm`.

[6] Costa, Dora L. 2002. "Changing Chronic Disease Rates and Long-Term Declines in Functional Limitation Among Older Men." *Demography* 39(1):119-37.

[7] Crimmins, Eileen M., Yasuhiko Saito, and Dominique Ingegneri. 1989. "Changes in Life Expectancy and Disability-Free Life Expectancy in the United States." *Population and Development Review* 15(2):235-67.

[8] Crimmins, Eileen M., Yasuhiko Saito, and Dominique Ingegneri. 1997. "Trends in Disability-Free Life Expectancy in the United States, 1970-1990." *Population and Development Review* 23(3):555-72.

[9] Das Gupta, P. 1999. "Decomposing the Difference Between Rates When the Rate Is a Function of Factors That Are Not Cross-Classified." *Genus* LV(1-2): 9-26.

[10] Flegal, Katherine M., Margaret D. Carroll and Clifford L. Johnson. 1998. "Overweight and Obesity in the United States: Prevalence and Trends." *International Journal of Obesity* 22(14):39-47.

[11] Flegal, Katherine M., Margaret D. Carroll, Cynthia L. Ogden, and Clifford L. Johnson. 2002. "Prevalence and Trends in Obesity Among US Adults, 1999-2000." *Journal of the American Medical Association* 288(14):1723-27.

[12] Flegal, Katherine M., Barry I. Graubard, David F. Williamson, and Mitchell H. Gail. 2005. "Excess Deaths Associated With Underweight, Overweight, and Obesity." *Journal of the American Medical Association* 293(15):1861-67.

[13] Fogel, Robert W. 1994. "Economic Growth, Population Theory, and Physiology: The Bearing of Long-Term Processes on the Making of Economic Policy." *The American Economic Review* 84(3):369-95.

[14] Freedman, V. A., E. Crimmins, R. F. Schoeni, B. C. Spillman, H. Aykan, E. Kramarow, K. Land, J. Lubitz, K. Manton, L. G. Martin, D. Shinberg and T. Waidman. 2004. "Resolving Inconsistencies in Trens in Old-Age Disability: Report from a Technical Working Group". *Demography* 41(3):417-441.

[15] Greenberg, James A. 2006. "Correcting Biases in Estimates of Mortality Attributable to Obesity." *Obesity: Obesity* 14(11):2071-79.

[16] Gregg, Edward W., Yiling J. Cheng, Betsy L. Cadwell, Giuseppina Imperatore, Desmond E. Williams, Katherine M. Flegal, K. M. V. Narayan, and David F. Williamson. 2005. "Secular Trends in Cardiovascular Disease Risk Factors According to Body Mass Index in US Adults." *Journal of the American Medical Association* 293(15):1868-74.

[17] Lakdawalla, Darius, Jayanta Bhattacharya, and Dana P. Goldman. 2004. "Are the Young Becoming More Disabled?" *Health Tracking* 168-76.

[18] Manton, Kenneth, Eric Stallard, and Larry Corder. 1997. "Changes in the Age Dependence of Mortality and Disability: Cohort and Other Determinants." *Demography* 34(1):135-57.

[19] Ogden, Cynthia L., Cheryl D. Fryar, Margaret D. Carroll, and Katherine M. Flegal. 2004. "Mean Body Weight, Height, and Body Mass Index, United States 1960-2002." *Advance Data From Vital and Health Statistics* 347.

[20] Olshansky, S. J., Douglas J. Passaro, Ronald C. Hershow, Jennifer Layden, Bruce A. Carnes, Jacob Brody, Leonard Hayflick, Robert N. Butler, David B. Allison, and David S. Ludwig. 2005. "A Potential Decline in Life Expectancy in the United States in the 21st Century." *New England Journal of Medicine* 352(11):1138-45.

[21] Preston, Samuel and Haidong Wang. 2006. "Sex Mortality Differences in the United States: The Role of Cohort Smoking Patterns." *Demography* 43(4).

[22] Reynolds, Sandra L., Eileen Crimmins, and Yasuhiko Saito. 1998. "Cohort Differences in Disability and Disease Presence." *The Gerontologist* 38(5):578-90.

[23] Su, Dejun. 2005. "Body Mass Index and Old-Age Survival: A Comparative Study between the Union Army Records and the NHANES-I Epidemiological Follow-Up Sample." *American Journal of Human Biology* 17:341-354.

[24] Sturm, R., J. S. Ringel, and T. Andreyeva. 2004. "Increasing Obesity Rates and Disability Trends." *Health Affairs* 23(2).

[25] Verbrugge, L. M. 1984. "Longer Life but Worsening Health? Trends n Health and Mortality of Middle-Aged and Older Persons." *Milbank Memorial Fund Quarterly: Health and Society* 62475-519.

[26] World Health Organization (WHO). 2000. *Obesity: Preventing and Managing the Global Epidemic: Report of a WHO Consultation*. Geneva.

Table 1: Sample Sizes in NHANES II and NHANES III

	Men						Women					
Broad	Ever Smoke			Never Smoke			Ever Smoke			Never Smoke		
Age groups	Lean	Over	Obese	Lean	Over	Obese	Lean	Over	Obese	Lean	Over	Obese
NHANES II												
20-44	950	613	178	424	237	86	951	247	189	831	250	185
45-64	650	693	221	131	163	59	509	289	186	470	353	285
65-74	443	355	125	109	127	40	226	130	70	350	400	240
Total	2043	1661	524	664	527	185	1686	666	445	1651	1003	710
NHANES III												
20-44	992	809	434	701	607	287	809	452	435	1205	708	783
45-64	506	656	396	110	184	112	345	311	352	281	390	479
65-74	306	390	214	68	96	49	151	161	124	210	250	234
75-89	341	312	89	105	96	19	148	99	55	349	295	171
Total	2145	2167	1133	984	983	467	1453	1023	966	2045	1643	1667

Figure 1: Observed Proportions Ever-smoking, NHANES II and NHANES III, Sampling Weights Used

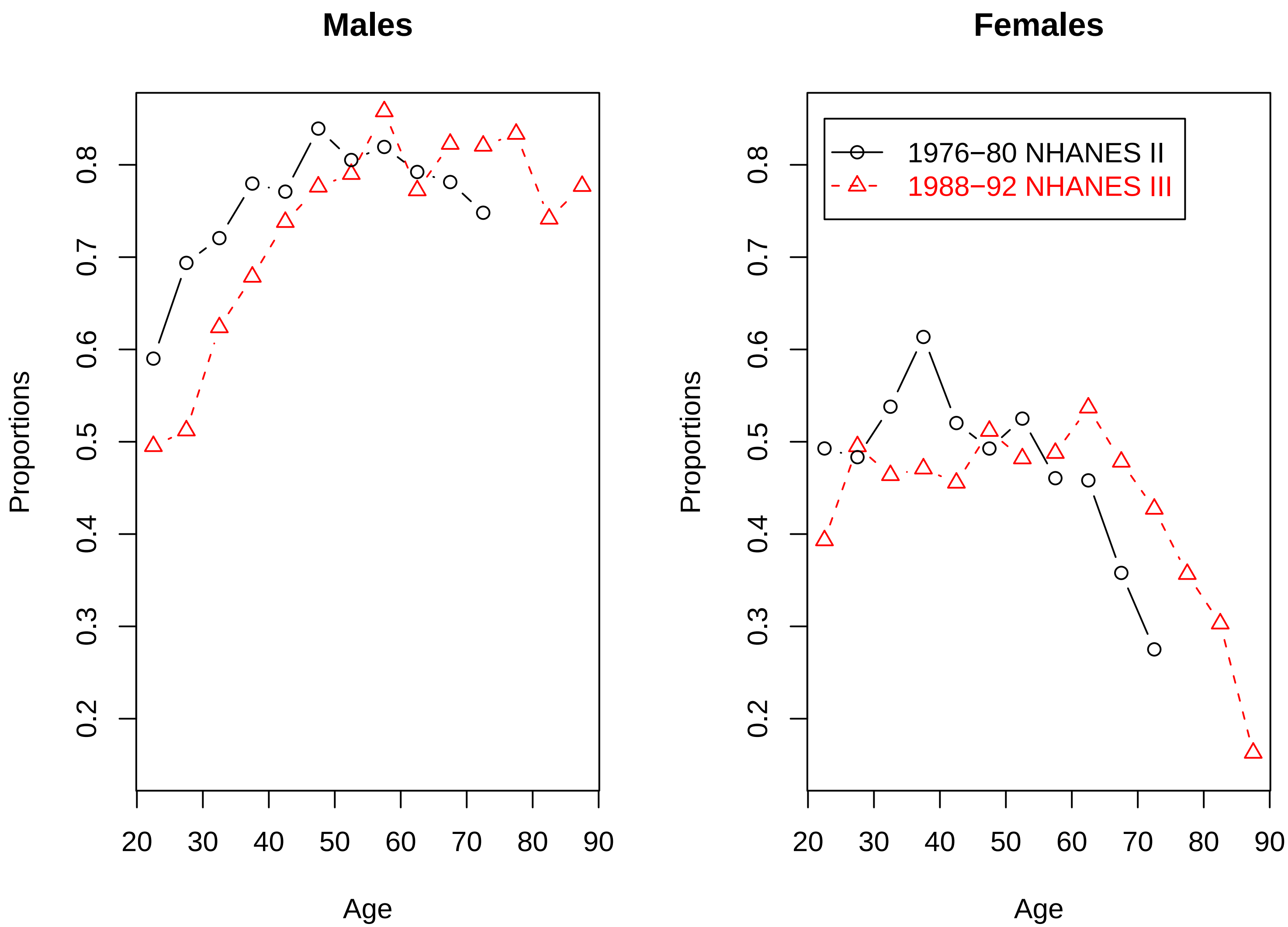

Figure 2: Observed Proportions of Body Mass Index ≥ 25 (Overweight or Obese), by Smoking Status, NHANES II and NHANES III, Sampling Weights Used

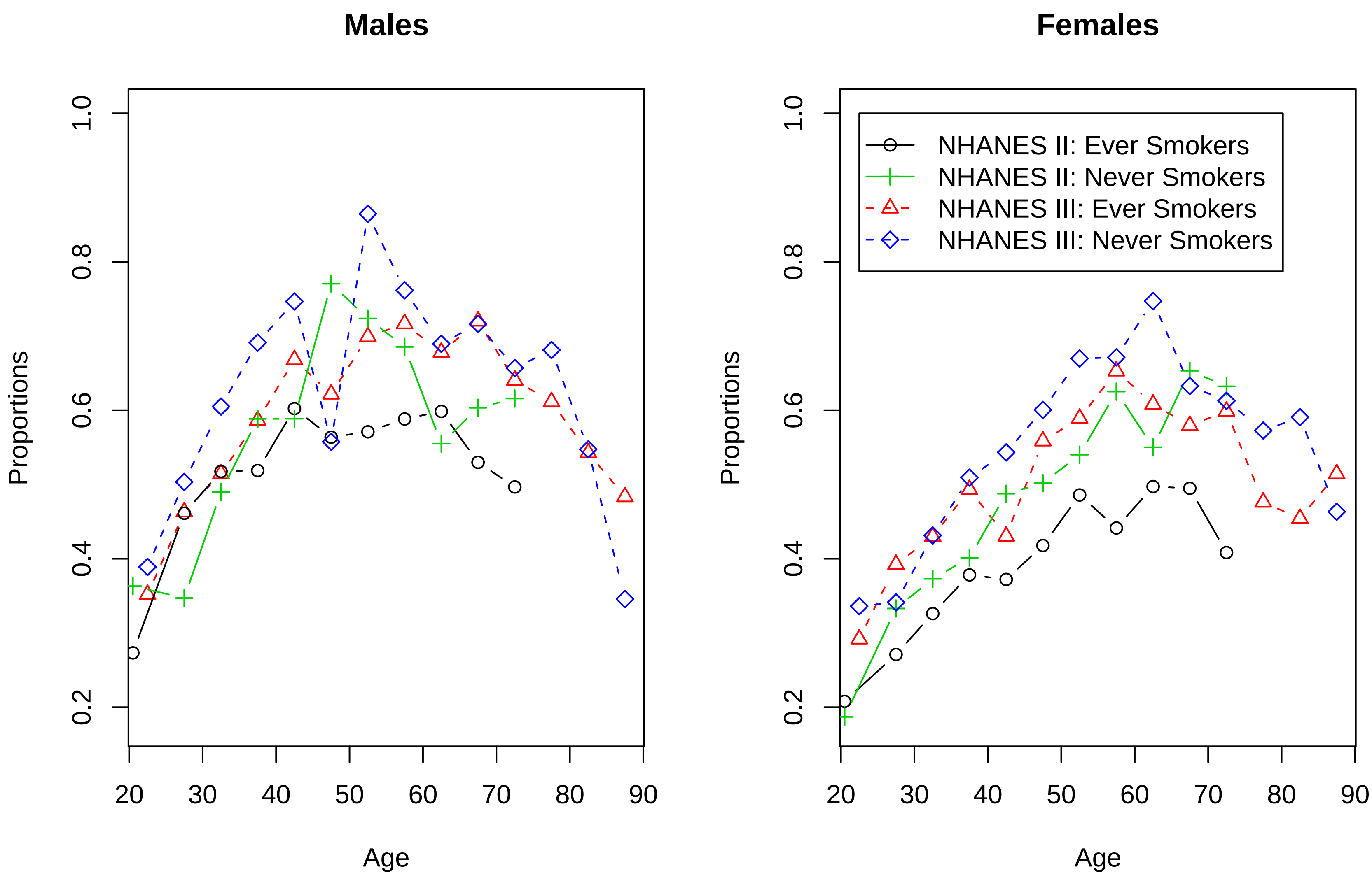

Figure 3: Observed Mortality Ratios by Smoking Status, Males, NHANES II and NHANES III, Sampling Weights Used

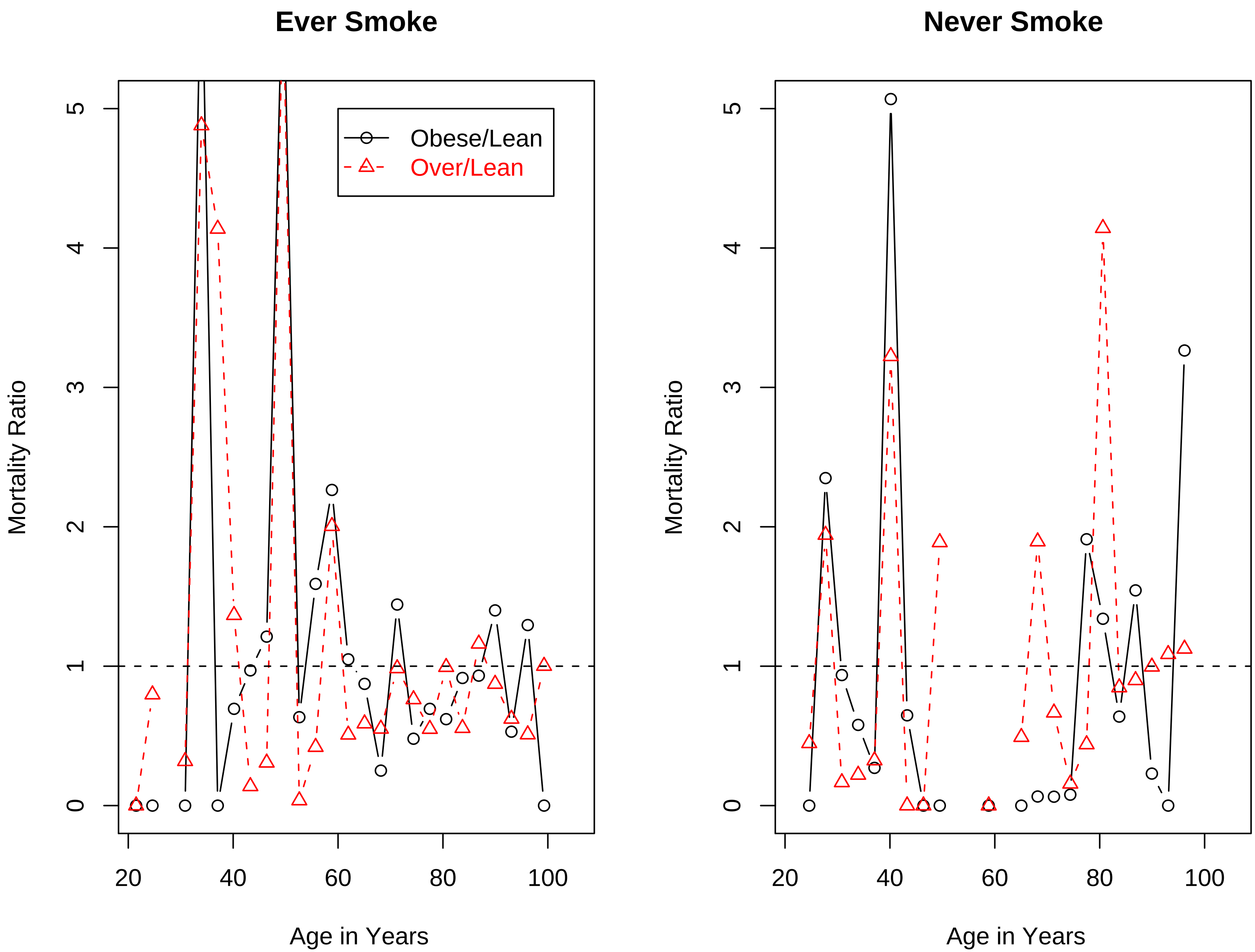

Figure 4: Observed Mortality Ratios by Smoking Status, Females, NHANES II and NHANES III, Sampling Weights Used