# Causal Inference: What If. R and Stata code for Exercises

Book by M. A. Hernán and J. M. Robins    R code by Joy Shi and Sean McGrath
Stata code by Eleanor Murray and Roger Logan
R Markdown code by Tom Palmer

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# Contents

# Preface

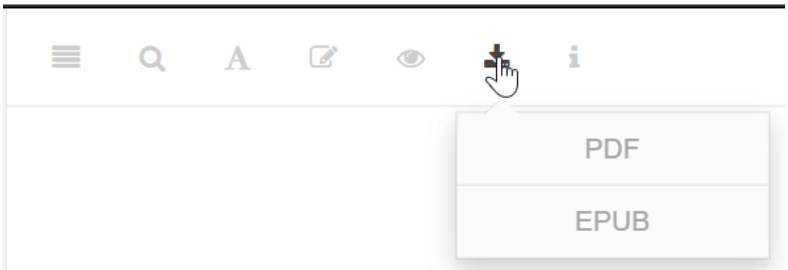
This book presents code examples from Hernán and Robins (2020), which is available in draft form from the following webpage.

https://www.hsph.harvard.edu/miguel-hernan/causal-inference-book/

The R code is based on the code by Joy Shi and Sean McGrath given here.

The Stata code is based on the code by Eleanor Murray and Roger Logan given here.

This repo is rendered at https://remlapmot.github.io/cibookex-r/. Click the download button above for the pdf and eBook versions.

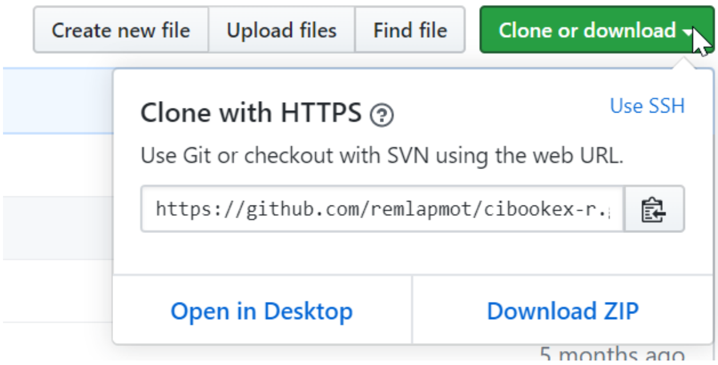



## Downloading the code

The repo is available on GitHub here. There are a number of ways to download the code.

Either,

- click the green *Clone or download* button then choose to *Open in Desktop* or *Download ZIP*.




  The *Desktop* option means open in the GitHub Desktop app (if you have that installed on your machine). The *ZIP* option will give you a zip archive of the repo, which you then unzip.

- or fork the repo into your own GitHub account and then clone or download your forked repo to your machine.


## Installing dependency packages

It is easiest to open the repo in RStudio, as an RStudio project, by doubling click the `.Rproj` file. This makes sure that R's working directory is at the top level of the repo. If you don't want to open the repo as a project set the working directory to the top level of the repo directories using `setwd()`. Then run:

```
# install.packages("devtools") # uncomment if devtools not installed
devtools::install_dev_deps()
```

## Downloading the datasets

We assume that you have downloaded the data from the Causal Inference Book website and saved it to a `data` subdirectory. You can do this manually or with the following code (nb. we use the `here` package to reference the data subdirectory).

```
library(here)
```

```
dataurls <- list()
stub <- "https://cdn1.sph.harvard.edu/wp-content/uploads/sites/1268/"
dataurls[[1]] <- paste0(stub, "2012/10/nhefs_sas.zip")
dataurls[[2]] <- paste0(stub, "2012/10/nhefs_stata.zip")
dataurls[[3]] <- paste0(stub, "2017/01/nhefs_excel.zip")
dataurls[[4]] <- paste0(stub, "1268/20/nhefs.csv")

temp <- tempfile()
for (i in 1:3) {
  download.file(dataurls[[i]], temp)
  unzip(temp, exdir = "data")
}

download.file(dataurls[[4]], here("data", "nhefs.csv"))
```

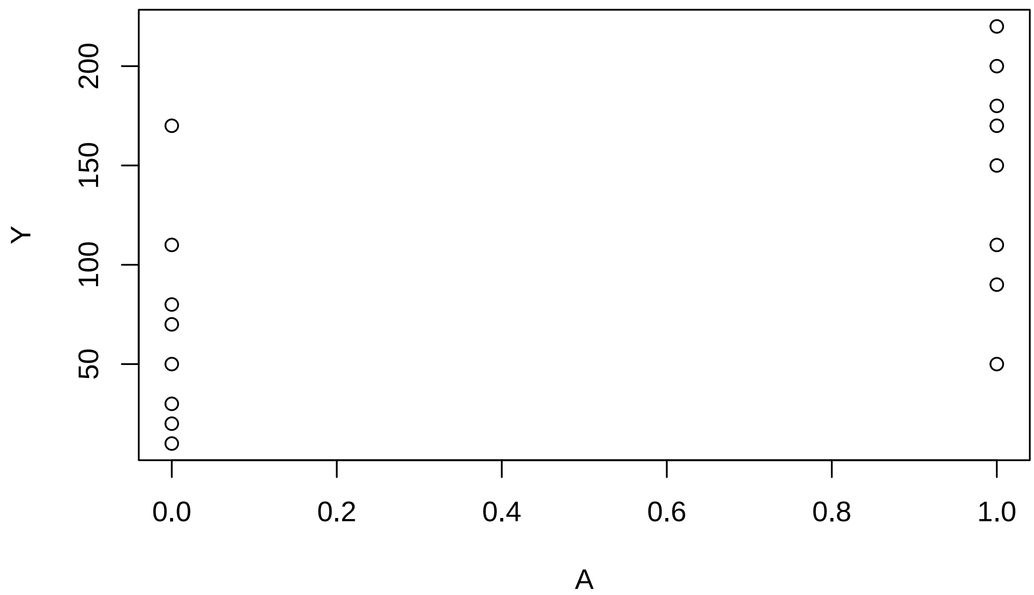
# R code

# 11. Why model?

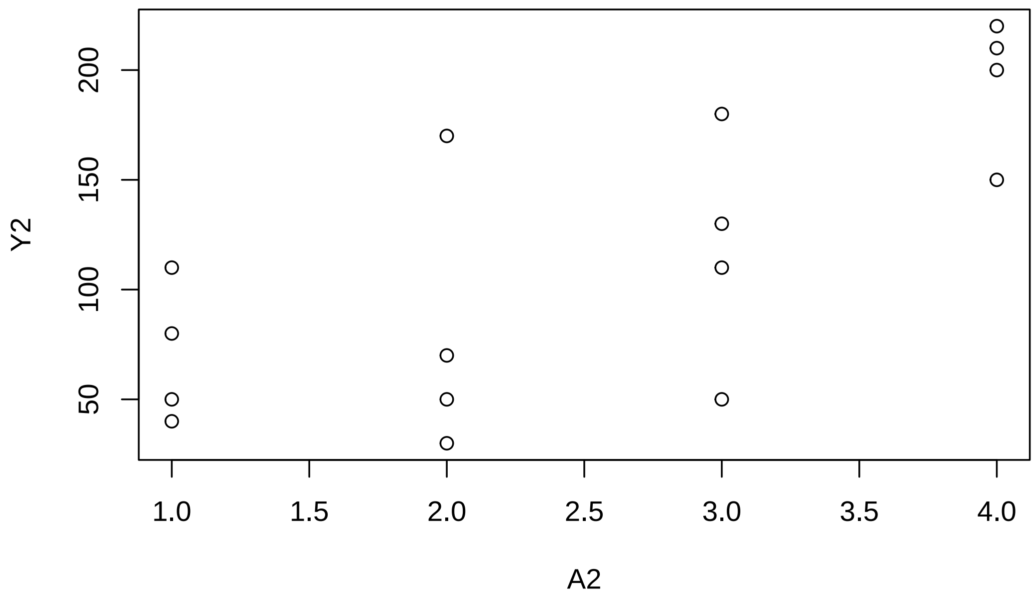
## Program 11.1

- Sample averages by treatment level
- Data from Figures 11.1 and 11.2

```
A <- c(1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0)
Y <- c(200, 150, 220, 110, 50, 180, 90, 170, 170, 30,
       70, 110, 80, 50, 10, 20)

plot(A, Y)
```




```
summary(Y[A == 0])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    10.0    27.5    60.0    67.5    87.5   170.0
summary(Y[A == 1])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    50.0   105.0   160.0   146.2   185.0   220.0

A2 <- c(1, 1, 1, 1, 2, 2, 2, 2, 3, 3, 3, 3, 4, 4, 4, 4)
Y2 <- c(110, 80, 50, 40, 170, 30, 70, 50, 110, 50, 180,
        130, 200, 150, 220, 210)

plot(A2, Y2)
```

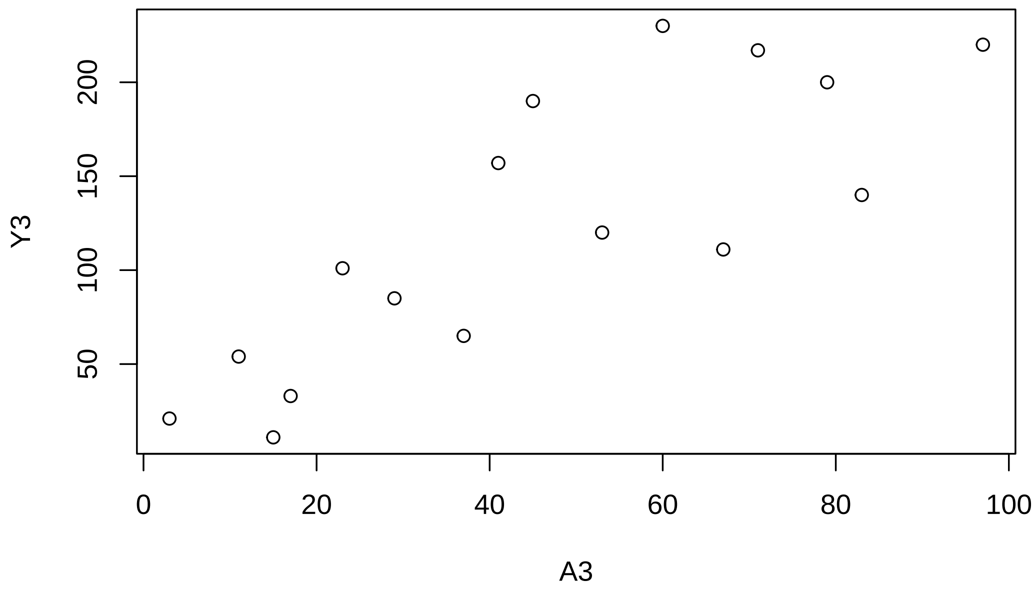



```
summary(Y2[A2 == 1])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    40.0    47.5    65.0    70.0    87.5   110.0
summary(Y2[A2 == 2])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      30      45      60      80      95     170
summary(Y2[A2 == 3])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    50.0    95.0   120.0   117.5   142.5   180.0
summary(Y2[A2 == 4])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   150.0   187.5   205.0   195.0   212.5   220.0
```

## Program 11.2

- 2-parameter linear model
- Data from Figures 11.3 and 11.1

```
A3 <-
  c(3, 11, 17, 23, 29, 37, 41, 53, 67, 79, 83, 97, 60, 71, 15, 45)
Y3 <-
  c(21, 54, 33, 101, 85, 65, 157, 120, 111, 200, 140, 220, 230, 217,
    11, 190)

plot(Y3 ~ A3)
```




```
summary(glm(Y3 ~ A3))
##
## Call:
## glm(formula = Y3 ~ A3)
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  24.5464    21.3300   1.151 0.269094
## A3            2.1372     0.3997   5.347 0.000103 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 1944.109)
##
##     Null deviance: 82800  on 15  degrees of freedom
## Residual deviance: 27218  on 14  degrees of freedom
## AIC: 170.43
##
## Number of Fisher Scoring iterations: 2
predict(glm(Y3 ~ A3), data.frame(A3 = 90))
##      1
## 216.89

summary(glm(Y ~ A))
##
## Call:
## glm(formula = Y ~ A)
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    67.50      19.72   3.424  0.00412 **
## A              78.75      27.88   2.824  0.01352 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## (Dispersion parameter for gaussian family taken to be 3109.821)
##
##     Null deviance: 68344  on 15  degrees of freedom
## Residual deviance: 43538  on 14  degrees of freedom
## AIC: 177.95
##
## Number of Fisher Scoring iterations: 2
```

# Program 11.3

- 3-parameter linear model
- Data from Figure 11.3

```
Asq <- A3 * A3

mod3 <- glm(Y3 ~ A3 + Asq)
summary(mod3)
##
## Call:
## glm(formula = Y3 ~ A3 + Asq)
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -7.40688   31.74777  -0.233   0.8192
## A3           4.10723    1.53088   2.683   0.0188 *
## Asq         -0.02038    0.01532  -1.331   0.2062
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 1842.697)
##
##     Null deviance: 82800  on 15  degrees of freedom
## Residual deviance: 23955  on 13  degrees of freedom
## AIC: 170.39
##
## Number of Fisher Scoring iterations: 2
predict(mod3, data.frame(cbind(A3 = 90, Asq = 8100)))
##        1
## 197.1269
```

# 12. IP Weighting and Marginal Structural Models

## Program 12.1

- Descriptive statistics from NHEFS data (Table 12.1)

```
library(here)
```

```
# install.packages("readxl") # install package if required
library("readxl")

nhefs <- read_excel(here("data", "NHEFS.xls"))
nhefs$cens <- ifelse(is.na(nhefs$wt82), 1, 0)

# provisionally ignore subjects with missing values for weight in 1982
nhefs.nmv <-
  nhefs[which(!is.na(nhefs$wt82)),]

lm(wt82_71 ~ qsmk, data = nhefs.nmv)
##
## Call:
## lm(formula = wt82_71 ~ qsmk, data = nhefs.nmv)
##
## Coefficients:
## (Intercept)         qsmk
##       1.984        2.541
# Smoking cessation
predict(lm(wt82_71 ~ qsmk, data = nhefs.nmv), data.frame(qsmk = 1))
##        1
## 4.525079
# No smoking cessation
predict(lm(wt82_71 ~ qsmk, data = nhefs.nmv), data.frame(qsmk = 0))
##        1
## 1.984498

# Table
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 0),]$age)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   25.00   33.00   42.00   42.79   51.00   72.00
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 0),]$wt71)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   40.82   59.19   68.49   70.30   79.38  151.73
```

```
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 0),]$smokeintensity)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1.00   15.00   20.00   21.19   30.00   60.00
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 0),]$smokeyrs)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1.00   15.00   23.00   24.09   32.00   64.00

summary(nhefs.nmv[which(nhefs.nmv$qsmk == 1),]$age)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   25.00   35.00   46.00   46.17   56.00   74.00
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 1),]$wt71)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   39.58   60.67   71.21   72.35   81.08  136.98
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 1),]$smokeintensity)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##     1.0    10.0    20.0    18.6    25.0    80.0
summary(nhefs.nmv[which(nhefs.nmv$qsmk == 1),]$smokeyrs)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1.00   15.00   26.00   26.03   35.00   60.00

table(nhefs.nmv$qsmk, nhefs.nmv$sex)
##
##       0   1
##   0 542 621
##   1 220 183
prop.table(table(nhefs.nmv$qsmk, nhefs.nmv$sex), 1)
##
##             0         1
##   0 0.4660361 0.5339639
##   1 0.5459057 0.4540943

table(nhefs.nmv$qsmk, nhefs.nmv$race)
##
##       0   1
##   0 993 170
##   1 367  36
prop.table(table(nhefs.nmv$qsmk, nhefs.nmv$race), 1)
##
##              0          1
##   0 0.85382631 0.14617369
##   1 0.91066998 0.08933002

table(nhefs.nmv$qsmk, nhefs.nmv$education)
##
##       1   2   3   4   5
##   0 210 266 480  92 115
##   1  81  74 157  29  62
prop.table(table(nhefs.nmv$qsmk, nhefs.nmv$education), 1)
##
##              1          2          3          4          5
##   0 0.18056750 0.22871883 0.41272571 0.07910576 0.09888220
##   1 0.20099256 0.18362283 0.38957816 0.07196030 0.15384615
```

```r
table(nhefs.nmv$qsmk, nhefs.nmv$exercise)
##
##       0   1   2
##   0 237 485 441
##   1  63 176 164
prop.table(table(nhefs.nmv$qsmk, nhefs.nmv$exercise), 1)
##
##             0         1         2
##   0 0.2037833 0.4170249 0.3791917
##   1 0.1563275 0.4367246 0.4069479

table(nhefs.nmv$qsmk, nhefs.nmv$active)
##
##       0   1   2
##   0 532 527 104
##   1 170 188  45
prop.table(table(nhefs.nmv$qsmk, nhefs.nmv$active), 1)
##
##             0         1         2
##   0 0.4574377 0.4531384 0.0894239
##   1 0.4218362 0.4665012 0.1116625
```

# Program 12.2

- Estimating IP weights
- Data from NHEFS

```r
# Estimation of ip weights via a logistic model
fit <- glm(
  qsmk ~ sex + race + age + I(age ^ 2) +
    as.factor(education) + smokeintensity +
    I(smokeintensity ^ 2) + smokeyrs + I(smokeyrs ^ 2) +
    as.factor(exercise) + as.factor(active) + wt71 + I(wt71 ^ 2),
  family = binomial(),
  data = nhefs.nmv
)
summary(fit)
##
## Call:
## glm(formula = qsmk ~ sex + race + age + I(age^2) + as.factor(education) +
##     smokeintensity + I(smokeintensity^2) + smokeyrs + I(smokeyrs^2) +
##     as.factor(exercise) + as.factor(active) + wt71 + I(wt71^2),
##     family = binomial(), data = nhefs.nmv)
##
## Coefficients:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)            -2.2425191  1.3808360  -1.624 0.104369
## sex                    -0.5274782  0.1540496  -3.424 0.000617 ***
## race                   -0.8392636  0.2100665  -3.995 6.46e-05 ***
## age                     0.1212052  0.0512663   2.364 0.018068 *
## I(age^2)               -0.0008246  0.0005361  -1.538 0.124039
## as.factor(education)2 -0.0287755  0.1983506  -0.145 0.884653
```

```
## as.factor(education)3  0.0864318  0.1780850   0.485 0.627435
## as.factor(education)4  0.0636010  0.2732108   0.233 0.815924
## as.factor(education)5  0.4759606  0.2262237   2.104 0.035384 *
## smokeintensity        -0.0772704  0.0152499  -5.067 4.04e-07 ***
## I(smokeintensity^2)    0.0010451  0.0002866   3.647 0.000265 ***
## smokeyrs              -0.0735966  0.0277775  -2.650 0.008061 **
## I(smokeyrs^2)          0.0008441  0.0004632   1.822 0.068398 .
## as.factor(exercise)1   0.3548405  0.1801351   1.970 0.048855 *
## as.factor(exercise)2   0.3957040  0.1872400   2.113 0.034571 *
## as.factor(active)1     0.0319445  0.1329372   0.240 0.810100
## as.factor(active)2     0.1767840  0.2149720   0.822 0.410873
## wt71                  -0.0152357  0.0263161  -0.579 0.562625
## I(wt71^2)              0.0001352  0.0001632   0.829 0.407370
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1786.1  on 1565  degrees of freedom
## Residual deviance: 1676.9  on 1547  degrees of freedom
## AIC: 1714.9
##
## Number of Fisher Scoring iterations: 4

p.qsmk.obs <-
  ifelse(nhefs.nmv$qsmk == 0,
         1 - predict(fit, type = "response"),
         predict(fit, type = "response"))

nhefs.nmv$w <- 1 / p.qsmk.obs
summary(nhefs.nmv$w)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.054   1.230   1.373   1.996   1.990  16.700
sd(nhefs.nmv$w)
## [1] 1.474787

# install.packages("geepack") # install package if required
library("geepack")
msm.w <- geeglm(
  wt82_71 ~ qsmk,
  data = nhefs.nmv,
  weights = w,
  id = seqn,
  corstr = "independence"
)
summary(msm.w)
##
## Call:
## geeglm(formula = wt82_71 ~ qsmk, data = nhefs.nmv, weights = w,
##     id = seqn, corstr = "independence")
##
##  Coefficients:
```

```
##              Estimate Std.err  Wald Pr(>|W|)
## (Intercept)   1.7800  0.2247 62.73 2.33e-15 ***
## qsmk          3.4405  0.5255 42.87 5.86e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)    65.06   4.221
## Number of clusters:   1566  Maximum cluster size: 1

beta <- coef(msm.w)
SE <- coef(summary(msm.w))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##              beta   lcl  ucl
## (Intercept) 1.780 1.340 2.22
## qsmk        3.441 2.411 4.47

# no association between sex and qsmk in pseudo-population
xtabs(nhefs.nmv$w ~ nhefs.nmv$sex + nhefs.nmv$qsmk)
##              nhefs.nmv$qsmk
## nhefs.nmv$sex     0     1
##             0 763.6 763.6
##             1 801.7 797.2

# "check" for positivity (White women)
table(nhefs.nmv$age[nhefs.nmv$race == 0 & nhefs.nmv$sex == 1],
      nhefs.nmv$qsmk[nhefs.nmv$race == 0 & nhefs.nmv$sex == 1])
##
##       0  1
##   25 24  3
##   26 14  5
##   27 18  2
##   28 20  5
##   29 15  4
##   30 14  5
##   31 11  5
##   32 14  7
##   33 12  3
##   34 22  5
##   35 16  5
##   36 13  3
##   37 14  1
##   38  6  2
##   39 19  4
##   40 10  4
##   41 13  3
##   42 16  3
```

```
##    43 14   3
##    44   9   4
##    45 12   5
##    46 19   4
##    47 19   4
##    48 19   4
##    49 11   3
##    50 18   4
##    51   9   3
##    52 11   3
##    53 11   4
##    54 17   9
##    55   9   4
##    56   8   7
##    57   9   2
##    58   8   4
##    59   5   4
##    60   5   4
##    61   5   2
##    62   6   5
##    63   3   3
##    64   7   1
##    65   3   2
##    66   4   0
##    67   2   0
##    69   6   2
##    70   2   1
##    71   0   1
##    72   2   2
##    74   0   1
```

# Program 12.3

- Estimating stabilized IP weights
- Data from NHEFS

```
# estimation of denominator of ip weights
denom.fit <-
  glm(
    qsmk ~ as.factor(sex) + as.factor(race) + age + I(age ^ 2) +
      as.factor(education) + smokeintensity +
      I(smokeintensity ^ 2) + smokeyrs + I(smokeyrs ^ 2) +
      as.factor(exercise) + as.factor(active) + wt71 + I(wt71 ^ 2),
    family = binomial(),
    data = nhefs.nmv
  )
summary(denom.fit)
##
## Call:
## glm(formula = qsmk ~ as.factor(sex) + as.factor(race) + age +
##     I(age^2) + as.factor(education) + smokeintensity + I(smokeintensity^2) +
##     smokeyrs + I(smokeyrs^2) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71^2), family = binomial(), data = nhefs.nmv)
```

```
##
## Coefficients:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -2.242519   1.380836   -1.62  0.10437
## as.factor(sex)1       -0.527478   0.154050   -3.42  0.00062 ***
## as.factor(race)1      -0.839264   0.210067   -4.00  6.5e-05 ***
## age                    0.121205   0.051266    2.36  0.01807 *
## I(age^2)              -0.000825   0.000536   -1.54  0.12404
## as.factor(education)2 -0.028776   0.198351   -0.15  0.88465
## as.factor(education)3  0.086432   0.178085    0.49  0.62744
## as.factor(education)4  0.063601   0.273211    0.23  0.81592
## as.factor(education)5  0.475961   0.226224    2.10  0.03538 *
## smokeintensity        -0.077270   0.015250   -5.07  4.0e-07 ***
## I(smokeintensity^2)    0.001045   0.000287    3.65  0.00027 ***
## smokeyrs              -0.073597   0.027777   -2.65  0.00806 **
## I(smokeyrs^2)          0.000844   0.000463    1.82  0.06840 .
## as.factor(exercise)1   0.354841   0.180135    1.97  0.04885 *
## as.factor(exercise)2   0.395704   0.187240    2.11  0.03457 *
## as.factor(active)1     0.031944   0.132937    0.24  0.81010
## as.factor(active)2     0.176784   0.214972    0.82  0.41087
## wt71                  -0.015236   0.026316   -0.58  0.56262
## I(wt71^2)              0.000135   0.000163    0.83  0.40737
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1786.1  on 1565  degrees of freedom
## Residual deviance: 1676.9  on 1547  degrees of freedom
## AIC: 1715
##
## Number of Fisher Scoring iterations: 4

pd.qsmk <- predict(denom.fit, type = "response")

# estimation of numerator of ip weights
numer.fit <- glm(qsmk ~ 1, family = binomial(), data = nhefs.nmv)
summary(numer.fit)
##
## Call:
## glm(formula = qsmk ~ 1, family = binomial(), data = nhefs.nmv)
##
## Coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -1.0598     0.0578   -18.3   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1786.1  on 1565  degrees of freedom
## Residual deviance: 1786.1  on 1565  degrees of freedom
```

```
## AIC: 1788
##
## Number of Fisher Scoring iterations: 4

pn.qsmk <- predict(numer.fit, type = "response")

nhefs.nmv$sw <-
  ifelse(nhefs.nmv$qsmk == 0, ((1 - pn.qsmk) / (1 - pd.qsmk)),
         (pn.qsmk / pd.qsmk))

summary(nhefs.nmv$sw)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.331   0.867   0.950   0.999   1.079   4.298


msm.sw <- geeglm(
  wt82_71 ~ qsmk,
  data = nhefs.nmv,
  weights = sw,
  id = seqn,
  corstr = "independence"
)
summary(msm.sw)
##
## Call:
## geeglm(formula = wt82_71 ~ qsmk, data = nhefs.nmv, weights = sw,
##     id = seqn, corstr = "independence")
##
##  Coefficients:
##             Estimate Std.err Wald Pr(>|W|)
## (Intercept)    1.780   0.225 62.7  2.3e-15 ***
## qsmk           3.441   0.525 42.9  5.9e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)     60.7    3.71
## Number of clusters:   1566  Maximum cluster size: 1

beta <- coef(msm.sw)
SE <- coef(summary(msm.sw))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##             beta  lcl  ucl
## (Intercept) 1.78 1.34 2.22
## qsmk        3.44 2.41 4.47

# no association between sex and qsmk in pseudo-population
```

```r
xtabs(nhefs.nmv$sw ~ nhefs.nmv$sex + nhefs.nmv$qsmk)
##                nhefs.nmv$qsmk
## nhefs.nmv$sex   0   1
##               0 567 197
##               1 595 205
```

# Program 12.4

- Estimating the parameters of a marginal structural mean model with a continuous treatment Data from NHEFS

```r
# Analysis restricted to subjects reporting ≤25 cig/day at baseline
nhefs.nmv.s <- subset(nhefs.nmv, smokeintensity <= 25)

# estimation of denominator of ip weights
den.fit.obj <- lm(
  smkintensity82_71 ~ as.factor(sex) +
    as.factor(race) + age + I(age ^ 2) +
    as.factor(education) + smokeintensity + I(smokeintensity ^ 2) +
    smokeyrs + I(smokeyrs ^ 2) + as.factor(exercise) + as.factor(active) + wt71 +
    I(wt71 ^ 2),
  data = nhefs.nmv.s
)
p.den <- predict(den.fit.obj, type = "response")
dens.den <-
  dnorm(nhefs.nmv.s$smkintensity82_71,
        p.den,
        summary(den.fit.obj)$sigma)

# estimation of numerator of ip weights
num.fit.obj <- lm(smkintensity82_71 ~ 1, data = nhefs.nmv.s)
p.num <- predict(num.fit.obj, type = "response")
dens.num <-
  dnorm(nhefs.nmv.s$smkintensity82_71,
        p.num,
        summary(num.fit.obj)$sigma)

nhefs.nmv.s$sw.a <- dens.num / dens.den
summary(nhefs.nmv.s$sw.a)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.19    0.89    0.97    1.00    1.05    5.10

msm.sw.cont <-
  geeglm(
    wt82_71 ~ smkintensity82_71 + I(smkintensity82_71 * smkintensity82_71),
    data = nhefs.nmv.s,
    weights = sw.a,
    id = seqn,
    corstr = "independence"
  )
summary(msm.sw.cont)
##
```

```
## Call:
## geeglm(formula = wt82_71 ~ smkintensity82_71 + I(smkintensity82_71 *
##     smkintensity82_71), data = nhefs.nmv.s, weights = sw.a, id = seqn,
##     corstr = "independence")
##
##  Coefficients:
##                                         Estimate  Std.err  Wald Pr(>|W|)
## (Intercept)                              2.00452  0.29512 46.13  1.1e-11 ***
## smkintensity82_71                       -0.10899  0.03154 11.94  0.00055 ***
## I(smkintensity82_71 * smkintensity82_71)  0.00269  0.00242  1.24  0.26489
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)     60.5     4.5
## Number of clusters:   1162  Maximum cluster size: 1

beta <- coef(msm.sw.cont)
SE <- coef(summary(msm.sw.cont))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##                                              beta      lcl      ucl
## (Intercept)                               2.00452  1.42610  2.58295
## smkintensity82_71                        -0.10899 -0.17080 -0.04718
## I(smkintensity82_71 * smkintensity82_71)  0.00269 -0.00204  0.00743
```

## Program 12.5

- Estimating the parameters of a marginal structural logistic model
- Data from NHEFS

```
table(nhefs.nmv$qsmk, nhefs.nmv$death)
##
##       0   1
##   0 963 200
##   1 312  91

# First, estimation of stabilized weights sw (same as in Program 12.3)
# Second, fit logistic model below
msm.logistic <- geeglm(
  death ~ qsmk,
  data = nhefs.nmv,
  weights = sw,
  id = seqn,
  family = binomial(),
  corstr = "independence"
)
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
```

```
summary(msm.logistic)
##
## Call:
## geeglm(formula = death ~ qsmk, family = binomial(), data = nhefs.nmv,
##     weights = sw, id = seqn, corstr = "independence")
##
##  Coefficients:
##             Estimate Std.err   Wald Pr(>|W|)
## (Intercept)  -1.4905  0.0789 356.50   <2e-16 ***
## qsmk          0.0301  0.1573   0.04     0.85
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)        1  0.0678
## Number of clusters:   1566  Maximum cluster size: 1

beta <- coef(msm.logistic)
SE <- coef(summary(msm.logistic))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##                beta    lcl    ucl
## (Intercept) -1.4905 -1.645 -1.336
## qsmk         0.0301 -0.278  0.338
```

## Program 12.6

- Assessing effect modification by sex using a marginal structural mean model
- Data from NHEFS

```
table(nhefs.nmv$sex)
##
##   0   1
## 762 804

# estimation of denominator of ip weights
denom.fit <-
  glm(
    qsmk ~ as.factor(sex) + as.factor(race) + age + I(age ^ 2) +
      as.factor(education) + smokeintensity +
      I(smokeintensity ^ 2) + smokeyrs + I(smokeyrs ^ 2) +
      as.factor(exercise) + as.factor(active) + wt71 + I(wt71 ^ 2),
    family = binomial(),
    data = nhefs.nmv
  )
summary(denom.fit)
##
## Call:
```

```
## glm(formula = qsmk ~ as.factor(sex) + as.factor(race) + age +
##     I(age^2) + as.factor(education) + smokeintensity + I(smokeintensity^2) +
##     smokeyrs + I(smokeyrs^2) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71^2), family = binomial(), data = nhefs.nmv)
##
## Coefficients:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -2.242519   1.380836   -1.62  0.10437
## as.factor(sex)1       -0.527478   0.154050   -3.42  0.00062 ***
## as.factor(race)1      -0.839264   0.210067   -4.00  6.5e-05 ***
## age                    0.121205   0.051266    2.36  0.01807 *
## I(age^2)              -0.000825   0.000536   -1.54  0.12404
## as.factor(education)2 -0.028776   0.198351   -0.15  0.88465
## as.factor(education)3  0.086432   0.178085    0.49  0.62744
## as.factor(education)4  0.063601   0.273211    0.23  0.81592
## as.factor(education)5  0.475961   0.226224    2.10  0.03538 *
## smokeintensity        -0.077270   0.015250   -5.07  4.0e-07 ***
## I(smokeintensity^2)    0.001045   0.000287    3.65  0.00027 ***
## smokeyrs              -0.073597   0.027777   -2.65  0.00806 **
## I(smokeyrs^2)          0.000844   0.000463    1.82  0.06840 .
## as.factor(exercise)1   0.354841   0.180135    1.97  0.04885 *
## as.factor(exercise)2   0.395704   0.187240    2.11  0.03457 *
## as.factor(active)1     0.031944   0.132937    0.24  0.81010
## as.factor(active)2     0.176784   0.214972    0.82  0.41087
## wt71                  -0.015236   0.026316   -0.58  0.56262
## I(wt71^2)              0.000135   0.000163    0.83  0.40737
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1786.1  on 1565  degrees of freedom
## Residual deviance: 1676.9  on 1547  degrees of freedom
## AIC: 1715
##
## Number of Fisher Scoring iterations: 4

pd.qsmk <- predict(denom.fit, type = "response")

# estimation of numerator of ip weights
numer.fit <-
  glm(qsmk ~ as.factor(sex), family = binomial(), data = nhefs.nmv)
summary(numer.fit)
##
## Call:
## glm(formula = qsmk ~ as.factor(sex), family = binomial(), data = nhefs.nmv)
##
## Coefficients:
##                 Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -0.9016     0.0799  -11.28   <2e-16 ***
## as.factor(sex)1  -0.3202     0.1160   -2.76   0.0058 **
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1786.1  on 1565  degrees of freedom
## Residual deviance: 1778.4  on 1564  degrees of freedom
## AIC: 1782
##
## Number of Fisher Scoring iterations: 4
pn.qsmk <- predict(numer.fit, type = "response")

nhefs.nmv$sw.a <-
  ifelse(nhefs.nmv$qsmk == 0, ((1 - pn.qsmk) / (1 - pd.qsmk)),
         (pn.qsmk / pd.qsmk))

summary(nhefs.nmv$sw.a)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.29    0.88    0.96    1.00    1.08    3.80
sd(nhefs.nmv$sw.a)
## [1] 0.271

# Estimating parameters of a marginal structural mean model
msm.emm <- geeglm(
  wt82_71 ~ as.factor(qsmk) + as.factor(sex)
  + as.factor(qsmk):as.factor(sex),
  data = nhefs.nmv,
  weights = sw.a,
  id = seqn,
  corstr = "independence"
)
summary(msm.emm)
##
## Call:
## geeglm(formula = wt82_71 ~ as.factor(qsmk) + as.factor(sex) +
##     as.factor(qsmk):as.factor(sex), data = nhefs.nmv, weights = sw.a,
##     id = seqn, corstr = "independence")
##
##  Coefficients:
##                                  Estimate  Std.err  Wald Pr(>|W|)
## (Intercept)                       1.78445  0.30984 33.17  8.5e-09 ***
## as.factor(qsmk)1                  3.52198  0.65707 28.73  8.3e-08 ***
## as.factor(sex)1                  -0.00872  0.44882  0.00     0.98
## as.factor(qsmk)1:as.factor(sex)1 -0.15948  1.04608  0.02     0.88
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)     60.8    3.71
## Number of clusters:   1566  Maximum cluster size: 1
```

```r
beta <- coef(msm.emm)
SE <- coef(summary(msm.emm))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##                                     beta    lcl   ucl
## (Intercept)                      1.78445  1.177 2.392
## as.factor(qsmk)1                 3.52198  2.234 4.810
## as.factor(sex)1                 -0.00872 -0.888 0.871
## as.factor(qsmk)1:as.factor(sex)1 -0.15948 -2.210 1.891
```

# Program 12.7

- Estimating IP weights to adjust for selection bias due to censoring
- Data from NHEFS

```r
table(nhefs$qsmk, nhefs$cens)
##
##        0    1
##   0 1163   38
##   1  403   25

summary(nhefs[which(nhefs$cens == 0),]$wt71)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    39.6    59.5    69.2    70.8    79.8   151.7
summary(nhefs[which(nhefs$cens == 1),]$wt71)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    36.2    63.1    72.1    76.6    87.9   169.2

# estimation of denominator of ip weights for A
denom.fit <-
  glm(
    qsmk ~ as.factor(sex) + as.factor(race) + age + I(age ^ 2) +
      as.factor(education) + smokeintensity +
      I(smokeintensity ^ 2) + smokeyrs + I(smokeyrs ^ 2) +
      as.factor(exercise) + as.factor(active) + wt71 + I(wt71 ^ 2),
    family = binomial(),
    data = nhefs
  )
summary(denom.fit)
##
## Call:
## glm(formula = qsmk ~ as.factor(sex) + as.factor(race) + age +
##     I(age^2) + as.factor(education) + smokeintensity + I(smokeintensity^2) +
##     smokeyrs + I(smokeyrs^2) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71^2), family = binomial(), data = nhefs)
##
## Coefficients:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)             -1.988902   1.241279   -1.60  0.10909
## as.factor(sex)1         -0.507522   0.148232   -3.42  0.00062 ***
## as.factor(race)1        -0.850231   0.205872   -4.13  3.6e-05 ***
```

```
## age                       0.103013   0.048900    2.11  0.03515 *
## I(age^2)                 -0.000605   0.000507   -1.19  0.23297
## as.factor(education)2 -0.098320   0.190655   -0.52  0.60607
## as.factor(education)3  0.015699   0.170714    0.09  0.92673
## as.factor(education)4 -0.042526   0.264276   -0.16  0.87216
## as.factor(education)5  0.379663   0.220395    1.72  0.08495 .
## smokeintensity           -0.065156   0.014759   -4.41  1.0e-05 ***
## I(smokeintensity^2)       0.000846   0.000276    3.07  0.00216 **
## smokeyrs                 -0.073371   0.026996   -2.72  0.00657 **
## I(smokeyrs^2)             0.000838   0.000443    1.89  0.05867 .
## as.factor(exercise)1    0.291412   0.173554    1.68  0.09314 .
## as.factor(exercise)2    0.355052   0.179929    1.97  0.04846 *
## as.factor(active)1      0.010875   0.129832    0.08  0.93324
## as.factor(active)2      0.068312   0.208727    0.33  0.74346
## wt71                     -0.012848   0.022283   -0.58  0.56423
## I(wt71^2)                 0.000121   0.000135    0.89  0.37096
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1876.3  on 1628  degrees of freedom
## Residual deviance: 1766.7  on 1610  degrees of freedom
## AIC: 1805
##
## Number of Fisher Scoring iterations: 4

pd.qsmk <- predict(denom.fit, type = "response")

# estimation of numerator of ip weights for A
numer.fit <- glm(qsmk ~ 1, family = binomial(), data = nhefs)
summary(numer.fit)
##
## Call:
## glm(formula = qsmk ~ 1, family = binomial(), data = nhefs)
##
## Coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -1.0318     0.0563   -18.3   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1876.3  on 1628  degrees of freedom
## Residual deviance: 1876.3  on 1628  degrees of freedom
## AIC: 1878
##
## Number of Fisher Scoring iterations: 4
pn.qsmk <- predict(numer.fit, type = "response")

# estimation of denominator of ip weights for C
```

```r
denom.cens <- glm(
  cens ~ as.factor(qsmk) + as.factor(sex) +
    as.factor(race) + age + I(age ^ 2) +
    as.factor(education) + smokeintensity +
    I(smokeintensity ^ 2) + smokeyrs + I(smokeyrs ^ 2) +
    as.factor(exercise) + as.factor(active) + wt71 + I(wt71 ^ 2),
  family = binomial(),
  data = nhefs
)
summary(denom.cens)
##
## Call:
## glm(formula = cens ~ as.factor(qsmk) + as.factor(sex) + as.factor(race) +
##     age + I(age^2) + as.factor(education) + smokeintensity +
##     I(smokeintensity^2) + smokeyrs + I(smokeyrs^2) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71^2), family = binomial(),
##     data = nhefs)
##
## Coefficients:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)            4.014466   2.576106    1.56   0.1192
## as.factor(qsmk)1       0.516867   0.287716    1.80   0.0724 .
## as.factor(sex)1        0.057313   0.330278    0.17   0.8622
## as.factor(race)1      -0.012271   0.452489   -0.03   0.9784
## age                   -0.269729   0.117465   -2.30   0.0217 *
## I(age^2)               0.002884   0.001114    2.59   0.0096 **
## as.factor(education)2 -0.440788   0.419399   -1.05   0.2933
## as.factor(education)3 -0.164688   0.370547   -0.44   0.6567
## as.factor(education)4  0.138447   0.569797    0.24   0.8080
## as.factor(education)5 -0.382382   0.560181   -0.68   0.4949
## smokeintensity         0.015712   0.034732    0.45   0.6510
## I(smokeintensity^2)   -0.000113   0.000606   -0.19   0.8517
## smokeyrs               0.078597   0.074958    1.05   0.2944
## I(smokeyrs^2)         -0.000557   0.001032   -0.54   0.5894
## as.factor(exercise)1  -0.971471   0.387810   -2.51   0.0122 *
## as.factor(exercise)2  -0.583989   0.372313   -1.57   0.1168
## as.factor(active)1    -0.247479   0.325455   -0.76   0.4470
## as.factor(active)2     0.706583   0.396458    1.78   0.0747 .
## wt71                  -0.087887   0.040012   -2.20   0.0281 *
## I(wt71^2)              0.000635   0.000226    2.81   0.0049 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 533.36  on 1628  degrees of freedom
## Residual deviance: 465.36  on 1609  degrees of freedom
## AIC: 505.4
##
## Number of Fisher Scoring iterations: 7

pd.cens <- 1 - predict(denom.cens, type = "response")
```

```r
# estimation of numerator of ip weights for C
numer.cens <-
  glm(cens ~ as.factor(qsmk), family = binomial(), data = nhefs)
summary(numer.cens)
##
## Call:
## glm(formula = cens ~ as.factor(qsmk), family = binomial(), data = nhefs)
##
## Coefficients:
##                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)        -3.421      0.165  -20.75   <2e-16 ***
## as.factor(qsmk)1    0.641      0.264    2.43    0.015 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 533.36  on 1628  degrees of freedom
## Residual deviance: 527.76  on 1627  degrees of freedom
## AIC: 531.8
##
## Number of Fisher Scoring iterations: 6
pn.cens <- 1 - predict(numer.cens, type = "response")

nhefs$sw.a <-
  ifelse(nhefs$qsmk == 0, ((1 - pn.qsmk) / (1 - pd.qsmk)),
         (pn.qsmk / pd.qsmk))
nhefs$sw.c <- pn.cens / pd.cens
nhefs$sw <- nhefs$sw.c * nhefs$sw.a

summary(nhefs$sw.a)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.33    0.86    0.95    1.00    1.08    4.21
sd(nhefs$sw.a)
## [1] 0.284
summary(nhefs$sw.c)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.94    0.98    0.99    1.01    1.01    7.58
sd(nhefs$sw.c)
## [1] 0.178
summary(nhefs$sw)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.35    0.86    0.94    1.01    1.08   12.86
sd(nhefs$sw)
## [1] 0.411

msm.sw <- geeglm(
  wt82_71 ~ qsmk,
  data = nhefs,
  weights = sw,
  id = seqn,
  corstr = "independence"
```

```r
)
summary(msm.sw)
##
## Call:
## geeglm(formula = wt82_71 ~ qsmk, data = nhefs, weights = sw,
##     id = seqn, corstr = "independence")
##
##  Coefficients:
##             Estimate Std.err Wald Pr(>|W|)
## (Intercept)    1.662   0.233 51.0  9.3e-13 ***
## qsmk           3.496   0.526 44.2  2.9e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)     61.8    3.83
## Number of clusters:   1566  Maximum cluster size: 1

beta <- coef(msm.sw)
SE <- coef(summary(msm.sw))[, 2]
lcl <- beta - qnorm(0.975) * SE
ucl <- beta + qnorm(0.975) * SE
cbind(beta, lcl, ucl)
##             beta  lcl  ucl
## (Intercept) 1.66 1.21 2.12
## qsmk        3.50 2.47 4.53
```

# 13. Standardization and the parametric G-formula

## Program 13.1

- Estimating the mean outcome within levels of treatment and confounders
- Data from NHEFS

```
library(here)
```

```
#install.packages("readxl") # install package if required
library("readxl")
nhefs <- read_excel(here("data", "NHEFS.xls"))

# some preprocessing of the data
nhefs$cens <- ifelse(is.na(nhefs$wt82), 1, 0)

fit <-
  glm(
    wt82_71 ~ qsmk + sex + race + age + I(age * age) + as.factor(education)
    + smokeintensity + I(smokeintensity * smokeintensity) + smokeyrs
    + I(smokeyrs * smokeyrs) + as.factor(exercise) + as.factor(active)
    + wt71 + I(wt71 * wt71) + qsmk * smokeintensity,
    data = nhefs
  )
summary(fit)
##
## Call:
## glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71) + qsmk * smokeintensity,
##     data = nhefs)
##
## Coefficients:
##                                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)                        -1.5881657  4.3130359  -0.368 0.712756
## qsmk                                2.5595941  0.8091486   3.163 0.001590 **
## sex                                -1.4302717  0.4689576  -3.050 0.002328 **
## race                                0.5601096  0.5818888   0.963 0.335913
## age                                 0.3596353  0.1633188   2.202 0.027809 *
## I(age * age)                       -0.0061010  0.0017261  -3.534 0.000421 ***
## as.factor(education)2               0.7904440  0.6070005   1.302 0.193038
```

```
## as.factor(education)3              0.5563124  0.5561016   1.000 0.317284
## as.factor(education)4              1.4915695  0.8322704   1.792 0.073301 .
## as.factor(education)5             -0.1949770  0.7413692  -0.263 0.792589
## smokeintensity                     0.0491365  0.0517254   0.950 0.342287
## I(smokeintensity * smokeintensity) -0.0009907  0.0009380  -1.056 0.291097
## smokeyrs                           0.1343686  0.0917122   1.465 0.143094
## I(smokeyrs * smokeyrs)            -0.0018664  0.0015437  -1.209 0.226830
## as.factor(exercise)1               0.2959754  0.5351533   0.553 0.580298
## as.factor(exercise)2               0.3539128  0.5588587   0.633 0.526646
## as.factor(active)1                -0.9475695  0.4099344  -2.312 0.020935 *
## as.factor(active)2                -0.2613779  0.6845577  -0.382 0.702647
## wt71                               0.0455018  0.0833709   0.546 0.585299
## I(wt71 * wt71)                    -0.0009653  0.0005247  -1.840 0.066001 .
## qsmk:smokeintensity                0.0466628  0.0351448   1.328 0.184463
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 53.5683)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 82763  on 1545  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 10701
##
## Number of Fisher Scoring iterations: 2
nhefs$predicted.meanY <- predict(fit, nhefs)

nhefs[which(nhefs$seqn == 24770), c(
  "predicted.meanY",
  "qsmk",
  "sex",
  "race",
  "age",
  "education",
  "smokeintensity",
  "smokeyrs",
  "exercise",
  "active",
  "wt71"
)]
## # A tibble: 1 x 11
##   predicted.meanY  qsmk   sex  race   age education smokeintensity smokeyrs
##             <dbl> <dbl> <dbl> <dbl> <dbl>     <dbl>          <dbl>    <dbl>
## 1           0.342     0     0     0    26         4             15       12
## # i 3 more variables: exercise <dbl>, active <dbl>, wt71 <dbl>

summary(nhefs$predicted.meanY[nhefs$cens == 0])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -10.876   1.116   3.042   2.638   4.511   9.876
summary(nhefs$wt82_71[nhefs$cens == 0])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -41.280  -1.478   2.604   2.638   6.690  48.538
```

# Program 13.2

- Standardizing the mean outcome to the baseline confounders
- Data from Table 2.2

```
id <- c(
  "Rheia",
  "Kronos",
  "Demeter",
  "Hades",
  "Hestia",
  "Poseidon",
  "Hera",
  "Zeus",
  "Artemis",
  "Apollo",
  "Leto",
  "Ares",
  "Athena",
  "Hephaestus",
  "Aphrodite",
  "Cyclope",
  "Persephone",
  "Hermes",
  "Hebe",
  "Dionysus"
)
N <- length(id)
L <- c(0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1)
A <- c(0, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1)
Y <- c(0, 1, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 0, 0, 0)
interv <- rep(-1, N)
observed <- cbind(L, A, Y, interv)
untreated <- cbind(L, rep(0, N), rep(NA, N), rep(0, N))
treated <- cbind(L, rep(1, N), rep(NA, N), rep(1, N))
table22 <- as.data.frame(rbind(observed, untreated, treated))
table22$id <- rep(id, 3)

glm.obj <- glm(Y ~ A * L, data = table22)
summary(glm.obj)
##
## Call:
## glm(formula = Y ~ A * L, data = table22)
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  2.500e-01  2.552e-01   0.980    0.342
## A            2.602e-16  3.608e-01   0.000    1.000
## L            4.167e-01  3.898e-01   1.069    0.301
## A:L         -3.237e-16  4.959e-01   0.000    1.000
##
## (Dispersion parameter for gaussian family taken to be 0.2604167)
##
##     Null deviance: 5.0000  on 19  degrees of freedom
```

```
## Residual deviance: 4.1667  on 16  degrees of freedom
##   (40 observations deleted due to missingness)
## AIC: 35.385
##
## Number of Fisher Scoring iterations: 2
table22$predicted.meanY <- predict(glm.obj, table22)

mean(table22$predicted.meanY[table22$interv == -1])
## [1] 0.5
mean(table22$predicted.meanY[table22$interv == 0])
## [1] 0.5
mean(table22$predicted.meanY[table22$interv == 1])
## [1] 0.5
```

## Program 13.3

- Standardizing the mean outcome to the baseline confounders:
- Data from NHEFS

```
# create a dataset with 3 copies of each subject
nhefs$interv <- -1 # 1st copy: equal to original one

interv0 <- nhefs # 2nd copy: treatment set to 0, outcome to missing
interv0$interv <- 0
interv0$qsmk <- 0
interv0$wt82_71 <- NA

interv1 <- nhefs # 3rd copy: treatment set to 1, outcome to missing
interv1$interv <- 1
interv1$qsmk <- 1
interv1$wt82_71 <- NA

onesample <- rbind(nhefs, interv0, interv1) # combining datasets

# linear model to estimate mean outcome conditional on treatment and confounders
# parameters are estimated using original observations only (nhefs)
# parameter estimates are used to predict mean outcome for observations with
# treatment set to 0 (interv=0) and to 1 (interv=1)

std <- glm(
  wt82_71 ~ qsmk + sex + race + age + I(age * age)
  + as.factor(education) + smokeintensity
  + I(smokeintensity * smokeintensity) + smokeyrs
  + I(smokeyrs * smokeyrs) + as.factor(exercise)
  + as.factor(active) + wt71 + I(wt71 * wt71) + I(qsmk * smokeintensity),
  data = onesample
)
summary(std)
##
## Call:
## glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
```

```
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71) + I(qsmk * smokeintensity),
##     data = onesample)
##
## Coefficients:
##                                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)                        -1.5881657  4.3130359  -0.368 0.712756
## qsmk                                2.5595941  0.8091486   3.163 0.001590 **
## sex                                -1.4302717  0.4689576  -3.050 0.002328 **
## race                                0.5601096  0.5818888   0.963 0.335913
## age                                 0.3596353  0.1633188   2.202 0.027809 *
## I(age * age)                       -0.0061010  0.0017261  -3.534 0.000421 ***
## as.factor(education)2               0.7904440  0.6070005   1.302 0.193038
## as.factor(education)3               0.5563124  0.5561016   1.000 0.317284
## as.factor(education)4               1.4915695  0.8322704   1.792 0.073301 .
## as.factor(education)5              -0.1949770  0.7413692  -0.263 0.792589
## smokeintensity                      0.0491365  0.0517254   0.950 0.342287
## I(smokeintensity * smokeintensity) -0.0009907  0.0009380  -1.056 0.291097
## smokeyrs                            0.1343686  0.0917122   1.465 0.143094
## I(smokeyrs * smokeyrs)             -0.0018664  0.0015437  -1.209 0.226830
## as.factor(exercise)1                0.2959754  0.5351533   0.553 0.580298
## as.factor(exercise)2                0.3539128  0.5588587   0.633 0.526646
## as.factor(active)1                 -0.9475695  0.4099344  -2.312 0.020935 *
## as.factor(active)2                 -0.2613779  0.6845577  -0.382 0.702647
## wt71                                0.0455018  0.0833709   0.546 0.585299
## I(wt71 * wt71)                     -0.0009653  0.0005247  -1.840 0.066001 .
## I(qsmk * smokeintensity)            0.0466628  0.0351448   1.328 0.184463
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 53.5683)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 82763  on 1545  degrees of freedom
##   (3321 observations deleted due to missingness)
## AIC: 10701
##
## Number of Fisher Scoring iterations: 2
onesample$predicted_meanY <- predict(std, onesample)

# estimate mean outcome in each of the groups interv=0, and interv=1
# this mean outcome is a weighted average of the mean outcomes in each combination
# of values of treatment and confounders, that is, the standardized outcome
mean(onesample[which(onesample$interv == -1), ]$predicted_meanY)
## [1] 2.56319
mean(onesample[which(onesample$interv == 0), ]$predicted_meanY)
## [1] 1.660267
mean(onesample[which(onesample$interv == 1), ]$predicted_meanY)
## [1] 5.178841
```

## Program 13.4

- Computing the 95% confidence interval of the standardized means and their difference
- Data from NHEFS

```
#install.packages("boot") # install package if required
library(boot)

# function to calculate difference in means
standardization <- function(data, indices) {
  # create a dataset with 3 copies of each subject
  d <- data[indices, ] # 1st copy: equal to original one`
  d$interv <- -1
  d0 <- d # 2nd copy: treatment set to 0, outcome to missing
  d0$interv <- 0
  d0$qsmk <- 0
  d0$wt82_71 <- NA
  d1 <- d # 3rd copy: treatment set to 1, outcome to missing
  d1$interv <- 1
  d1$qsmk <- 1
  d1$wt82_71 <- NA
  d.onesample <- rbind(d, d0, d1) # combining datasets

  # linear model to estimate mean outcome conditional on treatment and confounders
  # parameters are estimated using original observations only (interv= -1)
  # parameter estimates are used to predict mean outcome for observations with set
  # treatment (interv=0 and interv=1)
  fit <- glm(
    wt82_71 ~ qsmk + sex + race + age + I(age * age) +
      as.factor(education) + smokeintensity +
      I(smokeintensity * smokeintensity) + smokeyrs + I(smokeyrs *
                                                         smokeyrs) +
      as.factor(exercise) + as.factor(active) + wt71 + I(wt71 *
                                                          wt71),
    data = d.onesample
  )

  d.onesample$predicted_meanY <- predict(fit, d.onesample)

  # estimate mean outcome in each of the groups interv=-1, interv=0, and interv=1
  return(c(
    mean(d.onesample$predicted_meanY[d.onesample$interv == -1]),
    mean(d.onesample$predicted_meanY[d.onesample$interv == 0]),
    mean(d.onesample$predicted_meanY[d.onesample$interv == 1]),
    mean(d.onesample$predicted_meanY[d.onesample$interv == 1]) -
      mean(d.onesample$predicted_meanY[d.onesample$interv == 0])
  ))
}

# bootstrap
results <- boot(data = nhefs,
                statistic = standardization,
                R = 5)
```

```
# generating confidence intervals
se <- c(sd(results$t[, 1]),
        sd(results$t[, 2]),
        sd(results$t[, 3]),
        sd(results$t[, 4]))
mean <- results$t0
ll <- mean - qnorm(0.975) * se
ul <- mean + qnorm(0.975) * se

bootstrap <-
  data.frame(cbind(
    c(
      "Observed",
      "No Treatment",
      "Treatment",
      "Treatment - No Treatment"
    ),
    mean,
    se,
    ll,
    ul
  ))
bootstrap
##                          V1             mean                 se               ll
## 1                  Observed 2.56188497106103 0.166759462538625 2.23504243040407
## 2              No Treatment 1.65212306626748 0.218888477867158 1.22310953301706
## 3                 Treatment  5.1147448954934 0.344569425114411 4.43940123209548
## 4 Treatment - No Treatment 3.46262182922592 0.439020375326088 2.60215770510753
##                  ul
## 1 2.88872751171799
## 2  2.0811365995179
## 3 5.79008855889132
## 4 4.32308595334431
```

# 14. G-estimation of Structural Nested Models

## Program 14.1

- Preprocessing, ranks of extreme observations, IP weights for censoring
- Data from NHEFS

```
library(here)
```

```
#install.packages("readxl") # install package if required
library("readxl")
nhefs <- read_excel(here("data", "NHEFS.xls"))

# some processing of the data
nhefs$cens <- ifelse(is.na(nhefs$wt82), 1, 0)

# ranking of extreme observations
#install.packages("Hmisc")
library(Hmisc)
##
## Attaching package: 'Hmisc'
## The following objects are masked from 'package:base':
##
##     format.pval, units
describe(nhefs$wt82_71)
## nhefs$wt82_71
##        n  missing distinct     Info     Mean      Gmd      .05      .10
##     1566       63     1510        1    2.638    8.337   -9.752   -6.292
##      .25      .50      .75      .90      .95
##   -1.478    2.604    6.690   11.117   14.739
##
## lowest : -41.2805 -30.5019 -30.0501 -29.0258 -25.9706
## highest: 34.0178  36.9693  37.6505  47.5113  48.5384

# estimation of denominator of ip weights for C
cw.denom <- glm(cens==0 ~ qsmk + sex + race + age + I(age^2)
                     + as.factor(education) + smokeintensity + I(smokeintensity^2)
                     + smokeyrs + I(smokeyrs^2) + as.factor(exercise)
                     + as.factor(active) + wt71 + I(wt71^2),
                     data = nhefs, family = binomial("logit"))
summary(cw.denom)
##
```

```
## Call:
## glm(formula = cens == 0 ~ qsmk + sex + race + age + I(age^2) +
##     as.factor(education) + smokeintensity + I(smokeintensity^2) +
##     smokeyrs + I(smokeyrs^2) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71^2), family = binomial("logit"), data = nhefs)
##
## Coefficients:
##                         Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -4.0144661  2.5761058  -1.558  0.11915
## qsmk                  -0.5168674  0.2877162  -1.796  0.07242 .
## sex                   -0.0573131  0.3302775  -0.174  0.86223
## race                   0.0122715  0.4524887   0.027  0.97836
## age                    0.2697293  0.1174647   2.296  0.02166 *
## I(age^2)              -0.0028837  0.0011135  -2.590  0.00961 **
## as.factor(education)2  0.4407884  0.4193993   1.051  0.29326
## as.factor(education)3  0.1646881  0.3705471   0.444  0.65672
## as.factor(education)4 -0.1384470  0.5697969  -0.243  0.80802
## as.factor(education)5  0.3823818  0.5601808   0.683  0.49486
## smokeintensity        -0.0157119  0.0347319  -0.452  0.65100
## I(smokeintensity^2)    0.0001133  0.0006058   0.187  0.85171
## smokeyrs              -0.0785973  0.0749576  -1.049  0.29438
## I(smokeyrs^2)          0.0005569  0.0010318   0.540  0.58938
## as.factor(exercise)1   0.9714714  0.3878101   2.505  0.01224 *
## as.factor(exercise)2   0.5839890  0.3723133   1.569  0.11675
## as.factor(active)1     0.2474785  0.3254548   0.760  0.44701
## as.factor(active)2    -0.7065829  0.3964577  -1.782  0.07471 .
## wt71                   0.0878871  0.0400115   2.197  0.02805 *
## I(wt71^2)             -0.0006351  0.0002257  -2.813  0.00490 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 533.36  on 1628  degrees of freedom
## Residual deviance: 465.36  on 1609  degrees of freedom
## AIC: 505.36
##
## Number of Fisher Scoring iterations: 7
nhefs$pd.c <- predict(cw.denom, nhefs, type="response")
nhefs$wc <- ifelse(nhefs$cens==0, 1/nhefs$pd.c, NA)
# observations with cens=1 only contribute to censoring models
```

# Program 14.2

- G-estimation of a 1-parameter structural nested mean model
- Brute force search
- Data from NHEFS

## G-estimation: Checking one possible value of psi

```
#install.packages("geepack")
library("geepack")
```

```r
nhefs$psi <- 3.446
nhefs$Hpsi <- nhefs$wt82_71 - nhefs$psi*nhefs$qsmk

fit <- geeglm(qsmk ~ sex + race + age + I(age*age) + as.factor(education)
           + smokeintensity + I(smokeintensity*smokeintensity) + smokeyrs
           + I(smokeyrs*smokeyrs) + as.factor(exercise) + as.factor(active)
           + wt71 + I(wt71*wt71) + Hpsi, family=binomial, data=nhefs,
           weights=wc, id=seqn, corstr="independence")
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
summary(fit)
##
## Call:
## geeglm(formula = qsmk ~ sex + race + age + I(age * age) + as.factor(education) +
##     smokeintensity + I(smokeintensity * smokeintensity) + smokeyrs +
##     I(smokeyrs * smokeyrs) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71 * wt71) + Hpsi, family = binomial, data = nhefs,
##     weights = wc, id = seqn, corstr = "independence")
##
##  Coefficients:
##                                     Estimate    Std.err   Wald Pr(>|W|)
## (Intercept)                       -2.403e+00  1.329e+00  3.269 0.070604 .
## sex                               -5.137e-01  1.536e-01 11.193 0.000821 ***
## race                              -8.609e-01  2.099e-01 16.826 4.10e-05 ***
## age                                1.152e-01  5.020e-02  5.263 0.021779 *
## I(age * age)                      -7.593e-04  5.296e-04  2.056 0.151619
## as.factor(education)2             -2.894e-02  1.964e-01  0.022 0.882859
## as.factor(education)3              8.771e-02  1.726e-01  0.258 0.611329
## as.factor(education)4              6.637e-02  2.698e-01  0.061 0.805645
## as.factor(education)5              4.711e-01  2.247e-01  4.395 0.036036 *
## smokeintensity                    -7.834e-02  1.464e-02 28.635 8.74e-08 ***
## I(smokeintensity * smokeintensity)  1.072e-03  2.650e-04 16.368 5.21e-05 ***
## smokeyrs                          -7.111e-02  2.639e-02  7.261 0.007047 **
## I(smokeyrs * smokeyrs)             8.153e-04  4.490e-04  3.298 0.069384 .
## as.factor(exercise)1               3.363e-01  1.828e-01  3.384 0.065844 .
## as.factor(exercise)2               3.800e-01  1.889e-01  4.049 0.044187 *
## as.factor(active)1                 3.412e-02  1.339e-01  0.065 0.798778
## as.factor(active)2                 2.135e-01  2.121e-01  1.012 0.314308
## wt71                              -7.661e-03  2.562e-02  0.089 0.764963
## I(wt71 * wt71)                     8.655e-05  1.582e-04  0.299 0.584233
## Hpsi                              -1.903e-06  8.839e-03  0.000 0.999828
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)   0.9969 0.06717
## Number of clusters:   1566  Maximum cluster size: 1
```

### G-estimation: Checking multiple possible values of psi

```
#install.packages("geepack")
grid <- seq(from = 2,to = 5, by = 0.1)
j = 0
Hpsi.coefs <- cbind(rep(NA,length(grid)), rep(NA, length(grid)))
colnames(Hpsi.coefs) <- c("Estimate", "p-value")

for (i in grid){
  psi = i
  j = j+1
  nhefs$Hpsi <- nhefs$wt82_71 - psi * nhefs$qsmk

  gest.fit <- geeglm(qsmk ~ sex + race + age + I(age*age) + as.factor(education)
                 + smokeintensity + I(smokeintensity*smokeintensity) + smokeyrs
                 + I(smokeyrs*smokeyrs) + as.factor(exercise) + as.factor(active)
                 + wt71 + I(wt71*wt71) + Hpsi, family=binomial, data=nhefs,
                 weights=wc, id=seqn, corstr="independence")
  Hpsi.coefs[j,1] <- summary(gest.fit)$coefficients["Hpsi", "Estimate"]
  Hpsi.coefs[j,2] <- summary(gest.fit)$coefficients["Hpsi", "Pr(>|W|)"]
}
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

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## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
```

```
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

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## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

## Warning in eval(family$initialize): non-integer #successes in a binomial glm!

## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
Hpsi.coefs
##          Estimate  p-value
##  [1,]  0.0267219 0.001772
##  [2,]  0.0248946 0.003580
##  [3,]  0.0230655 0.006963
##  [4,]  0.0212344 0.013026
##  [5,]  0.0194009 0.023417
##  [6,]  0.0175647 0.040430
##  [7,]  0.0157254 0.067015
##  [8,]  0.0138827 0.106626
##  [9,]  0.0120362 0.162877
## [10,]  0.0101857 0.238979
## [11,]  0.0083308 0.337048
## [12,]  0.0064713 0.457433
## [13,]  0.0046069 0.598235
## [14,]  0.0027374 0.755204
## [15,]  0.0008624 0.922101
## [16,] -0.0010181 0.908537
## [17,] -0.0029044 0.744362
## [18,] -0.0047967 0.592188
## [19,] -0.0066950 0.457169
## [20,] -0.0085997 0.342360
## [21,] -0.0105107 0.248681
```

```
## [22,] -0.0124282 0.175239
## [23,] -0.0143523 0.119841
## [24,] -0.0162831 0.079580
## [25,] -0.0182206 0.051347
## [26,] -0.0201649 0.032218
## [27,] -0.0221160 0.019675
## [28,] -0.0240740 0.011706
## [29,] -0.0260389 0.006792
## [30,] -0.0280106 0.003847
## [31,] -0.0299893 0.002129
```

# Program 14.3

- G-estimation for 2-parameter structural nested mean model
- Closed form estimator
- Data from NHEFS

## G-estimation: Closed form estimator linear mean models

```
logit.est <- glm(qsmk ~ sex + race + age + I(age^2) + as.factor(education)
                 + smokeintensity + I(smokeintensity^2) + smokeyrs
                 + I(smokeyrs^2) + as.factor(exercise) + as.factor(active)
                 + wt71 + I(wt71^2), data = nhefs, weight = wc,
                 family = binomial())
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
summary(logit.est)
##
## Call:
## glm(formula = qsmk ~ sex + race + age + I(age^2) + as.factor(education) +
##     smokeintensity + I(smokeintensity^2) + smokeyrs + I(smokeyrs^2) +
##     as.factor(exercise) + as.factor(active) + wt71 + I(wt71^2),
##     family = binomial(), data = nhefs, weights = wc)
##
## Coefficients:
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)          -2.40e+00   1.31e+00   -1.83  0.06743 .
## sex                  -5.14e-01   1.50e-01   -3.42  0.00062 ***
## race                 -8.61e-01   2.06e-01   -4.18  2.9e-05 ***
## age                   1.15e-01   4.95e-02    2.33  0.01992 *
## I(age^2)             -7.59e-04   5.14e-04   -1.48  0.13953
## as.factor(education)2 -2.89e-02   1.93e-01   -0.15  0.88079
## as.factor(education)3  8.77e-02   1.73e-01    0.51  0.61244
## as.factor(education)4  6.64e-02   2.66e-01    0.25  0.80301
## as.factor(education)5  4.71e-01   2.21e-01    2.13  0.03314 *
## smokeintensity       -7.83e-02   1.49e-02   -5.27  1.4e-07 ***
## I(smokeintensity^2)   1.07e-03   2.78e-04    3.85  0.00012 ***
## smokeyrs             -7.11e-02   2.71e-02   -2.63  0.00862 **
## I(smokeyrs^2)         8.15e-04   4.45e-04    1.83  0.06722 .
## as.factor(exercise)1  3.36e-01   1.75e-01    1.92  0.05467 .
## as.factor(exercise)2  3.80e-01   1.82e-01    2.09  0.03637 *
## as.factor(active)1    3.41e-02   1.30e-01    0.26  0.79337
## as.factor(active)2    2.13e-01   2.06e-01    1.04  0.30033
```

```
## wt71                  -7.66e-03   2.46e-02   -0.31  0.75530
## I(wt71^2)              8.66e-05   1.51e-04    0.57  0.56586
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1872.2  on 1565  degrees of freedom
## Residual deviance: 1755.6  on 1547  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 1719
##
## Number of Fisher Scoring iterations: 4
nhefs$pqsmk <- predict(logit.est, nhefs, type = "response")
describe(nhefs$pqsmk)
## nhefs$pqsmk
##        n  missing distinct     Info     Mean      Gmd      .05      .10
##     1629        0     1629        1   0.2622   0.1302   0.1015   0.1261
##      .25      .50      .75      .90      .95
##   0.1780   0.2426   0.3251   0.4221   0.4965
##
## lowest : 0.0514466 0.0515703 0.0543802 0.0558308 0.0593059
## highest: 0.672083  0.686432  0.713913  0.733299  0.78914
summary(nhefs$pqsmk)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.0514  0.1780  0.2426  0.2622  0.3251  0.7891

# solve sum(w_c * H(psi) * (qsmk - E[qsmk | L]))  = 0
# for a single psi and H(psi) = wt82_71 - psi * qsmk
# this can be solved as
# psi = sum( w_c * wt82_71 * (qsmk - pqsmk)) / sum(w_c * qsmk * (qsmk - pqsmk))

nhefs.c <- nhefs[which(!is.na(nhefs$wt82)),]
with(nhefs.c, sum(wc*wt82_71*(qsmk-pqsmk)) / sum(wc*qsmk*(qsmk - pqsmk)))
## [1] 3.446
```

### G-estimation: Closed form estimator for 2-parameter model

```
diff = with(nhefs.c, qsmk - pqsmk)
diff2 = with(nhefs.c, wc * diff)

lhs = matrix(0,2,2)
lhs[1,1] = with(nhefs.c, sum(qsmk * diff2))
lhs[1,2] = with(nhefs.c, sum(qsmk * smokeintensity  * diff2))
lhs[2,1] = with(nhefs.c, sum(qsmk * smokeintensity * diff2))
lhs[2,2] = with(nhefs.c, sum(qsmk * smokeintensity * smokeintensity * diff2))

rhs = matrix(0,2,1)
rhs[1] = with(nhefs.c, sum(wt82_71 * diff2))
rhs[2] = with(nhefs.c, sum(wt82_71 * smokeintensity * diff2))

psi = t(solve(lhs,rhs))
```

```
psi
##        [,1]    [,2]
## [1,] 2.859 0.03004
```

# 15. Outcome regression and propensity scores

## Program 15.1

- Estimating the average causal effect within levels of confounders under the assumption of effect-measure modification by smoking intensity ONLY
- Data from NHEFS

```
library(here)
```

```
#install.packages("readxl") # install package if required
library("readxl")

nhefs <- read_excel(here("data", "NHEFS.xls"))
nhefs$cens <- ifelse(is.na(nhefs$wt82), 1, 0)

# regression on covariates, allowing for some effect modification
fit <- glm(wt82_71 ~ qsmk + sex + race + age + I(age*age) + as.factor(education)
           + smokeintensity + I(smokeintensity*smokeintensity) + smokeyrs
           + I(smokeyrs*smokeyrs) + as.factor(exercise) + as.factor(active)
           + wt71 + I(wt71*wt71) + I(qsmk*smokeintensity), data=nhefs)
summary(fit)
##
## Call:
## glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71) + I(qsmk * smokeintensity),
##     data = nhefs)
##
## Coefficients:
##                                       Estimate Std. Error t value Pr(>|t|)
## (Intercept)                         -1.5881657  4.3130359  -0.368 0.712756
## qsmk                                 2.5595941  0.8091486   3.163 0.001590 **
## sex                                 -1.4302717  0.4689576  -3.050 0.002328 **
## race                                 0.5601096  0.5818888   0.963 0.335913
## age                                  0.3596353  0.1633188   2.202 0.027809 *
## I(age * age)                        -0.0061010  0.0017261  -3.534 0.000421 ***
## as.factor(education)2                0.7904440  0.6070005   1.302 0.193038
## as.factor(education)3                0.5563124  0.5561016   1.000 0.317284
## as.factor(education)4                1.4915695  0.8322704   1.792 0.073301 .
## as.factor(education)5               -0.1949770  0.7413692  -0.263 0.792589
```

```
## smokeintensity                          0.0491365  0.0517254   0.950 0.342287
## I(smokeintensity * smokeintensity) -0.0009907  0.0009380  -1.056 0.291097
## smokeyrs                                0.1343686  0.0917122   1.465 0.143094
## I(smokeyrs * smokeyrs)                 -0.0018664  0.0015437  -1.209 0.226830
## as.factor(exercise)1                    0.2959754  0.5351533   0.553 0.580298
## as.factor(exercise)2                    0.3539128  0.5588587   0.633 0.526646
## as.factor(active)1                     -0.9475695  0.4099344  -2.312 0.020935 *
## as.factor(active)2                     -0.2613779  0.6845577  -0.382 0.702647
## wt71                                    0.0455018  0.0833709   0.546 0.585299
## I(wt71 * wt71)                         -0.0009653  0.0005247  -1.840 0.066001 .
## I(qsmk * smokeintensity)                0.0466628  0.0351448   1.328 0.184463
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 53.5683)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 82763  on 1545  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 10701
##
## Number of Fisher Scoring iterations: 2

# (step 1) build the contrast matrix with all zeros
# this function builds the blank matrix
# install.packages("multcomp") # install packages if necessary
library("multcomp")
## Loading required package: mvtnorm
## Loading required package: survival
## Loading required package: TH.data
## Loading required package: MASS
##
## Attaching package: 'TH.data'
## The following object is masked from 'package:MASS':
##
##     geyser
makeContrastMatrix <- function(model, nrow, names) {
  m <- matrix(0, nrow = nrow, ncol = length(coef(model)))
  colnames(m) <- names(coef(model))
  rownames(m) <- names
  return(m)
}
K1 <-
  makeContrastMatrix(
    fit,
    2,
    c(
      'Effect of Quitting Smoking at Smokeintensity of 5',
      'Effect of Quitting Smoking at Smokeintensity of 40'
    )
  )
# (step 2) fill in the relevant non-zero elements
```

```
K1[1:2, 'qsmk'] <- 1
K1[1:2, 'I(qsmk * smokeintensity)'] <- c(5, 40)

# (step 3) check the contrast matrix
K1
##                                                      (Intercept) qsmk sex race
## Effect of Quitting Smoking at Smokeintensity of 5              0    1   0    0
## Effect of Quitting Smoking at Smokeintensity of 40             0    1   0    0
##                                                      age I(age * age)
## Effect of Quitting Smoking at Smokeintensity of 5      0            0
## Effect of Quitting Smoking at Smokeintensity of 40     0            0
##                                                      as.factor(education)2
## Effect of Quitting Smoking at Smokeintensity of 5                        0
## Effect of Quitting Smoking at Smokeintensity of 40                       0
##                                                      as.factor(education)3
## Effect of Quitting Smoking at Smokeintensity of 5                        0
## Effect of Quitting Smoking at Smokeintensity of 40                       0
##                                                      as.factor(education)4
## Effect of Quitting Smoking at Smokeintensity of 5                        0
## Effect of Quitting Smoking at Smokeintensity of 40                       0
##                                                      as.factor(education)5
## Effect of Quitting Smoking at Smokeintensity of 5                        0
## Effect of Quitting Smoking at Smokeintensity of 40                       0
##                                                      smokeintensity
## Effect of Quitting Smoking at Smokeintensity of 5                 0
## Effect of Quitting Smoking at Smokeintensity of 40                0
##                                                      I(smokeintensity * smokeintensity)
## Effect of Quitting Smoking at Smokeintensity of 5                                     0
## Effect of Quitting Smoking at Smokeintensity of 40                                    0
##                                                      smokeyrs
## Effect of Quitting Smoking at Smokeintensity of 5           0
## Effect of Quitting Smoking at Smokeintensity of 40          0
##                                                      I(smokeyrs * smokeyrs)
## Effect of Quitting Smoking at Smokeintensity of 5                         0
## Effect of Quitting Smoking at Smokeintensity of 40                        0
##                                                      as.factor(exercise)1
## Effect of Quitting Smoking at Smokeintensity of 5                       0
## Effect of Quitting Smoking at Smokeintensity of 40                      0
##                                                      as.factor(exercise)2
## Effect of Quitting Smoking at Smokeintensity of 5                       0
## Effect of Quitting Smoking at Smokeintensity of 40                      0
##                                                      as.factor(active)1
## Effect of Quitting Smoking at Smokeintensity of 5                     0
## Effect of Quitting Smoking at Smokeintensity of 40                    0
##                                                      as.factor(active)2 wt71
## Effect of Quitting Smoking at Smokeintensity of 5                     0    0
## Effect of Quitting Smoking at Smokeintensity of 40                    0    0
##                                                      I(wt71 * wt71)
## Effect of Quitting Smoking at Smokeintensity of 5                 0
## Effect of Quitting Smoking at Smokeintensity of 40                0
##                                                      I(qsmk * smokeintensity)
## Effect of Quitting Smoking at Smokeintensity of 5                           5
```

```
## Effect of Quitting Smoking at Smokeintensity of 40                       40

# (step 4) estimate the contrasts, get tests and confidence intervals for them
estimates1 <- glht(fit, K1)
  summary(estimates1)
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Fit: glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71) + I(qsmk * smokeintensity),
##     data = nhefs)
##
## Linear Hypotheses:
##                                                            Estimate Std. Error
## Effect of Quitting Smoking at Smokeintensity of 5 == 0    2.7929     0.6683
## Effect of Quitting Smoking at Smokeintensity of 40 == 0   4.4261     0.8478
##                                                            z value Pr(>|z|)
## Effect of Quitting Smoking at Smokeintensity of 5 == 0    4.179 5.84e-05 ***
## Effect of Quitting Smoking at Smokeintensity of 40 == 0   5.221 3.56e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
  confint(estimates1)
##
##   Simultaneous Confidence Intervals
##
## Fit: glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71) + I(qsmk * smokeintensity),
##     data = nhefs)
##
## Quantile = 2.2281
## 95% family-wise confidence level
##
##
## Linear Hypotheses:
##                                                            Estimate lwr    upr
## Effect of Quitting Smoking at Smokeintensity of 5 == 0    2.7929   1.3039 4.2819
## Effect of Quitting Smoking at Smokeintensity of 40 == 0 4.4261   2.5372 6.3151

# regression on covariates, not allowing for effect modification
fit2 <- glm(wt82_71 ~ qsmk + sex + race + age + I(age*age) + as.factor(education)
           + smokeintensity + I(smokeintensity*smokeintensity) + smokeyrs
           + I(smokeyrs*smokeyrs) + as.factor(exercise) + as.factor(active)
           + wt71 + I(wt71*wt71), data=nhefs)

summary(fit2)
##
## Call:
```

```
## glm(formula = wt82_71 ~ qsmk + sex + race + age + I(age * age) +
##     as.factor(education) + smokeintensity + I(smokeintensity *
##     smokeintensity) + smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71), data = nhefs)
##
## Coefficients:
##                                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)                        -1.6586176  4.3137734  -0.384 0.700666
## qsmk                                3.4626218  0.4384543   7.897 5.36e-15 ***
## sex                                -1.4650496  0.4683410  -3.128 0.001792 **
## race                                0.5864117  0.5816949   1.008 0.313560
## age                                 0.3626624  0.1633431   2.220 0.026546 *
## I(age * age)                       -0.0061377  0.0017263  -3.555 0.000389 ***
## as.factor(education)2               0.8185263  0.6067815   1.349 0.177546
## as.factor(education)3               0.5715004  0.5561211   1.028 0.304273
## as.factor(education)4               1.5085173  0.8323778   1.812 0.070134 .
## as.factor(education)5              -0.1708264  0.7413289  -0.230 0.817786
## smokeintensity                      0.0651533  0.0503115   1.295 0.195514
## I(smokeintensity * smokeintensity) -0.0010468  0.0009373  -1.117 0.264261
## smokeyrs                            0.1333931  0.0917319   1.454 0.146104
## I(smokeyrs * smokeyrs)             -0.0018270  0.0015438  -1.183 0.236818
## as.factor(exercise)1                0.3206824  0.5349616   0.599 0.548961
## as.factor(exercise)2                0.3628786  0.5589557   0.649 0.516300
## as.factor(active)1                 -0.9429574  0.4100208  -2.300 0.021593 *
## as.factor(active)2                 -0.2580374  0.6847219  -0.377 0.706337
## wt71                                0.0373642  0.0831658   0.449 0.653297
## I(wt71 * wt71)                     -0.0009158  0.0005235  -1.749 0.080426 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 53.59474)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 82857  on 1546  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 10701
##
## Number of Fisher Scoring iterations: 2
```

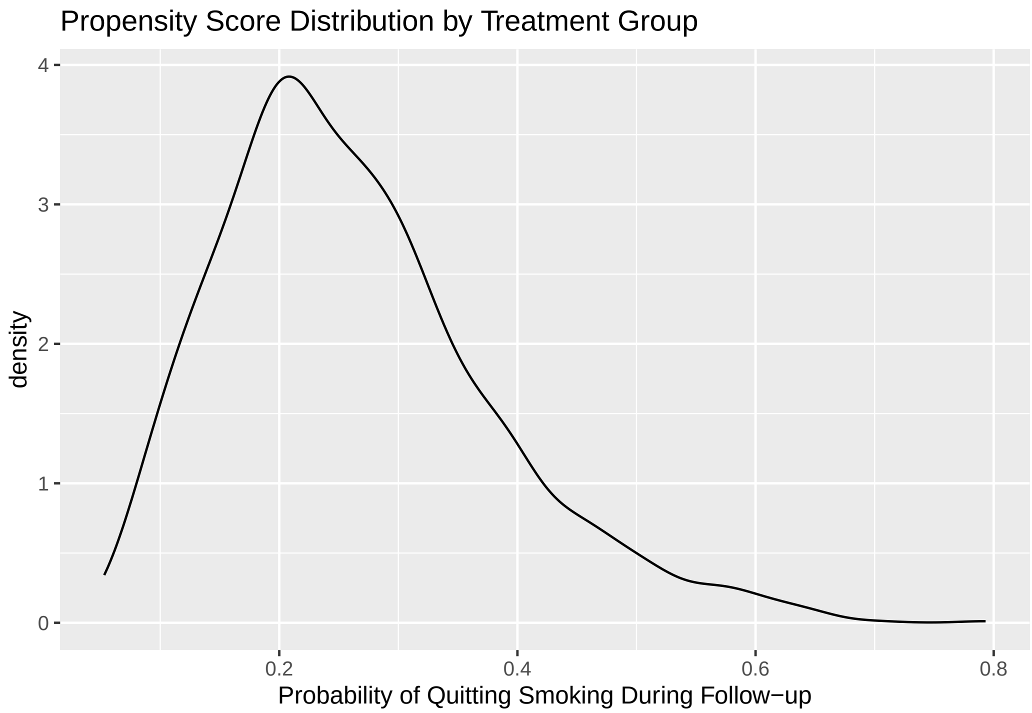
## Program 15.2

- Estimating and plotting the propensity score
- Data from NHEFS

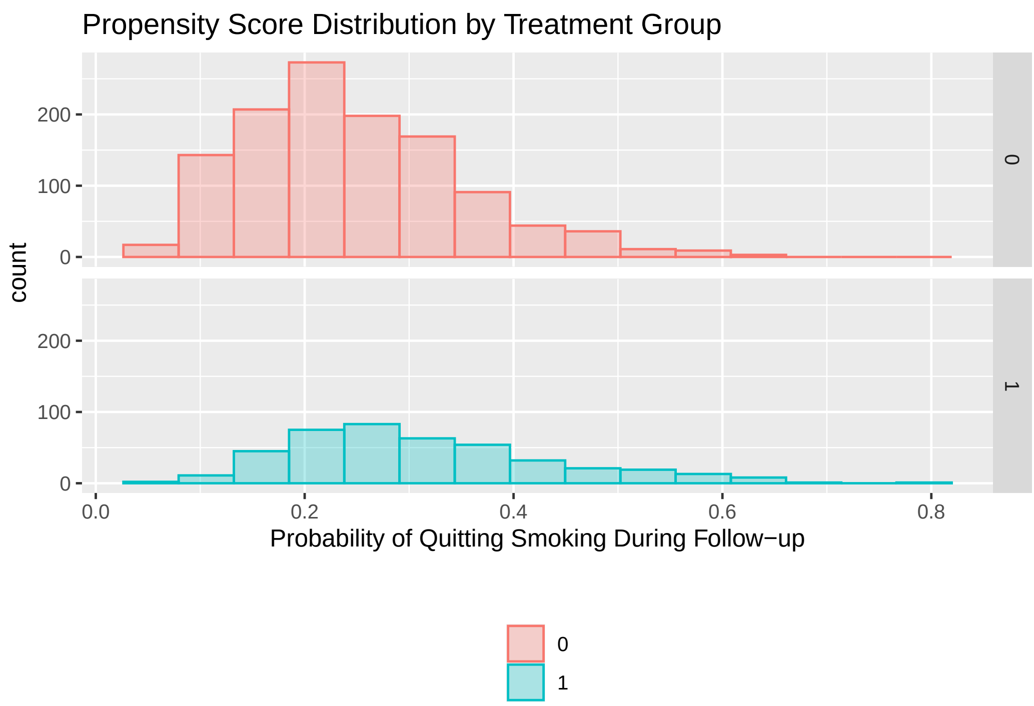
```
fit3 <- glm(qsmk ~ sex + race + age + I(age*age) + as.factor(education)
            + smokeintensity + I(smokeintensity*smokeintensity) + smokeyrs
            + I(smokeyrs*smokeyrs) + as.factor(exercise) + as.factor(active)
            + wt71 + I(wt71*wt71), data=nhefs, family=binomial())
summary(fit3)
##
## Call:
## glm(formula = qsmk ~ sex + race + age + I(age * age) + as.factor(education) +
```

```r
##     smokeintensity + I(smokeintensity * smokeintensity) + smokeyrs +
##     I(smokeyrs * smokeyrs) + as.factor(exercise) + as.factor(active) +
##     wt71 + I(wt71 * wt71), family = binomial(), data = nhefs)
##
## Coefficients:
##                                      Estimate Std. Error z value Pr(>|z|)
## (Intercept)                        -1.9889022  1.2412792  -1.602 0.109089
## sex                                -0.5075218  0.1482316  -3.424 0.000617 ***
## race                               -0.8502312  0.2058720  -4.130 3.63e-05 ***
## age                                 0.1030132  0.0488996   2.107 0.035150 *
## I(age * age)                       -0.0006052  0.0005074  -1.193 0.232973
## as.factor(education)2              -0.0983203  0.1906553  -0.516 0.606066
## as.factor(education)3               0.0156987  0.1707139   0.092 0.926730
## as.factor(education)4              -0.0425260  0.2642761  -0.161 0.872160
## as.factor(education)5               0.3796632  0.2203947   1.723 0.084952 .
## smokeintensity                     -0.0651561  0.0147589  -4.415 1.01e-05 ***
## I(smokeintensity * smokeintensity)  0.0008461  0.0002758   3.067 0.002160 **
## smokeyrs                           -0.0733708  0.0269958  -2.718 0.006571 **
## I(smokeyrs * smokeyrs)              0.0008384  0.0004435   1.891 0.058669 .
## as.factor(exercise)1                0.2914117  0.1735543   1.679 0.093136 .
## as.factor(exercise)2                0.3550517  0.1799293   1.973 0.048463 *
## as.factor(active)1                  0.0108754  0.1298320   0.084 0.933243
## as.factor(active)2                  0.0683123  0.2087269   0.327 0.743455
## wt71                               -0.0128478  0.0222829  -0.577 0.564226
## I(wt71 * wt71)                      0.0001209  0.0001352   0.895 0.370957
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1876.3  on 1628  degrees of freedom
## Residual deviance: 1766.7  on 1610  degrees of freedom
## AIC: 1804.7
##
## Number of Fisher Scoring iterations: 4
nhefs$ps <- predict(fit3, nhefs, type="response")

summary(nhefs$ps[nhefs$qsmk==0])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05298 0.16949 0.22747 0.24504 0.30441 0.65788
summary(nhefs$ps[nhefs$qsmk==1])
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06248 0.22046 0.28897 0.31240 0.38122 0.79320

# # plotting the estimated propensity score
# install.packages("ggplot2") # install packages if necessary
# install.packages("dplyr")
library("ggplot2")
library("dplyr")
##
## Attaching package: 'dplyr'
## The following object is masked from 'package:MASS':
```

```
##
##     select
## The following objects are masked from 'package:stats':
##
##     filter, lag
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
ggplot(nhefs, aes(x = ps, fill = qsmk)) + geom_density(alpha = 0.2) +
  xlab('Probability of Quitting Smoking During Follow-up') +
  ggtitle('Propensity Score Distribution by Treatment Group') +
  scale_fill_discrete('') +
  theme(legend.position = 'bottom', legend.direction = 'vertical')
## Warning: The following aesthetics were dropped during statistical transformation: fill
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a `group` aesthetic or to convert a numerical
##   variable into a factor?
```




```
# alternative plot with histograms
nhefs <- nhefs %>% mutate(qsmklabel = ifelse(qsmk == 1,
                          yes = 'Quit Smoking 1971-1982',
                          no = 'Did Not Quit Smoking 1971-1982'))
ggplot(nhefs, aes(x = ps, fill = as.factor(qsmk), color = as.factor(qsmk))) +
  geom_histogram(alpha = 0.3, position = 'identity', bins=15) +
  facet_grid(as.factor(qsmk) ~ .) +
  xlab('Probability of Quitting Smoking During Follow-up') +
  ggtitle('Propensity Score Distribution by Treatment Group') +
  scale_fill_discrete('') +
  scale_color_discrete('') +
  theme(legend.position = 'bottom', legend.direction = 'vertical')
```




```
# attempt to reproduce plot from the book
nhefs %>%
  mutate(ps.grp = round(ps/0.05) * 0.05) %>%
  group_by(qsmk, ps.grp) %>%
  summarize(n = n()) %>%
  ungroup() %>%
  mutate(n2 = ifelse(qsmk == 0, yes = n, no =  -1*n)) %>%
  ggplot(aes(x = ps.grp, y = n2, fill = as.factor(qsmk))) +
  geom_bar(stat = 'identity', position = 'identity') +
  geom_text(aes(label = n, x = ps.grp, y = n2 + ifelse(qsmk == 0, 8, -8))) +
  xlab('Probability of Quitting Smoking During Follow-up') +
  ylab('N') +
  ggtitle('Propensity Score Distribution by Treatment Group') +
  scale_fill_discrete('') +
  scale_x_continuous(breaks = seq(0, 1, 0.05)) +
  theme(legend.position = 'bottom', legend.direction = 'vertical',
        axis.ticks.y = element_blank(),
        axis.text.y = element_blank())
```

## Program 15.3

- Stratification on the propensity score
- Data from NHEFS

```
# calculation of deciles
nhefs$ps.dec <- cut(nhefs$ps,
                    breaks=c(quantile(nhefs$ps, probs=seq(0,1,0.1))),
                    labels=seq(1:10),
                    include.lowest=TRUE)

#install.packages("psych") # install package if required
library("psych")
```

```
##
## Attaching package: 'psych'
## The following objects are masked from 'package:ggplot2':
##
##     %+%, alpha
describeBy(nhefs$ps, list(nhefs$ps.dec, nhefs$qsmk))
##
##  Descriptive statistics by group
## : 1
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 151  0.1 0.02   0.11     0.1 0.02 0.05 0.13  0.08 -0.55    -0.53  0
## ------------------------------------------------------------
## : 2
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 136 0.15 0.01   0.15    0.15 0.01 0.13 0.17  0.04 -0.04    -1.23  0
## ------------------------------------------------------------
## : 3
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 134 0.18 0.01   0.18    0.18 0.01 0.17 0.19  0.03 -0.08    -1.34  0
## ------------------------------------------------------------
## : 4
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 129 0.21 0.01   0.21    0.21 0.01 0.19 0.22  0.02 -0.04    -1.13  0
## ------------------------------------------------------------
## : 5
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 120 0.23 0.01   0.23    0.23 0.01 0.22 0.25  0.03 0.24    -1.22  0
## ------------------------------------------------------------
## : 6
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 117 0.26 0.01   0.26    0.26 0.01 0.25 0.27  0.03 -0.11    -1.29  0
## ------------------------------------------------------------
## : 7
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 120 0.29 0.01   0.29    0.29 0.01 0.27 0.31  0.03 -0.23    -1.19  0
## ------------------------------------------------------------
## : 8
## : 0
##    vars   n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 112 0.33 0.01   0.33    0.33 0.02 0.31 0.35  0.04 0.15     -1.1  0
## ------------------------------------------------------------
## : 9
## : 0
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 96 0.38 0.02   0.38    0.38 0.02 0.35 0.42  0.06 0.13    -1.15  0
```

```
## --------------------------------------------------------------
## : 10
## : 0
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis   se
## X1    1 86 0.49 0.06   0.47    0.48 0.05 0.42 0.66  0.24  1.1     0.47 0.01
## --------------------------------------------------------------
## : 1
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis   se
## X1    1 12  0.1 0.02   0.11     0.1 0.03 0.06 0.13  0.07 -0.5    -1.36 0.01
## --------------------------------------------------------------
## : 2
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 27 0.15 0.01   0.15    0.15 0.01 0.13 0.17  0.03 -0.03    -1.34  0
## --------------------------------------------------------------
## : 3
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 29 0.18 0.01   0.18    0.18 0.01 0.17 0.19  0.03 0.01    -1.34  0
## --------------------------------------------------------------
## : 4
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range  skew kurtosis se
## X1    1 34 0.21 0.01   0.21    0.21 0.01 0.19 0.22  0.02 -0.31    -1.23  0
## --------------------------------------------------------------
## : 5
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 43 0.23 0.01   0.23    0.23 0.01 0.22 0.25  0.03 0.11    -1.23  0
## --------------------------------------------------------------
## : 6
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 45 0.26 0.01   0.26    0.26 0.01 0.25 0.27  0.03  0.2    -1.12  0
## --------------------------------------------------------------
## : 7
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 43 0.29 0.01   0.29    0.29 0.01 0.27 0.31  0.03 0.16    -1.25  0
## --------------------------------------------------------------
## : 8
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 51 0.33 0.01   0.33    0.33 0.02 0.31 0.35  0.04 0.11    -1.19  0
## --------------------------------------------------------------
## : 9
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis se
## X1    1 67 0.38 0.02   0.38    0.38 0.03 0.35 0.42  0.06 0.19    -1.27  0
## --------------------------------------------------------------
## : 10
```

```
## : 1
##    vars  n mean   sd median trimmed  mad  min  max range skew kurtosis   se
## X1    1 77 0.52 0.08   0.51    0.51 0.08 0.42 0.79  0.38 0.88     0.81 0.01

# function to create deciles easily
decile <- function(x) {
  return(factor(quantcut(x, seq(0, 1, 0.1), labels = FALSE)))
}

# regression on PS deciles, allowing for effect modification
for (deciles in c(1:10)) {
  print(t.test(wt82_71~qsmk, data=nhefs[which(nhefs$ps.dec==deciles),]))
}
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = 0.0060506, df = 11.571, p-value = 0.9953
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -5.283903  5.313210
## sample estimates:
## mean in group 0 mean in group 1
##        3.995205        3.980551
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -3.1117, df = 37.365, p-value = 0.003556
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -6.849335 -1.448161
## sample estimates:
## mean in group 0 mean in group 1
##        2.904679        7.053426
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -4.5301, df = 35.79, p-value = 6.317e-05
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -9.474961 -3.613990
## sample estimates:
## mean in group 0 mean in group 1
##        2.612094        9.156570
##
##
##  Welch Two Sample t-test
##
```

```
## data:  wt82_71 by qsmk
## t = -1.4117, df = 45.444, p-value = 0.1648
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -5.6831731  0.9985715
## sample estimates:
## mean in group 0 mean in group 1
##        3.474679        5.816979
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -3.1371, df = 74.249, p-value = 0.002446
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -6.753621 -1.507087
## sample estimates:
## mean in group 0 mean in group 1
##        2.098800        6.229154
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -2.1677, df = 50.665, p-value = 0.0349
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -8.7516605 -0.3350127
## sample estimates:
## mean in group 0 mean in group 1
##        1.847004        6.390340
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -3.3155, df = 84.724, p-value = 0.001348
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -6.904207 -1.727590
## sample estimates:
## mean in group 0 mean in group 1
##        1.560048        5.875946
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -2.664, df = 75.306, p-value = 0.009441
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
```

```
##  -6.2396014 -0.9005605
## sample estimates:
## mean in group 0 mean in group 1
##       0.2846851       3.8547661
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -1.9122, df = 129.12, p-value = 0.05806
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -4.68143608  0.07973698
## sample estimates:
## mean in group 0 mean in group 1
##      -0.8954482       1.4054014
##
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by qsmk
## t = -1.5925, df = 142.72, p-value = 0.1135
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -5.0209284  0.5404697
## sample estimates:
## mean in group 0 mean in group 1
##      -0.5043766       1.7358528

# regression on PS deciles, not allowing for effect modification
fit.psdec <- glm(wt82_71 ~ qsmk + as.factor(ps.dec), data = nhefs)
summary(fit.psdec)
##
## Call:
## glm(formula = wt82_71 ~ qsmk + as.factor(ps.dec), data = nhefs)
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)            3.7505     0.6089   6.159 9.29e-10 ***
## qsmk                   3.5005     0.4571   7.659 3.28e-14 ***
## as.factor(ps.dec)2   -0.7391     0.8611  -0.858   0.3908
## as.factor(ps.dec)3   -0.6182     0.8612  -0.718   0.4730
## as.factor(ps.dec)4   -0.5204     0.8584  -0.606   0.5444
## as.factor(ps.dec)5   -1.4884     0.8590  -1.733   0.0834 .
## as.factor(ps.dec)6   -1.6227     0.8675  -1.871   0.0616 .
## as.factor(ps.dec)7   -1.9853     0.8681  -2.287   0.0223 *
## as.factor(ps.dec)8   -3.4447     0.8749  -3.937 8.61e-05 ***
## as.factor(ps.dec)9   -5.1544     0.8848  -5.825 6.91e-09 ***
## as.factor(ps.dec)10  -4.8403     0.8828  -5.483 4.87e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## (Dispersion parameter for gaussian family taken to be 58.42297)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 90848  on 1555  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 10827
##
## Number of Fisher Scoring iterations: 2
confint.lm(fit.psdec)
##                         2.5 %      97.5 %
## (Intercept)          2.556098  4.94486263
## qsmk                 2.603953  4.39700504
## as.factor(ps.dec)2  -2.428074  0.94982494
## as.factor(ps.dec)3  -2.307454  1.07103569
## as.factor(ps.dec)4  -2.204103  1.16333143
## as.factor(ps.dec)5  -3.173337  0.19657938
## as.factor(ps.dec)6  -3.324345  0.07893027
## as.factor(ps.dec)7  -3.688043 -0.28248110
## as.factor(ps.dec)8  -5.160862 -1.72860113
## as.factor(ps.dec)9  -6.889923 -3.41883853
## as.factor(ps.dec)10 -6.571789 -3.10873731
```

# Program 15.4

- Standardization using the propensity score
- Data from NHEFS

```
#install.packages("boot") # install package if required
library("boot")
##
## Attaching package: 'boot'
## The following object is masked from 'package:psych':
##
##     logit
## The following object is masked from 'package:survival':
##
##     aml

# standardization by propensity score, agnostic regarding effect modification
std.ps <- function(data, indices) {
  d <- data[indices,] # 1st copy: equal to original one`
  # calculating propensity scores
  ps.fit <- glm(qsmk ~ sex + race + age + I(age*age)
                + as.factor(education) + smokeintensity
                + I(smokeintensity*smokeintensity) + smokeyrs
                + I(smokeyrs*smokeyrs) + as.factor(exercise)
                + as.factor(active) + wt71 + I(wt71*wt71),
                data=d, family=binomial())
  d$pscore <- predict(ps.fit, d, type="response")

  # create a dataset with 3 copies of each subject
  d$interv <- -1 # 1st copy: equal to original one`
```

```
  d0 <- d # 2nd copy: treatment set to 0, outcome to missing
  d0$interv <- 0
  d0$qsmk <- 0
  d0$wt82_71 <- NA
  d1 <- d # 3rd copy: treatment set to 1, outcome to missing
  d1$interv <- 1
  d1$qsmk <- 1
  d1$wt82_71 <- NA
  d.onesample <- rbind(d, d0, d1) # combining datasets

  std.fit <- glm(wt82_71 ~ qsmk + pscore + I(qsmk*pscore), data=d.onesample)
  d.onesample$predicted_meanY <- predict(std.fit, d.onesample)

  # estimate mean outcome in each of the groups interv=-1, interv=0, and interv=1
  return(c(mean(d.onesample$predicted_meanY[d.onesample$interv==-1]),
           mean(d.onesample$predicted_meanY[d.onesample$interv==0]),
           mean(d.onesample$predicted_meanY[d.onesample$interv==1]),
           mean(d.onesample$predicted_meanY[d.onesample$interv==1])-
             mean(d.onesample$predicted_meanY[d.onesample$interv==0])))
}

# bootstrap
results <- boot(data=nhefs, statistic=std.ps, R=5)

# generating confidence intervals
se <- c(sd(results$t[,1]), sd(results$t[,2]),
        sd(results$t[,3]), sd(results$t[,4]))
mean <- results$t0
ll <- mean - qnorm(0.975)*se
ul <- mean + qnorm(0.975)*se

bootstrap <- data.frame(cbind(c("Observed", "No Treatment", "Treatment",
                                "Treatment - No Treatment"), mean, se, ll, ul))
bootstrap
##                         V1             mean                se               ll
## 1                 Observed 2.63384609228479  0.10931939139797 2.41958402233293
## 2             No Treatment 1.71983636149845  0.20560687972976 1.31685428225446
## 3                Treatment 5.35072300362985 0.293832115555194 4.77482263964046
## 4 Treatment - No Treatment  3.6308866421314 0.433679379340606 2.78089067778612
##                 ul
## 1 2.84810816223665
## 2 2.12281844074244
## 3 5.92662336761924
## 4 4.48088260647667
```

```
# regression on the propensity score (linear term)
model6 <- glm(wt82_71 ~ qsmk + ps, data = nhefs) # p.qsmk
summary(model6)
##
## Call:
## glm(formula = wt82_71 ~ qsmk + ps, data = nhefs)
##
## Coefficients:
```

```
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   5.5945     0.4831  11.581  < 2e-16 ***
## qsmk          3.5506     0.4573   7.765 1.47e-14 ***
## ps          -14.8218     1.7576  -8.433  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 58.28455)
##
##     Null deviance: 97176  on 1565  degrees of freedom
## Residual deviance: 91099  on 1563  degrees of freedom
##   (63 observations deleted due to missingness)
## AIC: 10815
##
## Number of Fisher Scoring iterations: 2

# standarization on the propensity score
# (step 1) create two new datasets, one with all treated and one with all untreated
treated <- nhefs
  treated$qsmk <- 1

untreated <- nhefs
  untreated$qsmk <- 0

# (step 2) predict values for everyone in each new dataset based on above model
treated$pred.y <- predict(model6, treated)
untreated$pred.y <- predict(model6, untreated)

# (step 3) compare mean weight loss had all been treated vs. that had all been untreated
mean1 <- mean(treated$pred.y, na.rm = TRUE)
mean0 <- mean(untreated$pred.y, na.rm = TRUE)
mean1
## [1] 5.250824
mean0
## [1] 1.700228
mean1 - mean0
## [1] 3.550596

# (step 4) bootstrap a confidence interval
# number of bootstraps
nboot <- 100
# set up a matrix to store results
boots <- data.frame(i = 1:nboot,
                    mean1 = NA,
                    mean0 = NA,
                    difference = NA)
# loop to perform the bootstrapping
nhefs <- subset(nhefs, !is.na(ps) & !is.na(wt82_71)) # p.qsmk
for(i in 1:nboot) {
  # sample with replacement
  sampl <- nhefs[sample(1:nrow(nhefs), nrow(nhefs), replace = TRUE), ]
```

```
  # fit the model in the bootstrap sample
  bootmod <- glm(wt82_71 ~ qsmk + ps, data = sampl) # ps

  # create new datasets
  sampl.treated <- sampl %>%
    mutate(qsmk = 1)

  sampl.untreated <- sampl %>%
    mutate(qsmk = 0)

  # predict values
  sampl.treated$pred.y <- predict(bootmod, sampl.treated)
  sampl.untreated$pred.y <- predict(bootmod, sampl.untreated)

  # output results
  boots[i, 'mean1'] <- mean(sampl.treated$pred.y, na.rm = TRUE)
  boots[i, 'mean0'] <- mean(sampl.untreated$pred.y, na.rm = TRUE)
  boots[i, 'difference'] <- boots[i, 'mean1'] - boots[i, 'mean0']

  # once loop is done, print the results
  if(i == nboot) {
    cat('95% CI for the causal mean difference\n')
    cat(mean(boots$difference) - 1.96*sd(boots$difference),
        ',',
        mean(boots$difference) + 1.96*sd(boots$difference))
  }
}
## 95% CI for the causal mean difference
## 2.621386 , 4.509942
```

A more flexible and elegant way to do this is to write a function to perform the model fitting, prediction, bootstrapping, and reporting all at once.

# 16. Instrumental variables estimation

## Program 16.1

- Estimating the average causal using the standard IV estimator via the calculation of sample averages
- Data from NHEFS

```
library(here)
```

```
#install.packages("readxl") # install package if required
library("readxl")
nhefs <- read_excel(here("data", "NHEFS.xls"))

# some preprocessing of the data
nhefs$cens <- ifelse(is.na(nhefs$wt82), 1, 0)
summary(nhefs$price82)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##   1.452   1.740   1.815   1.806   1.868   2.103      92

# for simplicity, ignore subjects with missing outcome or missing instrument
nhefs.iv <- nhefs[which(!is.na(nhefs$wt82) & !is.na(nhefs$price82)),]
nhefs.iv$highprice <- ifelse(nhefs.iv$price82>=1.5, 1, 0)

table(nhefs.iv$highprice, nhefs.iv$qsmk)
##
##         0    1
##   0    33    8
##   1 1065  370

t.test(wt82_71 ~ highprice, data=nhefs.iv)
##
##  Welch Two Sample t-test
##
## data:  wt82_71 by highprice
## t = -0.10179, df = 41.644, p-value = 0.9194
## alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0
## 95 percent confidence interval:
##  -3.130588  2.830010
## sample estimates:
## mean in group 0 mean in group 1
##        2.535729        2.686018
```

## Program 16.2

- Estimating the average causal effect using the standard IV estimator via two-stage-least-squares regression
- Data from NHEFS

```
#install.packages ("sem") # install package if required
library(sem)

model1 <- tsls(wt82_71 ~ qsmk, ~ highprice, data = nhefs.iv)
summary(model1)
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk
##
## Instruments: ~highprice
##
## Residuals:
##      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
## -43.34863  -4.00206  -0.02712   0.00000   4.17040  46.47022
##
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  2.068164   5.085098 0.40671  0.68428
## qsmk         2.396270  19.840037 0.12078  0.90388
##
## Residual standard error: 7.8561141 on 1474 degrees of freedom
confint(model1)  # note the wide confidence intervals
##                  2.5 %   97.5 %
## (Intercept)  -7.898445 12.03477
## qsmk        -36.489487 41.28203
```

## Program 16.3

- Estimating the average causal using the standard IV estimator via additive marginal structural models
- Data from NHEFS
- G-estimation: Checking one possible value of psi
- See Chapter 14 for program that checks several values and computes 95% confidence intervals

```
nhefs.iv$psi <- 2.396
nhefs.iv$Hpsi <- nhefs.iv$wt82_71-nhefs.iv$psi*nhefs.iv$qsmk

#install.packages("geepack") # install package if required
library("geepack")
g.est <- geeglm(highprice ~ Hpsi, data=nhefs.iv, id=seqn, family=binomial(),
                corstr="independence")
summary(g.est)
##
## Call:
## geeglm(formula = highprice ~ Hpsi, family = binomial(), data = nhefs.iv,
##     id = seqn, corstr = "independence")
##
##  Coefficients:
```

```
##              Estimate   Std.err  Wald Pr(>|W|)
## (Intercept) 3.555e+00 1.652e-01 463.1   <2e-16 ***
## Hpsi        2.748e-07 2.273e-02   0.0        1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation structure = independence
## Estimated Scale Parameters:
##
##             Estimate Std.err
## (Intercept)        1  0.7607
## Number of clusters:   1476  Maximum cluster size: 1

beta <- coef(g.est)
SE <- coef(summary(g.est))[,2]
lcl <- beta-qnorm(0.975)*SE
ucl <- beta+qnorm(0.975)*SE
cbind(beta, lcl, ucl)
##                  beta      lcl     ucl
## (Intercept) 3.555e+00  3.23152 3.87917
## Hpsi        2.748e-07 -0.04456 0.04456
```

# Program 16.4

- Estimating the average causal using the standard IV estimator with altnerative proposed instruments
- Data from NHEFS

```
summary(tsls(wt82_71 ~ qsmk, ~ ifelse(price82 ≥ 1.6, 1, 0), data = nhefs.iv))
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk
##
## Instruments: ~ifelse(price82 ≥ 1.6, 1, 0)
##
## Residuals:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   -55.6   -13.5     7.6     0.0    12.5    56.4
##
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    -7.89      42.25  -0.187    0.852
## qsmk           41.28     164.95   0.250    0.802
##
## Residual standard error: 18.6055 on 1474 degrees of freedom
summary(tsls(wt82_71 ~ qsmk, ~ ifelse(price82 ≥ 1.7, 1, 0), data = nhefs.iv))
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk
##
## Instruments: ~ifelse(price82 ≥ 1.7, 1, 0)
```

```
##
## Residuals:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   -54.4   -13.4    -8.4     0.0    18.1    75.3
##
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    13.16      48.08   0.274    0.784
## qsmk          -40.91     187.74  -0.218    0.828
##
## Residual standard error: 20.591 on 1474 degrees of freedom
summary(tsls(wt82_71 ~ qsmk, ~ ifelse(price82 ⩾ 1.8, 1, 0), data = nhefs.iv))
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk
##
## Instruments: ~ifelse(price82 ⩾ 1.8, 1, 0)
##
## Residuals:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  -49.37   -8.31   -3.44    0.00    7.27   60.53
##
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    8.086      7.288   1.110    0.267
## qsmk         -21.103     28.428  -0.742    0.458
##
## Residual standard error: 13.0188 on 1474 degrees of freedom
summary(tsls(wt82_71 ~ qsmk, ~ ifelse(price82 ⩾ 1.9, 1, 0), data = nhefs.iv))
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk
##
## Instruments: ~ifelse(price82 ⩾ 1.9, 1, 0)
##
## Residuals:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  -47.24   -6.33   -1.43    0.00    5.52   54.36
##
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    5.963      6.067   0.983    0.326
## qsmk         -12.811     23.667  -0.541    0.588
##
## Residual standard error: 10.3637 on 1474 degrees of freedom
```

# Program 16.5

- Estimating the average causal using the standard IV estimator
- Conditional on baseline covariates
- Data from NHEFS

```r
model2 <- tsls(wt82_71 ~ qsmk + sex + race + age + smokeintensity + smokeyrs +
                      as.factor(exercise) + as.factor(active) + wt71,
             ~ highprice + sex + race + age + smokeintensity + smokeyrs + as.factor(exercise) +
               as.factor(active) + wt71, data = nhefs.iv)
summary(model2)
##
##  2SLS Estimates
##
## Model Formula: wt82_71 ~ qsmk + sex + race + age + smokeintensity + smokeyrs +
##     as.factor(exercise) + as.factor(active) + wt71
##
## Instruments: ~highprice + sex + race + age + smokeintensity + smokeyrs + as.factor(exercise) +
##     as.factor(active) + wt71
##
## Residuals:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  -42.23   -4.29   -0.62    0.00    3.87   46.74
##
##                       Estimate Std. Error t value Pr(>|t|)
## (Intercept)          17.280330   2.335402   7.399  2.3e-13 ***
## qsmk                 -1.042295  29.987369  -0.035   0.9723
## sex                  -1.644393   2.630831  -0.625   0.5320
## race                 -0.183255   4.650386  -0.039   0.9686
## age                  -0.163640   0.240548  -0.680   0.4964
## smokeintensity        0.005767   0.145504   0.040   0.9684
## smokeyrs              0.025836   0.161421   0.160   0.8729
## as.factor(exercise)1  0.498748   2.171239   0.230   0.8184
## as.factor(exercise)2  0.581834   2.183148   0.267   0.7899
## as.factor(active)1   -1.170145   0.607466  -1.926   0.0543 .
## as.factor(active)2   -0.512284   1.308451  -0.392   0.6955
## wt71                 -0.097949   0.036271  -2.701   0.0070 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.7162 on 1464 degrees of freedom
```

# 17. Causal survival analysis

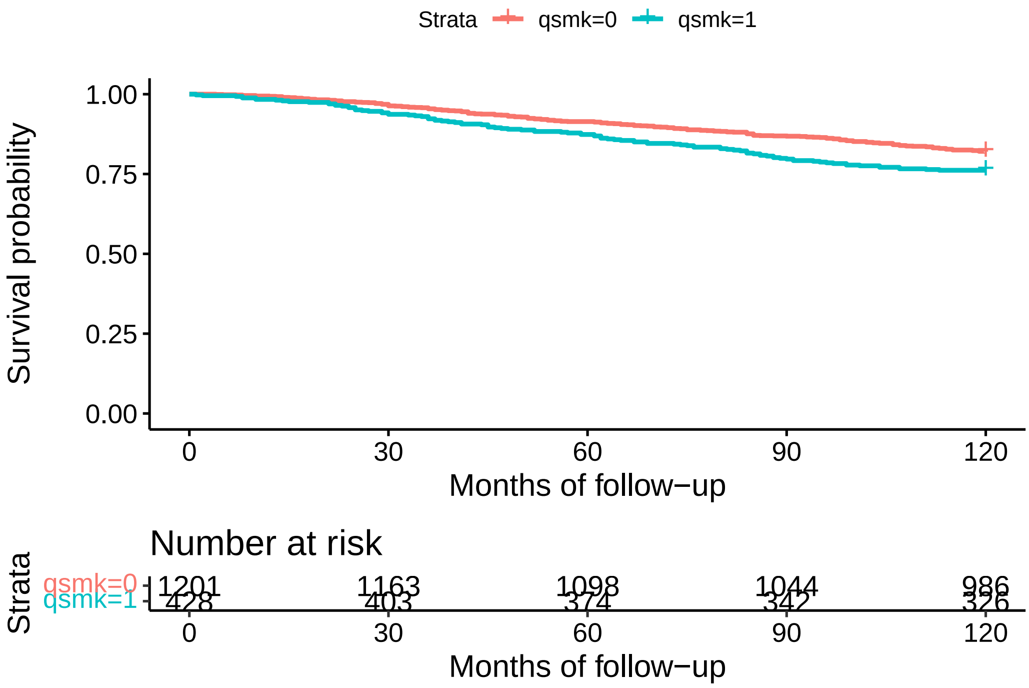
## Program 17.1

- Nonparametric estimation of survival curves
- Data from NHEFS

```
library(here)
```

```
library("readxl")
nhefs <- read_excel(here("data","NHEFS.xls"))

# some preprocessing of the data
nhefs$survtime <- ifelse(nhefs$death==0, 120,
                         (nhefs$yrdth-83)*12+nhefs$modth) # yrdth ranges from 83 to 92

table(nhefs$death, nhefs$qsmk)
##
##        0   1
##   0 985 326
##   1 216 102
summary(nhefs[which(nhefs$death==1),]$survtime)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1.00   35.00   61.00   61.14   86.75  120.00

#install.packages("survival")
#install.packages("ggplot2") # for plots
#install.packages("survminer") # for plots
library("survival")
library("ggplot2")
library("survminer")
## Loading required package: ggpubr
##
## Attaching package: 'survminer'
## The following object is masked from 'package:survival':
##
##     myeloma
survdiff(Surv(survtime, death) ~ qsmk, data=nhefs)
## Call:
## survdiff(formula = Surv(survtime, death) ~ qsmk, data = nhefs)
##
##           N Observed Expected (O-E)^2/E (O-E)^2/V
## qsmk=0 1201      216    237.5      1.95      7.73
## qsmk=1  428      102     80.5      5.76      7.73
```

```
##
##  Chisq= 7.7  on 1 degrees of freedom, p= 0.005

fit <- survfit(Surv(survtime, death) ~ qsmk, data=nhefs)
ggsurvplot(fit, data = nhefs, xlab="Months of follow-up",
           ylab="Survival probability",
           main="Product-Limit Survival Estimates", risk.table = TRUE)
```

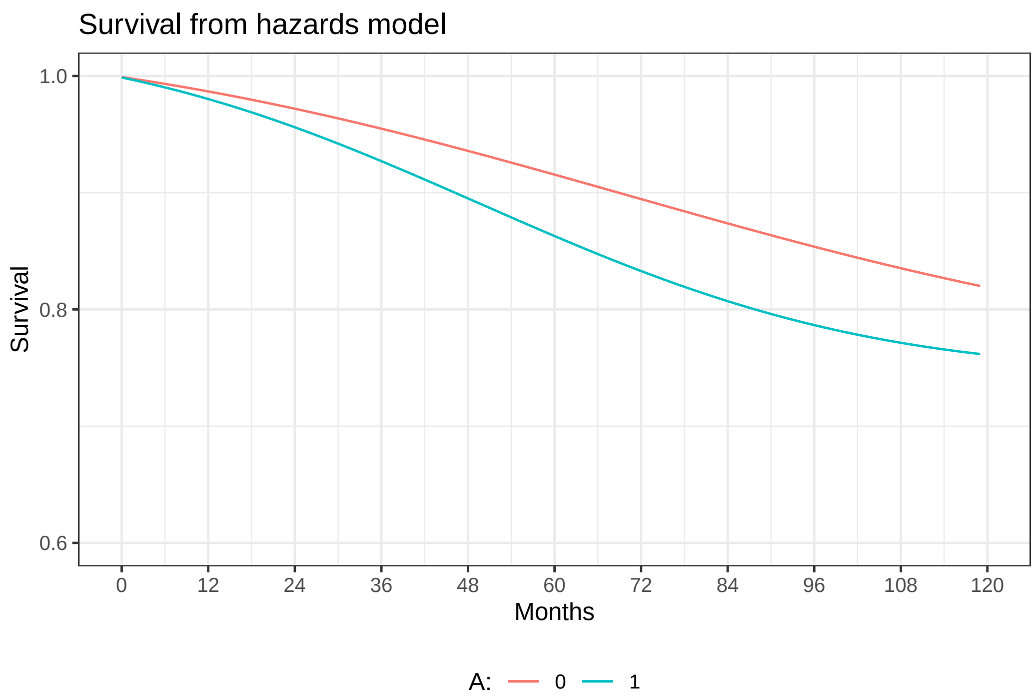



## Program 17.2

- Parametric estimation of survival curves via hazards model
- Data from NHEFS

```
# creation of person-month data
#install.packages("splitstackshape")
library("splitstackshape")
nhefs.surv <- expandRows(nhefs, "survtime", drop=F)
nhefs.surv$time <- sequence(rle(nhefs.surv$seqn)$lengths)-1
nhefs.surv$event <- ifelse(nhefs.surv$time==nhefs.surv$survtime-1 &
                             nhefs.surv$death==1, 1, 0)
nhefs.surv$timesq <- nhefs.surv$time^2

# fit of parametric hazards model
hazards.model <- glm(event==0 ~ qsmk + I(qsmk*time) + I(qsmk*timesq) +
                       time + timesq, family=binomial(), data=nhefs.surv)
summary(hazards.model)
##
## Call:
## glm(formula = event == 0 ~ qsmk + I(qsmk * time) + I(qsmk * timesq) +
##     time + timesq, family = binomial(), data = nhefs.surv)
##
## Coefficients:
##                    Estimate Std. Error z value Pr(>|z|)
```

```
## (Intercept)       6.996e+00  2.309e-01  30.292   <2e-16 ***
## qsmk             -3.355e-01  3.970e-01  -0.845   0.3981
## I(qsmk * time)   -1.208e-02  1.503e-02  -0.804   0.4215
## I(qsmk * timesq)  1.612e-04  1.246e-04   1.293   0.1960
## time             -1.960e-02  8.413e-03  -2.329   0.0198 *
## timesq            1.256e-04  6.686e-05   1.878   0.0604 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 4655.3  on 176763  degrees of freedom
## Residual deviance: 4631.3  on 176758  degrees of freedom
## AIC: 4643.3
##
## Number of Fisher Scoring iterations: 9

# creation of dataset with all time points under each treatment level
qsmk0 <- data.frame(cbind(seq(0, 119),0,(seq(0, 119))^2))
qsmk1 <- data.frame(cbind(seq(0, 119),1,(seq(0, 119))^2))

colnames(qsmk0) <- c("time", "qsmk", "timesq")
colnames(qsmk1) <- c("time", "qsmk", "timesq")

# assignment of estimated (1-hazard) to each person-month */
qsmk0$p.noevent0 <- predict(hazards.model, qsmk0, type="response")
qsmk1$p.noevent1 <- predict(hazards.model, qsmk1, type="response")

# computation of survival for each person-month
qsmk0$surv0 <- cumprod(qsmk0$p.noevent0)
qsmk1$surv1 <- cumprod(qsmk1$p.noevent1)

# some data management to plot estimated survival curves
hazards.graph <- merge(qsmk0, qsmk1, by=c("time", "timesq"))
hazards.graph$survdiff <- hazards.graph$surv1-hazards.graph$surv0

# plot
ggplot(hazards.graph, aes(x=time, y=surv)) +
  geom_line(aes(y = surv0, colour = "0")) +
  geom_line(aes(y = surv1, colour = "1")) +
  xlab("Months") +
  scale_x_continuous(limits = c(0, 120), breaks=seq(0,120,12)) +
  scale_y_continuous(limits=c(0.6, 1), breaks=seq(0.6, 1, 0.2)) +
  ylab("Survival") +
  ggtitle("Survival from hazards model") +
  labs(colour="A:") +
  theme_bw() +
  theme(legend.position="bottom")
```



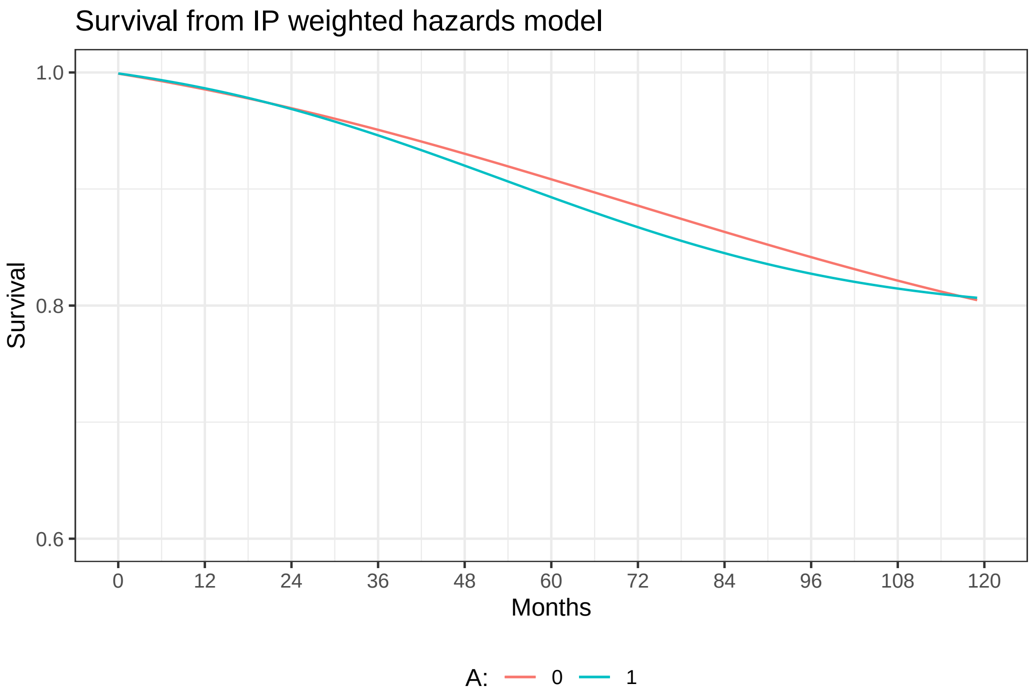

## Program 17.3

- Estimation of survival curves via IP weighted hazards model
- Data from NHEFS

```
# estimation of denominator of ip weights
p.denom <- glm(qsmk ~ sex + race + age + I(age*age) + as.factor(education)
               + smokeintensity + I(smokeintensity*smokeintensity)
               + smokeyrs + I(smokeyrs*smokeyrs) + as.factor(exercise)
               + as.factor(active) + wt71 + I(wt71*wt71),
               data=nhefs, family=binomial())
nhefs$pd.qsmk <- predict(p.denom, nhefs, type="response")

# estimation of numerator of ip weights
p.num <- glm(qsmk ~ 1, data=nhefs, family=binomial())
nhefs$pn.qsmk <- predict(p.num, nhefs, type="response")

# computation of estimated weights
nhefs$sw.a <- ifelse(nhefs$qsmk==1, nhefs$pn.qsmk/nhefs$pd.qsmk,
                     (1-nhefs$pn.qsmk)/(1-nhefs$pd.qsmk))
summary(nhefs$sw.a)
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3312  0.8640  0.9504  0.9991  1.0755  4.2054

# creation of person-month data
nhefs.ipw <- expandRows(nhefs, "survtime", drop=F)
nhefs.ipw$time <- sequence(rle(nhefs.ipw$seqn)$lengths)-1
nhefs.ipw$event <- ifelse(nhefs.ipw$time==nhefs.ipw$survtime-1 &
                            nhefs.ipw$death==1, 1, 0)
nhefs.ipw$timesq <- nhefs.ipw$time^2

# fit of weighted hazards model
```

```r
ipw.model <- glm(event==0 ~ qsmk + I(qsmk*time) + I(qsmk*timesq) +
                   time + timesq, family=binomial(), weight=sw.a,
                 data=nhefs.ipw)
## Warning in eval(family$initialize): non-integer #successes in a binomial glm!
summary(ipw.model)
##
## Call:
## glm(formula = event == 0 ~ qsmk + I(qsmk * time) + I(qsmk * timesq) +
##     time + timesq, family = binomial(), data = nhefs.ipw, weights = sw.a)
##
## Coefficients:
##                    Estimate Std. Error z value Pr(>|z|)
## (Intercept)       6.897e+00  2.208e-01  31.242   <2e-16 ***
## qsmk              1.794e-01  4.399e-01   0.408   0.6834
## I(qsmk * time)   -1.895e-02  1.640e-02  -1.155   0.2481
## I(qsmk * timesq)  2.103e-04  1.352e-04   1.556   0.1198
## time             -1.889e-02  8.053e-03  -2.345   0.0190 *
## timesq            1.181e-04  6.399e-05   1.846   0.0649 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 4643.9  on 176763  degrees of freedom
## Residual deviance: 4626.2  on 176758  degrees of freedom
## AIC: 4633.5
##
## Number of Fisher Scoring iterations: 9

# creation of survival curves
ipw.qsmk0 <- data.frame(cbind(seq(0, 119),0,(seq(0, 119))^2))
ipw.qsmk1 <- data.frame(cbind(seq(0, 119),1,(seq(0, 119))^2))

colnames(ipw.qsmk0) <- c("time", "qsmk", "timesq")
colnames(ipw.qsmk1) <- c("time", "qsmk", "timesq")

# assignment of estimated (1-hazard) to each person-month */
ipw.qsmk0$p.noevent0 <- predict(ipw.model, ipw.qsmk0, type="response")
ipw.qsmk1$p.noevent1 <- predict(ipw.model, ipw.qsmk1, type="response")

# computation of survival for each person-month
ipw.qsmk0$surv0 <- cumprod(ipw.qsmk0$p.noevent0)
ipw.qsmk1$surv1 <- cumprod(ipw.qsmk1$p.noevent1)

# some data management to plot estimated survival curves
ipw.graph <- merge(ipw.qsmk0, ipw.qsmk1, by=c("time", "timesq"))
ipw.graph$survdiff <- ipw.graph$surv1-ipw.graph$surv0

# plot
ggplot(ipw.graph, aes(x=time, y=surv)) +
  geom_line(aes(y = surv0, colour = "0")) +
  geom_line(aes(y = surv1, colour = "1")) +
```

```
  xlab("Months") +
  scale_x_continuous(limits = c(0, 120), breaks=seq(0,120,12)) +
  scale_y_continuous(limits=c(0.6, 1), breaks=seq(0.6, 1, 0.2)) +
  ylab("Survival") +
  ggtitle("Survival from IP weighted hazards model") +
  labs(colour="A:") +
  theme_bw() +
  theme(legend.position="bottom")
```



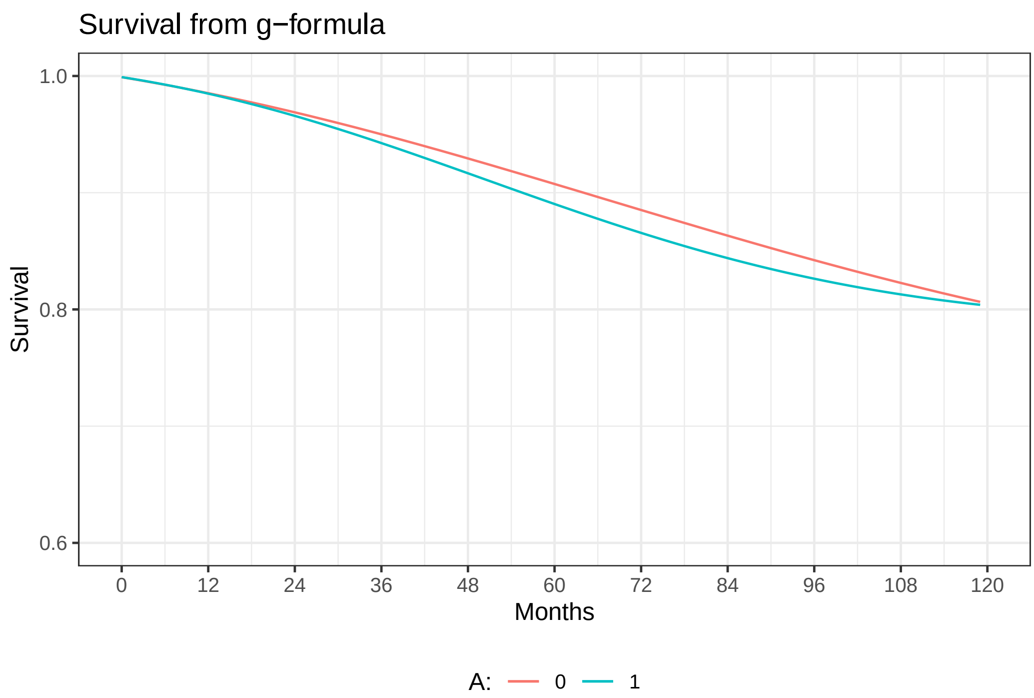

## Program 17.4

- Estimating of survival curves via g-formula
- Data from NHEFS

```
# fit of hazards model with covariates
gf.model <- glm(event==0 ~ qsmk + I(qsmk*time) + I(qsmk*timesq)
                + time + timesq + sex + race + age + I(age*age)
                + as.factor(education) + smokeintensity
                + I(smokeintensity*smokeintensity) + smkintensity82_71
                + smokeyrs + I(smokeyrs*smokeyrs) + as.factor(exercise)
                + as.factor(active) + wt71 + I(wt71*wt71),
                data=nhefs.surv, family=binomial())
summary(gf.model)
##
## Call:
## glm(formula = event == 0 ~ qsmk + I(qsmk * time) + I(qsmk * timesq) +
##     time + timesq + sex + race + age + I(age * age) + as.factor(education) +
##     smokeintensity + I(smokeintensity * smokeintensity) + smkintensity82_71 +
##     smokeyrs + I(smokeyrs * smokeyrs) + as.factor(exercise) +
##     as.factor(active) + wt71 + I(wt71 * wt71), family = binomial(),
##     data = nhefs.surv)
##
```

```
## Coefficients:
##                                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)                           9.272e+00  1.379e+00   6.724 1.76e-11 ***
## qsmk                                  5.959e-02  4.154e-01   0.143 0.885924
## I(qsmk * time)                       -1.485e-02  1.506e-02  -0.987 0.323824
## I(qsmk * timesq)                      1.702e-04  1.245e-04   1.367 0.171643
## time                                 -2.270e-02  8.437e-03  -2.690 0.007142 **
## timesq                                1.174e-04  6.709e-05   1.751 0.080020 .
## sex                                   4.368e-01  1.409e-01   3.101 0.001930 **
## race                                 -5.240e-02  1.734e-01  -0.302 0.762572
## age                                  -8.750e-02  5.907e-02  -1.481 0.138536
## I(age * age)                          8.128e-05  5.470e-04   0.149 0.881865
## as.factor(education)2                 1.401e-01  1.566e-01   0.895 0.370980
## as.factor(education)3                 4.335e-01  1.526e-01   2.841 0.004502 **
## as.factor(education)4                 2.350e-01  2.790e-01   0.842 0.399750
## as.factor(education)5                 3.750e-01  2.386e-01   1.571 0.116115
## smokeintensity                       -1.626e-03  1.430e-02  -0.114 0.909431
## I(smokeintensity * smokeintensity) -7.182e-05  2.390e-04  -0.301 0.763741
## smkintensity82_71                    -1.686e-03  6.501e-03  -0.259 0.795399
## smokeyrs                             -1.677e-02  3.065e-02  -0.547 0.584153
## I(smokeyrs * smokeyrs)               -5.280e-05  4.244e-04  -0.124 0.900997
## as.factor(exercise)1                  1.469e-01  1.792e-01   0.820 0.412300
## as.factor(exercise)2                 -1.504e-01  1.762e-01  -0.854 0.393177
## as.factor(active)1                   -1.601e-01  1.300e-01  -1.232 0.218048
## as.factor(active)2                   -2.294e-01  1.877e-01  -1.222 0.221766
## wt71                                  6.222e-02  1.902e-02   3.271 0.001073 **
## I(wt71 * wt71)                       -4.046e-04  1.129e-04  -3.584 0.000338 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 4655.3  on 176763  degrees of freedom
## Residual deviance: 4185.7  on 176739  degrees of freedom
## AIC: 4235.7
##
## Number of Fisher Scoring iterations: 10

# creation of dataset with all time points for
# each individual under each treatment level
gf.qsmk0 <- expandRows(nhefs, count=120, count.is.col=F)
gf.qsmk0$time <- rep(seq(0, 119), nrow(nhefs))
gf.qsmk0$timesq <- gf.qsmk0$time^2
gf.qsmk0$qsmk <- 0

gf.qsmk1 <- gf.qsmk0
gf.qsmk1$qsmk <- 1

gf.qsmk0$p.noevent0 <- predict(gf.model, gf.qsmk0, type="response")
gf.qsmk1$p.noevent1 <- predict(gf.model, gf.qsmk1, type="response")

#install.packages("dplyr")
```

```r
library("dplyr")
##
## Attaching package: 'dplyr'
## The following objects are masked from 'package:stats':
##
##     filter, lag
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
gf.qsmk0.surv <- gf.qsmk0 %>% group_by(seqn) %>% mutate(surv0 = cumprod(p.noevent0))
gf.qsmk1.surv <- gf.qsmk1 %>% group_by(seqn) %>% mutate(surv1 = cumprod(p.noevent1))

gf.surv0 <-
  aggregate(gf.qsmk0.surv,
            by = list(gf.qsmk0.surv$time),
            FUN = mean)[c("qsmk", "time", "surv0")]
gf.surv1 <-
  aggregate(gf.qsmk1.surv,
            by = list(gf.qsmk1.surv$time),
            FUN = mean)[c("qsmk", "time", "surv1")]

gf.graph <- merge(gf.surv0, gf.surv1, by=c("time"))
gf.graph$survdiff <- gf.graph$surv1-gf.graph$surv0

# plot
ggplot(gf.graph, aes(x=time, y=surv)) +
  geom_line(aes(y = surv0, colour = "0")) +
  geom_line(aes(y = surv1, colour = "1")) +
  xlab("Months") +
  scale_x_continuous(limits = c(0, 120), breaks=seq(0,120,12)) +
  scale_y_continuous(limits=c(0.6, 1), breaks=seq(0.6, 1, 0.2)) +
  ylab("Survival") +
  ggtitle("Survival from g-formula") +
  labs(colour="A:") +
  theme_bw() +
  theme(legend.position="bottom")
```




## Program 17.5

- Estimating of median survival time ratio via a structural nested AFT model
- Data from NHEFS

```
# some preprocessing of the data
nhefs <- read_excel(here("data", "NHEFS.xls"))
nhefs$survtime <-
  ifelse(nhefs$death == 0, NA, (nhefs$yrdth - 83) * 12 + nhefs$modth)
  # * yrdth ranges from 83 to 92

# model to estimate E[A|L]
modelA <- glm(qsmk ~ sex + race + age + I(age*age)
              + as.factor(education) + smokeintensity
              + I(smokeintensity*smokeintensity) + smokeyrs
              + I(smokeyrs*smokeyrs) + as.factor(exercise)
              + as.factor(active) + wt71 + I(wt71*wt71),
              data=nhefs, family=binomial())

nhefs$p.qsmk <- predict(modelA, nhefs, type="response")
d <- nhefs[!is.na(nhefs$survtime),] # select only those with observed death time
n <- nrow(d)

# define the estimating function that needs to be minimized
sumeef <- function(psi){

  # creation of delta indicator
  if (psi>=0){
    delta <- ifelse(d$qsmk==0 |
                    (d$qsmk==1 & psi <= log(120/d$survtime)),
                  1, 0)
  } else if (psi < 0) {
```

```r
    delta <- ifelse(d$qsmk==1 |
                      (d$qsmk==0 & psi > log(d$survtime/120)), 1, 0)
  }

  smat <- delta*(d$qsmk-d$p.qsmk)
  sval <- sum(smat, na.rm=T)
  save <- sval/n
  smat <- smat - rep(save, n)

  # covariance
  sigma <- t(smat) %*% smat
  if (sigma == 0){
    sigma <- 1e-16
  }
  estimeq <- sval*solve(sigma)*t(sval)
  return(estimeq)
}

res <- optimize(sumeef, interval = c(-0.2,0.2))
psi1 <- res$minimum
objfunc <- as.numeric(res$objective)


# Use simple bisection method to find estimates of lower and upper 95% confidence bounds
increm <- 0.1
for_conf <- function(x){
  return(sumeef(x) - 3.84)
}

if (objfunc < 3.84){
  # Find estimate of where sumeef(x) > 3.84

  # Lower bound of 95% CI
  psilow <- psi1
  testlow <- objfunc
  countlow <- 0
  while (testlow < 3.84 & countlow < 100){
    psilow <- psilow - increm
    testlow <- sumeef(psilow)
    countlow <- countlow + 1
  }

  # Upper bound of 95% CI
  psihigh <- psi1
  testhigh <- objfunc
  counthigh <- 0
  while (testhigh < 3.84 & counthigh < 100){
    psihigh <- psihigh + increm
    testhigh <- sumeef(psihigh)
    counthigh <- counthigh + 1
  }
```

```
# Better estimate using bisection method
if ((testhigh > 3.84) & (testlow > 3.84)){

  # Bisection method
  left <- psi1
  fleft <- objfunc - 3.84
  right <- psihigh
  fright <- testhigh - 3.84
  middle <- (left  + right) / 2
  fmiddle <- for_conf(middle)
  count <- 0
  diff <- right - left

  while (!(abs(fmiddle) < 0.0001 | diff < 0.0001 | count > 100)){
    test <- fmiddle * fleft
    if (test < 0){
      right <- middle
      fright <- fmiddle
    } else {
      left <- middle
      fleft <- fmiddle
    }
    middle <- (left + right) / 2
    fmiddle <- for_conf(middle)
    count <- count + 1
    diff <- right - left
  }

  psi_high <- middle
  objfunc_high <- fmiddle + 3.84

  # lower bound of 95% CI
  left <- psilow
  fleft <- testlow - 3.84
  right <- psi1
  fright <- objfunc - 3.84
  middle <- (left + right) / 2
  fmiddle <- for_conf(middle)
  count <- 0
  diff <- right - left

  while(!(abs(fmiddle) < 0.0001 | diff < 0.0001 | count > 100)){
    test <- fmiddle * fleft
    if (test < 0){
      right <- middle
      fright <- fmiddle
    } else {
      left <- middle
      fleft <- fmiddle
    }
    middle <- (left + right) / 2
    fmiddle <- for_conf(middle)
```

```r
      diff <- right - left
      count <- count + 1
    }
    psi_low <- middle
    objfunc_low <- fmiddle + 3.84
    psi <- psi1
  }
}
c(psi, psi_low, psi_high)
## [1] -0.05041591 -0.22312099  0.33312901
```

# Session information: R

For reproducibility.

```
# install.packages("sessioninfo")
sessioninfo::session_info()
## - Session info ---------------------------------------------------------------
##  setting  value
##  version  R version 4.3.2 (2023-10-31 ucrt)
##  os       Windows 11 x64 (build 22621)
##  system   x86_64, mingw32
##  ui       RTerm
##  language (EN)
##  collate  English_United Kingdom.utf8
##  ctype    English_United Kingdom.utf8
##  tz       Europe/London
##  date     2023-11-01
##  pandoc   3.1.1 @ C:/Program Files/RStudio/resources/app/bin/quarto/bin/tools/ (via rmarkdown)
##
## - Packages -------------------------------------------------------------------
##  package     * version date (UTC) lib source
##  bookdown      0.36    2023-10-16 [1] CRAN (R 4.3.1)
##  cli           3.6.1   2023-03-23 [1] CRAN (R 4.3.0)
##  digest        0.6.33  2023-07-07 [1] CRAN (R 4.3.1)
##  evaluate      0.22    2023-09-29 [1] CRAN (R 4.3.1)
##  fastmap       1.1.1   2023-02-24 [1] CRAN (R 4.3.0)
##  htmltools     0.5.6.1 2023-10-06 [1] CRAN (R 4.3.1)
##  knitr         1.45    2023-10-30 [1] CRAN (R 4.3.1)
##  rlang         1.1.1   2023-04-28 [1] CRAN (R 4.3.0)
##  rmarkdown     2.25    2023-09-18 [1] CRAN (R 4.3.1)
##  rstudioapi    0.15.0  2023-07-07 [1] CRAN (R 4.3.1)
##  sessioninfo   1.2.2   2021-12-06 [1] CRAN (R 4.3.0)
##  xfun          0.40    2023-08-09 [1] CRAN (R 4.3.1)
##  yaml          2.3.7   2023-01-23 [1] CRAN (R 4.3.0)
##
##  [1] C:/Users/tom/AppData/Local/R/win-library/4.3
##  [2] C:/Program Files/R/R-4.3.2/library
##
## ------------------------------------------------------------------------------
```

# Stata code

# 11. Why model: Stata

```
library(Statamarkdown)
```

```
do dependency
```

```
checking extremes consistency and verifying not already installed...
all files already exist and are up to date.

checking tomata consistency and verifying not already installed...
all files already exist and are up to date.

end of do-file
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

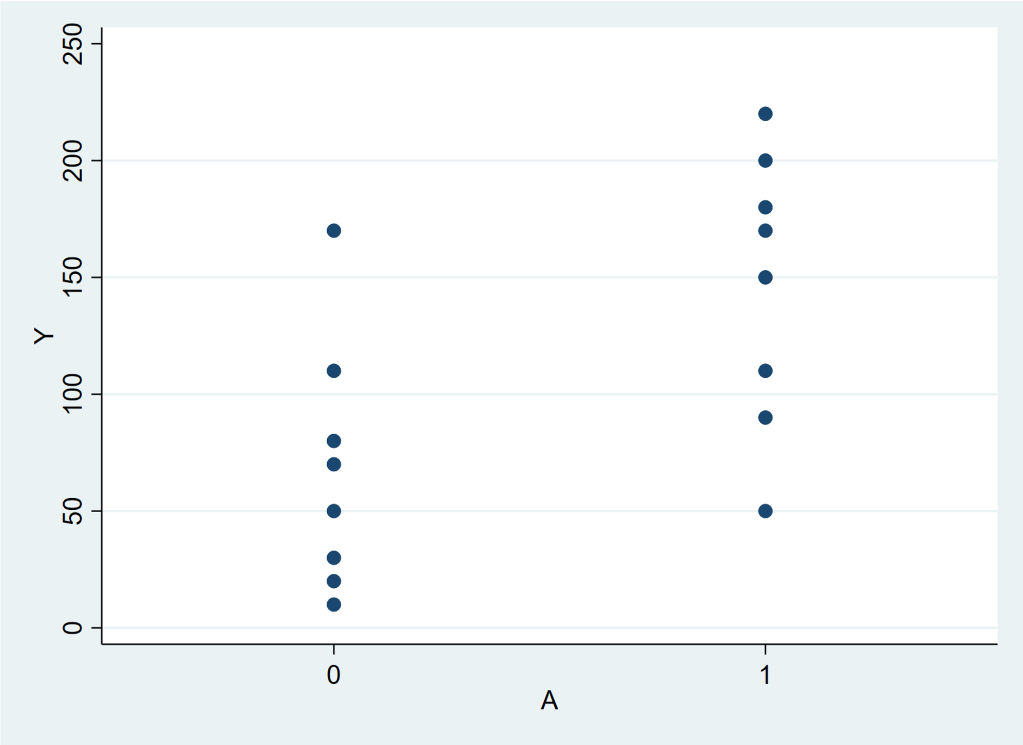
## Program 11.1

- Figures 11.1, 11.2, and 11.3
- Sample averages by treatment level

```
clear

**Figure 11.1**
*create the dataset*
input A Y
1 200
1 150
1 220
1 110
1 50
1 180
1 90
1 170
0 170
0 30
0 70
0 110
0 80
0 50
```

```
0 10
0 20
end

*Save the data*
qui save ./data/fig1, replace

*Build the scatterplot*
scatter Y A, ylab(0(50)250) xlab(0 1) xscale(range(-0.5 1.5))
qui gr export figs/stata-fig-11-1.png, replace

*Output the mean values for Y in each level of A*
bysort A: sum Y
```

```
              A           Y
  1. 1 200
  2. 1 150
  3. 1 220
  4. 1 110
  5. 1 50
  6. 1 180
  7. 1 90
  8. 1 170
  9. 0 170
 10. 0 30
 11. 0 70
 12. 0 110
 13. 0 80
 14. 0 50
 15. 0 10
 16. 0 20
 17. end




--------------------------------------------------------------------------------------
-> A = 0

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          8        67.5    53.11712         10        170

--------------------------------------------------------------------------------------
-> A = 1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          8      146.25     58.2942         50        220
```

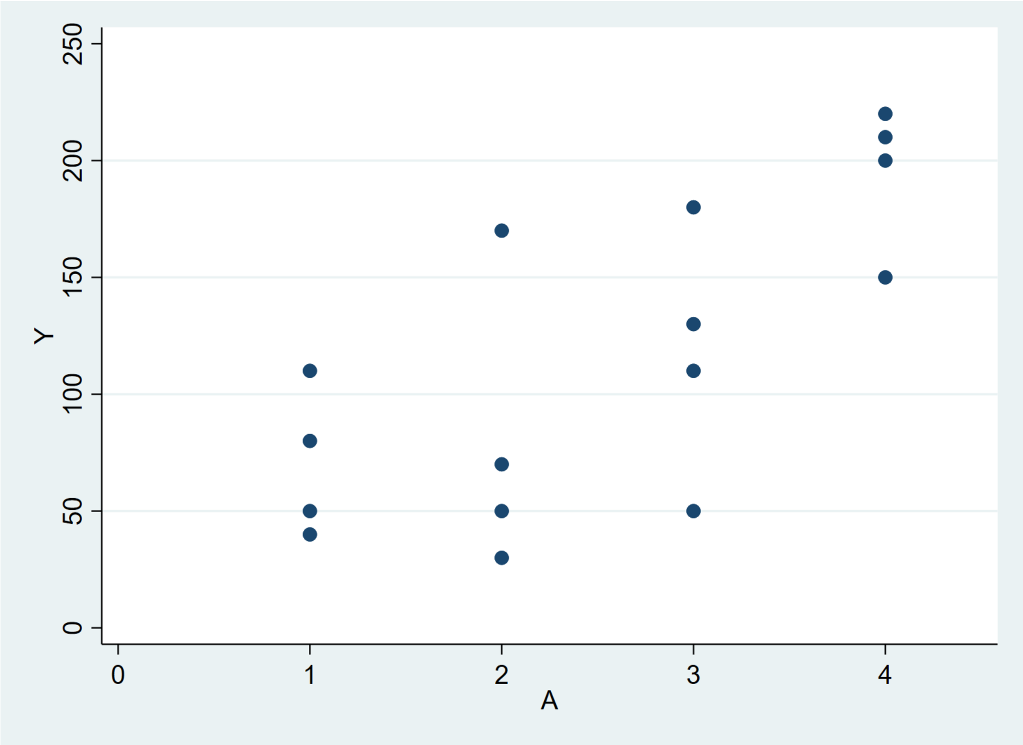



```
*Clear the workspace to be able to use a new dataset*
clear

**Figure 11.2**
input A Y
1 110
1 80
1 50
1 40
2 170
2 30
2 70
2 50
3 110
3 50
3 180
3 130
4 200
4 150
4 220
4 210
end

qui save ./data/fig2, replace

scatter Y A, ylab(0(50)250) xlab(0(1)4) xscale(range(0 4.5))
qui gr export figs/stata-fig-11-2.png, replace

bysort A: sum Y
```

A Y

```
  1. 1 110
  2. 1 80
  3. 1 50
  4. 1 40
  5. 2 170
  6. 2 30
  7. 2 70
  8. 2 50
  9. 3 110
 10. 3 50
 11. 3 180
 12. 3 130
 13. 4 200
 14. 4 150
 15. 4 220
 16. 4 210
 17. end
```

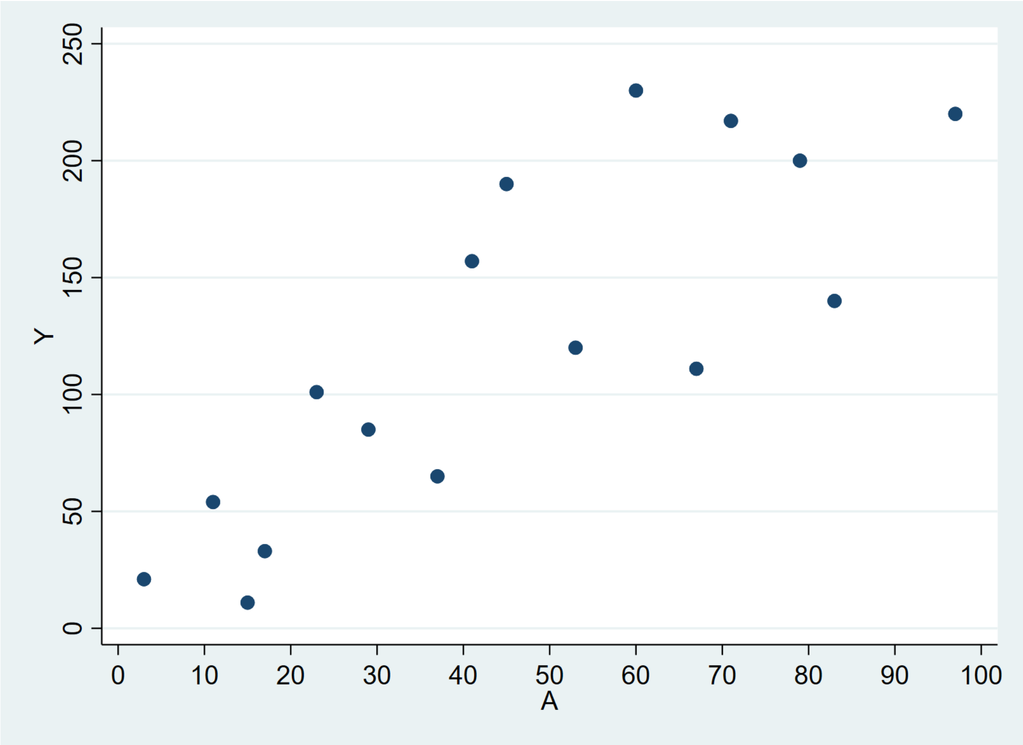
```
--------------------------------------------------------------------------------------
-> A = 1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          4          70    31.62278         40        110

--------------------------------------------------------------------------------------
-> A = 2

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          4          80    62.18253         30        170

--------------------------------------------------------------------------------------
-> A = 3

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          4       117.5    53.77422         50        180

--------------------------------------------------------------------------------------
-> A = 4

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           Y |          4         195    31.09126        150        220
```




```
clear

**Figure 11.3**
input A Y
3   21
11  54
17  33
23  101
29  85
37  65
41  157
53  120
67  111
79  200
83  140
97  220
60  230
71  217
15  11
45  190
end

qui save ./data/fig3, replace

scatter Y A, ylab(0(50)250) xlab(0(10)100) xscale(range(0 100))
qui gr export figs/stata-fig-11-3.png, replace
```

```
              A          Y
  1. 3    21
  2. 11       54
  3. 17       33
```

```
 4. 23       101
 5. 29       85
 6. 37       65
 7. 41       157
 8. 53       120
 9. 67       111
10. 79       200
11. 83       140
12. 97       220
13. 60       230
14. 71       217
15. 15       11
16. 45   190
17. end
```



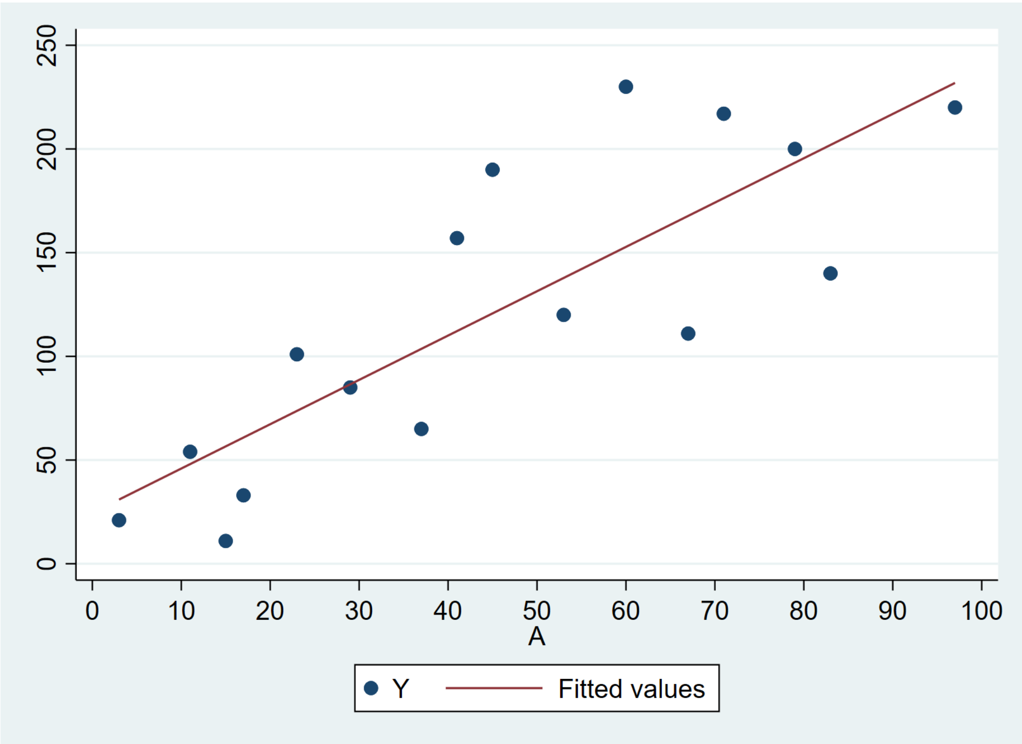

## Program 11.2

- 2-parameter linear model
- Creates Figure 11.4, parameter estimates with 95% confidence intervals from Section 11.2, and parameter estimates with 95% confidence intervals from Section 11.3

```
**Section 11.2: parametric estimators**
*Reload data
use ./data/fig3, clear

*Plot the data*
scatter Y A, ylab(0(50)250) xlab(0(10)100) xscale(range(0 100))

*Fit the regression model*
regress Y A, noheader cformat(%5.2f)
```

```
*Output the estimated mean Y value when A = 90*
lincom _b[_cons] + 90*_b[A]

*Plot the data with the regression line: Fig 11.4*
scatter Y A, ylab(0(50)250) xlab(0(10)100) xscale(range(0 100)) || lfit Y A
qui gr export figs/stata-fig-11-4.png, replace
```

```
           Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
           A |       2.14       0.40     5.35   0.000         1.28        2.99
       _cons |      24.55      21.33     1.15   0.269       -21.20       70.29
------------------------------------------------------------------------------


 ( 1)  90*A + _cons = 0

------------------------------------------------------------------------------
           Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         (1) |     216.89    20.8614    10.40   0.000     172.1468    261.6333
------------------------------------------------------------------------------
```




```
**Section 11.3: non-parametric estimation*
* Reload the data
use ./data/fig1, clear

*Fit the regression model*
regress Y A, noheader cformat(%5.2f)

*E[Y|A=1]*
di 67.50 + 78.75
```

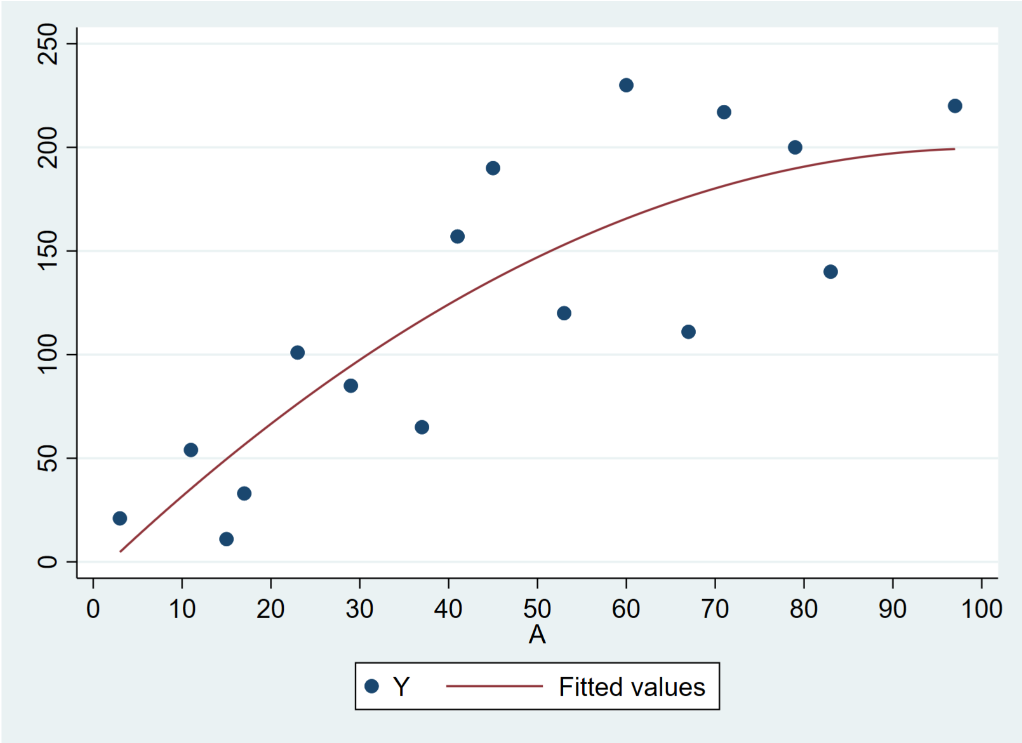
```
             Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
             A |      78.75      27.88     2.82   0.014        18.95      138.55
         _cons |      67.50      19.72     3.42   0.004        25.21      109.79
------------------------------------------------------------------------------

146.25
```

## Program 11.3

- 3-parameter linear model
- Creates Figure 11.5 and Parameter estimates for Section 11.4

```
* Reload the data
use ./data/fig3, clear

*Create the product term*
gen Asq = A*A

*Fit the regression model*
regress Y A Asq, noheader cformat(%5.2f)

*Output the estimated mean Y value when A = 90*
lincom _b[_cons] + 90*_b[A] + 90*90*_b[Asq]

*Plot the data with the regression line: Fig 11.5*
scatter Y A, ylab(0(50)250) xlab(0(10)100) xscale(range(0 100)) || qfit Y A
qui gr export figs/stata-fig-11-5.png, replace
```

```
             Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
             A |       4.11       1.53     2.68   0.019         0.80        7.41
           Asq |      -0.02       0.02    -1.33   0.206        -0.05        0.01
         _cons |      -7.41      31.75    -0.23   0.819       -75.99       61.18
------------------------------------------------------------------------------


 ( 1)  90*A + 8100*Asq + _cons = 0

------------------------------------------------------------------------------
             Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
           (1) |   197.1269   25.16157     7.83   0.000     142.7687    251.4852
------------------------------------------------------------------------------
```


250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
A
Y
Fitted values

# 12. IP Weighting and Marginal Structural Models: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

## Program 12.1

- Descriptive statistics from NHEFS data (Table 12.1)

```
use ./data/nhefs, clear

/*Provisionally ignore subjects with missing values for follow-up weight*/
/*Sample size after exclusion: N = 1566*/
drop if wt82==.

/* Calculate mean weight change in those with and without smoking cessation*/
label define qsmk 0 "No smoking cessation" 1 "Smoking cessation"
label values qsmk qsmk
by qsmk, sort: egen years = mean(age) if age < .
label var years "Age, years"
by qsmk, sort: egen male = mean(100 * (sex==0)) if sex < .
label var male "Men, %"
by qsmk, sort: egen white = mean(100 * (race==0)) if race < .
label var white "White, %"
by qsmk, sort: egen university = mean(100 * (education == 5)) if education < .
label var university "University, %"
by qsmk, sort: egen kg = mean(wt71) if wt71 < .
label var kg "Weight, kg"
by qsmk, sort: egen cigs = mean(smokeintensity) if smokeintensity < .
label var cigs "Cigarettes/day"
by qsmk, sort: egen meansmkyrs = mean(smokeyrs) if smokeyrs < .
label var kg "Years smoking"
by qsmk, sort: egen noexer = mean(100 * (exercise == 2)) if exercise < .
label var noexer "Little/no exercise"
by qsmk, sort: egen inactive = mean(100 * (active==2)) if active < .
```

```
label var inactive "Inactive daily life"
qui save ./data/nhefs-formatted, replace
```

```
(63 observations deleted)
```

```
use ./data/nhefs-formatted, clear

/*Output table*/
foreach var of varlist years male  white university kg cigs meansmkyrs noexer inactive {
  tabdisp qsmk, cell(`var') format(%3.1f)
}
```

```
  2.   tabdisp qsmk, cell(`var') format(%3.1f)
  3. }

---------------------------------
quit smoking between |
baseline and 1982    | Age, years
---------------------+-----------
No smoking cessation |       42.8
   Smoking cessation |       46.2
---------------------------------


---------------------------------
quit smoking between |
baseline and 1982    |     Men, %
---------------------+-----------
No smoking cessation |       46.6
   Smoking cessation |       54.6
---------------------------------


---------------------------------
quit smoking between |
baseline and 1982    |   White, %
---------------------+-----------
No smoking cessation |       85.4
   Smoking cessation |       91.1
---------------------------------


------------------------------------
quit smoking between |
baseline and 1982    | University, %
---------------------+--------------
No smoking cessation |           9.9
   Smoking cessation |          15.4
------------------------------------


------------------------------------
quit smoking between |
baseline and 1982    | Years smoking
---------------------+--------------
No smoking cessation |          70.3
   Smoking cessation |          72.4
------------------------------------
```

```
-------------------------------------
quit smoking between |
baseline and 1982    | Cigarettes/day
---------------------+---------------
No smoking cessation |           21.2
   Smoking cessation |           18.6
-------------------------------------

---------------------------------
quit smoking between |
baseline and 1982    | meansmkyrs
---------------------+-----------
No smoking cessation |       24.1
   Smoking cessation |       26.0
---------------------------------

-----------------------------------------
quit smoking between |
baseline and 1982    | Little/no exercise
---------------------+-------------------
No smoking cessation |               37.9
   Smoking cessation |               40.7
-----------------------------------------

------------------------------------------
quit smoking between |
baseline and 1982    | Inactive daily life
---------------------+--------------------
No smoking cessation |                 8.9
   Smoking cessation |                11.2
------------------------------------------
```

## Program 12.2

- Estimating IP weights for Section 12.2
- Data from NHEFS

```
use ./data/nhefs-formatted, clear

/*Fit a logistic model for the IP weights*/
logit qsmk sex race c.age##c.age ib(last).education c.smokeintensity##c.smokeintensity ///
c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active c.wt71##c.wt71

/*Output predicted conditional probability of quitting smoking for each individual*/
predict p_qsmk, pr

/*Generate nonstabilized weights as P(A=1|covariates) if A = 1 and */
/* 1-P(A=1|covariates) if A = 0*/
gen w=.
replace w=1/p_qsmk if qsmk==1
replace w=1/(1-p_qsmk) if qsmk==0
/*Check the mean of the weights; we expect it to be close to 2.0*/
```

```
summarize w

/*Fit marginal structural model in the pseudopopulation*/
/*Weights assigned using pweight = w*/
/*Robust standard errors using cluster() option where 'seqn' is the ID variable*/
regress wt82_71 qsmk [pweight=w], cluster(seqn)
```

```
Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
            qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-----------------+------------------------------------------------------------------
             sex |  -.5274782   .1540497    -3.42   0.001      -.82941   -.2255463
            race |  -.8392636   .2100668    -4.00   0.000    -1.250987   -.4275404
             age |   .1212052   .0512663     2.36   0.018     .0207251    .2216853
                 |
     c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753    .0002262
                 |
       education |
              1  |  -.4759606   .2262238    -2.10   0.035    -.9193511   -.0325701
              2  |  -.5047361    .217597    -2.32   0.020    -.9312184   -.0782538
              3  |  -.3895288   .1914353    -2.03   0.042    -.7647351   -.0143226
              4  |  -.4123596   .2772868    -1.49   0.137    -.9558318    .1311126
                 |
  smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                 |
c.smokeintensity#|
c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                 |
        smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                 |
     c.smokeyrs#|
      c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
                 |
        exercise |
              0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
              1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
                 |
          active |
              0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
              1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
                 |
            wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
                 |
```

```
    c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
                  |
            _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------


(1,566 missing values generated)

(403 real changes made)

(1,163 real changes made)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           w |      1,566    1.996284    1.474787   1.053742   16.70009

(sum of wgt is 3,126.18084549904)

Linear regression                               Number of obs     =      1,566
                                                F(1, 1565)        =      42.81
                                                Prob > F          =     0.0000
                                                R-squared         =     0.0435
                                                Root MSE          =     8.0713

                               (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------
             |               Robust
     wt82_71 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   3.440535   .5258294     6.54   0.000     2.409131     4.47194
       _cons |   1.779978   .2248742     7.92   0.000     1.338892    2.221065
------------------------------------------------------------------------------
```

## Program 12.3

- Estimating stabilized IP weights for Section 12.3
- Data from NHEFS

```
use ./data/nhefs-formatted, clear

/*Fit a logistic model for the denominator of the IP weights and predict the */
/* conditional probability of smoking */
logit qsmk sex race c.age##c.age ib(last).education c.smokeintensity##c.smokeintensity ///
c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active c.wt71##c.wt71
predict pd_qsmk, pr

/*Fit a logistic model for the numerator of ip weights and predict Pr(A=1) */
logit qsmk
predict pn_qsmk, pr

/*Generate stabilized weights as f(A)/f(A|L)*/
gen sw_a=.
replace sw_a=pn_qsmk/pd_qsmk if qsmk==1
```

```
replace sw_a=(1-pn_qsmk)/(1-pd_qsmk) if qsmk==0

/*Check distribution of the stabilized weights*/
summarize sw_a

/*Fit marginal structural model in the pseudopopulation*/
regress wt82_71 qsmk [pweight=sw_a], cluster(seqn)

/**********************************************************
FINE POINT 12.2
Checking positivity
**********************************************************/

/*Check for missing values within strata of covariates, for example: */
tab age qsmk if race==0 & sex==1 & wt82!=.
tab age qsmk if race==1 & sex==1 & wt82!=.
```

```
Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
             qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+-----------------------------------------------------------------
              sex |  -.5274782   .1540497    -3.42   0.001      -.82941   -.2255463
             race |  -.8392636   .2100668    -4.00   0.000    -1.250987   -.4275404
              age |   .1212052   .0512663     2.36   0.018     .0207251    .2216853
                  |
      c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753    .0002262
                  |
        education |
               1  |  -.4759606   .2262238    -2.10   0.035    -.9193511   -.0325701
               2  |  -.5047361    .217597    -2.32   0.020    -.9312184   -.0782538
               3  |  -.3895288   .1914353    -2.03   0.042    -.7647351   -.0143226
               4  |  -.4123596   .2772868    -1.49   0.137    -.9558318    .1311126
                  |
   smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                  |
         smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                  |
       c.smokeyrs#|
       c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
                  |
```

```
    exercise |
          0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
          1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
             |
      active |
          0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
          1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
             |
        wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
             |
c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
             |
       _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------


Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -893.02712

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(0)    =   0.00
                                                        Prob > chi2   =      .
Log likelihood = -893.02712                             Pseudo R2     = 0.0000

------------------------------------------------------------------------------
        qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       _cons |  -1.059822   .0578034   -18.33   0.000    -1.173114    -.946529
------------------------------------------------------------------------------


(1,566 missing values generated)

(403 real changes made)

(1,163 real changes made)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        sw_a |      1,566    .9988444    .2882233   .3312489   4.297662

(sum of wgt is 1,564.19025221467)

Linear regression                               Number of obs     =      1,566
                                                F(1, 1565)        =      42.81
                                                Prob > F          =     0.0000
                                                R-squared         =     0.0359
                                                Root MSE          =     7.7972

                               (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------
             |               Robust
```

```
    wt82_71 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   3.440535   .5258294     6.54   0.000     2.409131     4.47194
       _cons |   1.779978   .2248742     7.92   0.000     1.338892    2.221065
------------------------------------------------------------------------------

           | quit smoking between
           |   baseline and 1982
       age | No smokin  Smoking c |     Total
-----------+----------------------+----------
        25 |        24          3 |        27 
        26 |        14          5 |        19 
        27 |        18          2 |        20 
        28 |        20          5 |        25 
        29 |        15          4 |        19 
        30 |        14          5 |        19 
        31 |        11          5 |        16 
        32 |        14          7 |        21 
        33 |        12          3 |        15 
        34 |        22          5 |        27 
        35 |        16          5 |        21 
        36 |        13          3 |        16 
        37 |        14          1 |        15 
        38 |         6          2 |         8 
        39 |        19          4 |        23 
        40 |        10          4 |        14 
        41 |        13          3 |        16 
        42 |        16          3 |        19 
        43 |        14          3 |        17 
        44 |         9          4 |        13 
        45 |        12          5 |        17 
        46 |        19          4 |        23 
        47 |        19          4 |        23 
        48 |        19          4 |        23 
        49 |        11          3 |        14 
        50 |        18          4 |        22 
        51 |         9          3 |        12 
        52 |        11          3 |        14 
        53 |        11          4 |        15 
        54 |        17          9 |        26 
        55 |         9          4 |        13 
        56 |         8          7 |        15 
        57 |         9          2 |        11 
        58 |         8          4 |        12 
        59 |         5          4 |         9 
        60 |         5          4 |         9 
        61 |         5          2 |         7 
        62 |         6          5 |        11 
        63 |         3          3 |         6 
        64 |         7          1 |         8 
        65 |         3          2 |         5 
        66 |         4          0 |         4 
        67 |         2          0 |         2 
```

```
        69 |         6          2 |         8 
        70 |         2          1 |         3 
        71 |         0          1 |         1 
        72 |         2          2 |         4 
        74 |         0          1 |         1 
-----------+----------------------+----------
     Total |       524        164 |       688 

           | quit smoking between 
           |   baseline and 1982
       age | No smokin  Smoking c |     Total
-----------+----------------------+----------
        25 |         3          1 |         4 
        26 |         3          0 |         3 
        28 |         3          1 |         4 
        29 |         1          0 |         1 
        30 |         4          0 |         4 
        31 |         3          0 |         3 
        32 |         8          0 |         8 
        33 |         2          0 |         2 
        34 |         2          1 |         3 
        35 |         3          0 |         3 
        36 |         5          0 |         5 
        37 |         3          1 |         4 
        38 |         4          2 |         6 
        39 |         1          1 |         2 
        40 |         2          2 |         4 
        41 |         3          0 |         3 
        42 |         3          0 |         3 
        43 |         4          2 |         6 
        44 |         3          0 |         3 
        45 |         1          3 |         4 
        46 |         5          0 |         5 
        47 |         3          0 |         3 
        48 |         4          0 |         4 
        49 |         1          1 |         2 
        50 |         2          0 |         2 
        51 |         4          0 |         4 
        52 |         1          0 |         1 
        53 |         2          0 |         2 
        54 |         2          0 |         2 
        55 |         3          0 |         3 
        56 |         2          1 |         3 
        57 |         2          1 |         3 
        61 |         1          1 |         2 
        67 |         1          0 |         1 
        68 |         1          0 |         1 
        69 |         2          0 |         2 
        70 |         0          1 |         1 
-----------+----------------------+----------
     Total |        97         19 |       116 
```

## Program 12.4

- Estimating the parameters of a marginal structural mean model with a continuous treatment Data from NHEFS
- Section 12.4

```
use ./data/nhefs-formatted, clear

* drop sw_a

/*Analysis restricted to subjects reporting <=25 cig/day at baseline: N = 1162*/
keep if smokeintensity <=25

/*Fit a linear model for the denominator of the IP weights and calculate the */
/* mean expected smoking intensity*/
regress smkintensity82_71 sex race c.age##c.age ib(last).education ///
c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
ib(last).exercise ib(last).active c.wt71##c.wt71
quietly predict p_den

/*Generate the denisty of the denomiator expectation using the mean expected */
/* smoking intensity and the residuals, assuming a normal distribution*/
/*Note: The regress command in Stata saves the root mean squared error for the */
/* immediate regression as e(rmse), thus there is no need to calculate it again. */
gen dens_den = normalden(smkintensity82_71, p_den, e(rmse))

/*Fit a linear model for the numerator of ip weights, calculate the mean */
/* expected value, and generate the density*/
quietly regress smkintensity82_71
quietly predict p_num
gen dens_num = normalden( smkintensity82_71, p_num, e(rmse))

/*Generate the final stabilized weights from the estimated numerator and */
/* denominator, and check the weights distribution*/
gen sw_a=dens_num/dens_den
summarize sw_a

/*Fit a marginal structural model in the pseudopopulation*/
regress wt82_71  c.smkintensity82_71##c.smkintensity82_71 [pweight=sw_a], cluster(seqn)

/*Output the estimated mean Y value when smoke intensity is unchanged from */
/* baseline to 1982 */
lincom _b[_cons]

/*Output the estimated mean Y value when smoke intensity increases by 20 from */
/* baseline to 1982*/
lincom _b[_cons] + 20*_b[smkintensity82_71 ] + ///
  400*_b[c.smkintensity82_71#c.smkintensity82_71]
```

```
(404 observations deleted)

      Source |       SS           df       MS      Number of obs   =     1,162
-------------+----------------------------------   F(18, 1143)     =      5.39
       Model |  9956.95654        18  553.164252   Prob > F        =    0.0000
```

```
    Residual |   117260.18     1,143  102.589834   R-squared       =    0.0783
-------------+----------------------------------   Adj R-squared   =    0.0638
       Total |  127217.137     1,161  109.575484   Root MSE        =    10.129

------------------------------------------------------------------------------------
smkintensity82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
------------------+-----------------------------------------------------------------
              sex |   1.087021   .7425694     1.46   0.144    -.3699308    2.543973
             race |   .2319789   .8434739     0.28   0.783    -1.422952     1.88691
              age |  -.8099902   .2555388    -3.17   0.002    -1.311368   -.3086124
                  |
      c.age#c.age |   .0066545   .0026849     2.48   0.013     .0013865    .0119224
                  |
        education |
               1  |   1.508097   1.184063     1.27   0.203    -.8150843    3.831278
               2  |    2.02692   1.133772     1.79   0.074    -.1975876    4.251428
               3  |   2.240314   1.022556     2.19   0.029     .2340167    4.246611
               4  |   2.528767    1.44702     1.75   0.081    -.3103458     5.36788
                  |
   smokeintensity |  -.3589684   .2246653    -1.60   0.110     -.799771    .0818342
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0019582   .0085753     0.23   0.819    -.0148668    .0187832
                  |
         smokeyrs |   .3857088   .1416765     2.72   0.007     .1077336    .6636841
                  |
       c.smokeyrs#|
       c.smokeyrs |  -.0054871   .0023837    -2.30   0.022    -.0101641   -.0008101
                  |
         exercise |
               0  |   1.996904   .9080421     2.20   0.028      .215288    3.778521
               1  |    .988812   .6929239     1.43   0.154    -.3707334    2.348357
                  |
           active |
               0  |   .8451341   1.098573     0.77   0.442    -1.310312    3.000581
               1  |    .800114    1.08438     0.74   0.461    -1.327485    2.927712
                  |
             wt71 |  -.0656882    .136955    -0.48   0.632    -.3343996    .2030232
                  |
    c.wt71#c.wt71 |   .0005711    .000877     0.65   0.515    -.0011496    .0022918
                  |
            _cons |   16.86761   7.109189     2.37   0.018      2.91909    30.81614
------------------------------------------------------------------------------------

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        sw_a |      1,162    .9968057    .3222937   .1938336   5.102339

(sum of wgt is 1,158.28818286955)

Linear regression                               Number of obs     =      1,162
                                                F(2, 1161)        =      12.75
                                                Prob > F          =     0.0000
```

```
                                                R-squared         =     0.0233
                                                Root MSE          =     7.7864

                                     (Std. err. adjusted for 1,162 clusters in seqn)
------------------------------------------------------------------------------------
                    |               Robust
             wt82_71 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
--------------------+---------------------------------------------------------------
  smkintensity82_71 |  -.1089889   .0315762    -3.45   0.001    -.1709417   -.0470361
                    |
                 c. |
  smkintensity82_71#|
c.smkintensity82_71 |   .0026949   .0024203     1.11   0.266    -.0020537    .0074436
                    |
              _cons |   2.004525    .295502     6.78   0.000     1.424747    2.584302
------------------------------------------------------------------------------------


 ( 1)  _cons = 0

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         (1) |   2.004525    .295502     6.78   0.000     1.424747    2.584302
------------------------------------------------------------------------------


 ( 1)  20*smkintensity82_71 + 400*c.smkintensity82_71#c.smkintensity82_71 + _cons = 0

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         (1) |   .9027234   1.310533     0.69   0.491    -1.668554    3.474001
------------------------------------------------------------------------------
```

# Program 12.5

- Estimating the parameters of a marginal structural logistic model
- Data from NHEFS
- Section 12.4

```
use ./data/nhefs, clear

/*Provisionally ignore subjects with missing values for follow-up weight*/
/*Sample size after exclusion: N = 1566*/
drop if wt82==.

/*Estimate the stabilized weights for quitting smoking as in PROGRAM 12.3*/
/*Fit a logistic model for the denominator of the IP weights and predict the */
/* conditional probability of smoking*/
logit qsmk sex race c.age##c.age ib(last).education c.smokeintensity##c.smokeintensity ///
c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active c.wt71##c.wt71
predict pd_qsmk, pr
```

```
/*Fit a logistic model for the numerator of ip weights and predict Pr(A=1) */
logit qsmk
predict pn_qsmk, pr
/*Generate stabilized weights as f(A)/f(A|L)*/
gen sw_a=.
replace sw_a=pn_qsmk/pd_qsmk if qsmk==1
replace sw_a=(1-pn_qsmk)/(1-pd_qsmk) if qsmk==0
summarize sw_a

/*Fit marginal structural model in the pseudopopulation*/
/*NOTE: Stata has two commands for logistic regression, logit and logistic*/
/*Using logistic allows us to output the odds ratios directly*/
/*We can also output odds ratios from the logit command using the or option */
/* (default logit output is regression coefficients*/
logistic death qsmk [pweight=sw_a], cluster(seqn)
```

```
(63 observations deleted)


Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
             qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+-----------------------------------------------------------------
              sex |  -.5274782   .1540497    -3.42   0.001      -.82941   -.2255463
             race |  -.8392636   .2100668    -4.00   0.000    -1.250987   -.4275404
              age |   .1212052   .0512663     2.36   0.018     .0207251    .2216853
                  |
      c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753    .0002262
                  |
        education |
               1  |  -.4759606   .2262238    -2.10   0.035    -.9193511   -.0325701
               2  |  -.5047361    .217597    -2.32   0.020    -.9312184   -.0782538
               3  |  -.3895288   .1914353    -2.03   0.042    -.7647351   -.0143226
               4  |  -.4123596   .2772868    -1.49   0.137    -.9558318    .1311126
                  |
   smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                  |
         smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                  |
       c.smokeyrs#|
```

```
  c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
             |
    exercise |
          0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
          1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
             |
      active |
          0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
          1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
             |
        wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
             |
c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
             |
       _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------


Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -893.02712

Logistic regression                                     Number of obs =   1,566
                                                        LR chi2(0)    =   -0.00
                                                        Prob > chi2   =       .
Log likelihood = -893.02712                             Pseudo R2     = -0.0000

------------------------------------------------------------------------------
        qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       _cons |  -1.059822   .0578034   -18.33   0.000    -1.173114    -.946529
------------------------------------------------------------------------------


(1,566 missing values generated)

(403 real changes made)

(1,163 real changes made)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        sw_a |      1,566    .9988444    .2882233   .3312489   4.297662


Logistic regression                                     Number of obs =  1,566
                                                        Wald chi2(1)  =   0.04
                                                        Prob > chi2   = 0.8482
Log pseudolikelihood = -749.11596                       Pseudo R2     = 0.0000

                               (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------
             |               Robust
```

```
       death | Odds ratio   std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   1.030578   .1621842     0.19   0.848     .7570517    1.402931
       _cons |   .2252711   .0177882   -18.88   0.000     .1929707    .2629781
------------------------------------------------------------------------------
Note: _cons estimates baseline odds.
```

# Program 12.6

- Assessing effect modification by sex using a marginal structural mean model
- Data from NHEFS
- Section 12.5

```
use ./data/nhefs, clear

* drop pd_qsmk pn_qsmk sw_a

/*Check distribution of sex*/
tab sex

/*Fit logistc model for the denominator of IP weights, as in PROGRAM 12.3 */
logit qsmk sex race c.age##c.age ib(last).education c.smokeintensity##c.smokeintensity ///
c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active c.wt71##c.wt71
predict pd_qsmk, pr

/*Fit logistic model for the numerator of IP weights, no including sex */
logit qsmk sex
predict pn_qsmk, pr

/*Generate IP weights as before*/
gen sw_a=.
replace sw_a=pn_qsmk/pd_qsmk if qsmk==1
replace sw_a=(1-pn_qsmk)/(1-pd_qsmk) if qsmk==0

summarize sw_a

/*Fit marginal structural model in the pseudopopulation, including interaction */
/* term between quitting smoking and sex*/
regress wt82_71 qsmk##sex [pw=sw_a], cluster(seqn)
```

```
        sex |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |        799       49.05       49.05
          1 |        830       50.95      100.00
------------+-----------------------------------
      Total |      1,629      100.00


Iteration 0:   log likelihood = -938.14308
Iteration 1:   log likelihood = -884.53806
Iteration 2:   log likelihood = -883.35064
Iteration 3:   log likelihood = -883.34876
Iteration 4:   log likelihood = -883.34876
```

```
Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(18)   = 109.59
                                                        Prob > chi2   = 0.0000
Log likelihood = -883.34876                             Pseudo R2     = 0.0584

-----------------------------------------------------------------------------------
             qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+----------------------------------------------------------------
              sex |  -.5075218   .1482316    -3.42   0.001    -.7980505   -.2169932
             race |  -.8502312   .2058722    -4.13   0.000    -1.253733   -.4467292
              age |   .1030132   .0488996     2.11   0.035     .0071718    .1988547
                  |
      c.age#c.age |  -.0006052   .0005074    -1.19   0.233    -.0015998    .0003893
                  |
        education |
               1  |  -.3796632   .2203948    -1.72   0.085     -.811629    .0523026
               2  |  -.4779835   .2141771    -2.23   0.026    -.8977629   -.0582041
               3  |  -.3639645   .1885776    -1.93   0.054    -.7335698    .0056409
               4  |  -.4221892   .2717235    -1.55   0.120    -.9547574     .110379
                  |
   smokeintensity |  -.0651561   .0147589    -4.41   0.000    -.0940831   -.0362292
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0008461   .0002758     3.07   0.002     .0003054    .0013867
                  |
         smokeyrs |  -.0733708   .0269958    -2.72   0.007    -.1262816     -.02046
                  |
      c.smokeyrs#|
       c.smokeyrs |   .0008384   .0004435     1.89   0.059    -.0000307    .0017076
                  |
         exercise |
               0  |  -.3550517   .1799293    -1.97   0.048    -.7077067   -.0023967
               1  |    -.06364   .1351256    -0.47   0.638    -.3284812    .2012013
                  |
           active |
               0  |  -.0683123   .2087269    -0.33   0.743    -.4774095    .3407849
               1  |   -.057437   .2039967    -0.28   0.778    -.4572632    .3423892
                  |
             wt71 |  -.0128478   .0222829    -0.58   0.564    -.0565214    .0308258
                  |
    c.wt71#c.wt71 |   .0001209   .0001352     0.89   0.371     -.000144    .0003859
                  |
            _cons |  -1.185875   1.263142    -0.94   0.348    -3.661588    1.289838
-----------------------------------------------------------------------------------


Iteration 0:   log likelihood = -938.14308
Iteration 1:   log likelihood = -933.49896
Iteration 2:   log likelihood = -933.49126
Iteration 3:   log likelihood = -933.49126
```

```
Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(1)    =   9.30
                                                        Prob > chi2   = 0.0023
Log likelihood = -933.49126                             Pseudo R2     = 0.0050

------------------------------------------------------------------------------
        qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         sex |  -.3441893   .1131341    -3.04   0.002     -.565928   -.1224506
       _cons |  -.8634417   .0774517   -11.15   0.000    -1.015244   -.7116391
------------------------------------------------------------------------------


(1,629 missing values generated)

(428 real changes made)

(1,201 real changes made)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        sw_a |      1,629    .9991318    .2636164   .2901148   3.683352

(sum of wgt is 1,562.01032829285)

Linear regression                               Number of obs     =      1,566
                                                F(3, 1565)        =      16.31
                                                Prob > F          =     0.0000
                                                R-squared         =     0.0379
                                                Root MSE          =     7.8024

                               (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------
             |               Robust
     wt82_71 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
      1.qsmk |    3.60623   .6576053     5.48   0.000      2.31635     4.89611
       1.sex |  -.0040025   .4496206    -0.01   0.993    -.8859246    .8779197
             |
    qsmk#sex |
        1 1  |   -.161224   1.036143    -0.16   0.876      -2.1936    1.871152
             |
       _cons |   1.759045   .3102511     5.67   0.000     1.150494    2.367597
------------------------------------------------------------------------------
```

# Program 12.7

- Estimating IP weights to adjust for selection bias due to censoring
- Data from NHEFS
- Section 12.6

```
use ./data/nhefs, clear
```

```
/*Analysis including all individuals regardless of missing wt82 status: N=1629*/
/*Generate censoring indicator: C = 1 if wt82 missing*/
gen byte cens = (wt82 == .)

/*Check distribution of censoring by quitting smoking and baseline weight*/
tab cens qsmk, column
bys cens: summarize wt71

/*Fit logistic regression model for the  denominator of IP weight for A*/
logit qsmk sex race c.age##c.age ib(last).education c.smokeintensity##c.smokeintensity ///
c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active c.wt71##c.wt71
predict pd_qsmk, pr

/*Fit logistic regression model for the numerator of IP weights for A*/
logit qsmk
predict pn_qsmk, pr

/*Fit logistic regression model for the denominator of IP weights for C, */
/* including quitting smoking*/
logit cens qsmk sex race c.age##c.age ib(last).education ///
c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ib(last).exercise ///
ib(last).active c.wt71##c.wt71
predict pd_cens, pr

/*Fit logistic regression model for the  numerator of IP weights for C, */
/* including quitting smoking */
logit cens qsmk
predict pn_cens, pr

/*Generate the stabilized weights for A (sw_a)*/
gen sw_a=.
replace sw_a=pn_qsmk/pd_qsmk if qsmk==1
replace sw_a=(1-pn_qsmk)/(1-pd_qsmk) if qsmk==0

/*Generate the stabilized weights for C (sw_c)*/
/*NOTE: the conditional probability estimates generated by our logistic models */
/* for C represent the conditional probability of being censored (C=1)*/
/*We want weights for the conditional probability of bing uncensored, Pr(C=0|A,L)*/
gen sw_c=.
replace sw_c=(1-pn_cens)/(1-pd_cens) if cens==0

/*Generate the final stabilized weights and check distribution*/
gen sw=sw_a*sw_c
summarize sw

/*Fit marginal structural model in the pseudopopulation*/
regress wt82_71 qsmk [pw=sw], cluster(seqn)
```

```
| Key               |
|-------------------|
|     frequency     |
| column percentage |
+-------------------+
```

```
           | quit smoking between
           |   baseline and 1982
      cens |         0          1 |     Total
-----------+----------------------+----------
         0 |     1,163        403 |     1,566 
           |     96.84      94.16 |     96.13 
-----------+----------------------+----------
         1 |        38         25 |        63 
           |      3.16       5.84 |      3.87 
-----------+----------------------+----------
     Total |     1,201        428 |     1,629 
           |    100.00     100.00 |    100.00 


-------------------------------------------------------------------------------------
-> cens = 0

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        wt71 |      1,566    70.83092     15.3149      39.58     151.73

-------------------------------------------------------------------------------------
-> cens = 1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        wt71 |         63    76.55079     23.3326      36.17     169.19



Iteration 0:   log likelihood = -938.14308  
Iteration 1:   log likelihood = -884.53806  
Iteration 2:   log likelihood = -883.35064  
Iteration 3:   log likelihood = -883.34876  
Iteration 4:   log likelihood = -883.34876  

Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(18)   = 109.59
                                                        Prob > chi2   = 0.0000
Log likelihood = -883.34876                             Pseudo R2     = 0.0584

-----------------------------------------------------------------------------------
             qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+----------------------------------------------------------------
              sex |  -.5075218   .1482316    -3.42   0.001    -.7980505   -.2169932
             race |  -.8502312   .2058722    -4.13   0.000    -1.253733   -.4467292
              age |   .1030132   .0488996     2.11   0.035     .0071718    .1988547
                  |
      c.age#c.age |  -.0006052   .0005074    -1.19   0.233    -.0015998    .0003893
                  |
        education |
               1  |  -.3796632   .2203948    -1.72   0.085     -.811629    .0523026
```

```
              2  |  -.4779835   .2141771    -2.23   0.026    -.8977629   -.0582041
              3  |  -.3639645   .1885776    -1.93   0.054    -.7335698    .0056409
              4  |  -.4221892   .2717235    -1.55   0.120    -.9547574     .110379
                 |
  smokeintensity |  -.0651561   .0147589    -4.41   0.000    -.0940831   -.0362292
                 |
c.smokeintensity#|
c.smokeintensity |   .0008461   .0002758     3.07   0.002     .0003054    .0013867
                 |
        smokeyrs |  -.0733708   .0269958    -2.72   0.007    -.1262816     -.02046
                 |
      c.smokeyrs#|
      c.smokeyrs |   .0008384   .0004435     1.89   0.059    -.0000307    .0017076
                 |
        exercise |
              0  |  -.3550517   .1799293    -1.97   0.048    -.7077067   -.0023967
              1  |    -.06364   .1351256    -0.47   0.638    -.3284812    .2012013
                 |
          active |
              0  |  -.0683123   .2087269    -0.33   0.743    -.4774095    .3407849
              1  |   -.057437   .2039967    -0.28   0.778    -.4572632    .3423892
                 |
            wt71 |  -.0128478   .0222829    -0.58   0.564    -.0565214    .0308258
                 |
   c.wt71#c.wt71 |   .0001209   .0001352     0.89   0.371     -.000144    .0003859
                 |
           _cons |  -1.185875   1.263142    -0.94   0.348    -3.661588    1.289838
------------------------------------------------------------------------------------


Iteration 0:   log likelihood = -938.14308
Iteration 1:   log likelihood = -938.14308

Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(0)    =   0.00
                                                        Prob > chi2   =      .
Log likelihood = -938.14308                             Pseudo R2     = 0.0000

------------------------------------------------------------------------------
        qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       _cons |  -1.031787   .0562947   -18.33   0.000    -1.142122   -.9214511
------------------------------------------------------------------------------


Iteration 0:   log likelihood = -266.67873
Iteration 1:   log likelihood = -238.48654
Iteration 2:   log likelihood = -232.82848
Iteration 3:   log likelihood = -232.68043
Iteration 4:   log likelihood = -232.67999
Iteration 5:   log likelihood = -232.67999
```

```
Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(19)   =  68.00
                                                        Prob > chi2   = 0.0000
Log likelihood = -232.67999                             Pseudo R2     = 0.1275

-----------------------------------------------------------------------------------
             cens | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+----------------------------------------------------------------
             qsmk |   .5168674   .2877162     1.80   0.072    -.0470459    1.080781
              sex |   .0573131   .3302775     0.17   0.862     -.590019    .7046452
             race |  -.0122715   .4524888    -0.03   0.978    -.8991332    .8745902
              age |  -.2697293   .1174647    -2.30   0.022    -.4999559   -.0395027
                  |
      c.age#c.age |   .0028837   .0011135     2.59   0.010     .0007012    .0050661
                  |
        education |
               1  |   .3823818   .5601808     0.68   0.495    -.7155523    1.480316
               2  |  -.0584066   .5749586    -0.10   0.919    -1.185305    1.068491
               3  |   .2176937   .5225008     0.42   0.677    -.8063891    1.241776
               4  |   .5208288   .6678735     0.78   0.435    -.7881792    1.829837
                  |
   smokeintensity |   .0157119   .0347319     0.45   0.651    -.0523614    .0837851
                  |
 c.smokeintensity#|
 c.smokeintensity |  -.0001133   .0006058    -0.19   0.852    -.0013007    .0010742
                  |
         smokeyrs |   .0785973   .0749576     1.05   0.294    -.0683169    .2255116
                  |
      c.smokeyrs#|
       c.smokeyrs |  -.0005569   .0010318    -0.54   0.589    -.0025791    .0014653
                  |
         exercise |
               0  |    .583989   .3723133     1.57   0.117    -.1457317     1.31371
               1  |  -.3874824   .3439133    -1.13   0.260     -1.06154    .2865754
                  |
           active |
               0  |  -.7065829   .3964577    -1.78   0.075    -1.483626    .0704599
               1  |  -.9540614   .3893181    -2.45   0.014    -1.717111   -.1910119
                  |
             wt71 |  -.0878871   .0400115    -2.20   0.028    -.1663082   -.0094659
                  |
    c.wt71#c.wt71 |   .0006351   .0002257     2.81   0.005     .0001927    .0010775
                  |
            _cons |   3.754678   2.651222     1.42   0.157    -1.441622    8.950978
-----------------------------------------------------------------------------------


Iteration 0:   log likelihood = -266.67873
Iteration 1:   log likelihood = -264.00252
Iteration 2:   log likelihood = -263.88028
Iteration 3:   log likelihood = -263.88009
```

```
Iteration 4:   log likelihood = -263.88009

Logistic regression                                     Number of obs =  1,629
                                                        LR chi2(1)    =   5.60
                                                        Prob > chi2   = 0.0180
Log likelihood = -263.88009                             Pseudo R2     = 0.0105

------------------------------------------------------------------------------
        cens | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   .6411113   .2639262     2.43   0.015     .1238255    1.158397
       _cons |  -3.421172   .1648503   -20.75   0.000    -3.744273   -3.098071
------------------------------------------------------------------------------


(1,629 missing values generated)

(428 real changes made)

(1,201 real changes made)

(1,629 missing values generated)

(1,566 real changes made)

(63 missing values generated)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          sw |      1,566    .9962351    .2819583   .3546469   4.093113

(sum of wgt is 1,560.10419079661)

Linear regression                               Number of obs     =      1,566
                                                F(1, 1565)        =      44.19
                                                Prob > F          =     0.0000
                                                R-squared         =     0.0363
                                                Root MSE          =     7.8652

                              (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------
             |               Robust
     wt82_71 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   3.496493   .5259796     6.65   0.000     2.464794    4.528192
       _cons |    1.66199   .2328986     7.14   0.000     1.205164    2.118816
------------------------------------------------------------------------------
```

# 13. Standardization and the parametric G-formula: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

## Program 13.1

- Estimating the mean outcome within levels of treatment and confounders: Data from NHEFS
- Section 13.2

```
use ./data/nhefs-formatted, clear

/* Estimate the the conditional mean outcome within strata of quitting
smoking and covariates, among the uncensored */
glm wt82_71 qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71 ///
  qsmk##c.smokeintensity
predict meanY
summarize meanY

/*Look at the predicted value for subject ID = 24770*/
list meanY if seqn == 24770

/*Observed mean outcome for comparison */
summarize wt82_71
```

```
note: 1.qsmk omitted because of collinearity.
note: smokeintensity omitted because of collinearity.

Iteration 0:   log likelihood = -5328.5765

Generalized linear models                         Number of obs   =      1,566
Optimization     : ML                             Residual df     =      1,545
                                                  Scale parameter =    53.5683
Deviance         =  82763.02862                   (1/df) Deviance =    53.5683
```

```
Pearson          =  82763.02862                  (1/df) Pearson  =    53.5683

Variance function: V(u) = 1                      [Gaussian]
Link function    : g(u) = u                      [Identity]

                                                 AIC             =   6.832154
Log likelihood   = -5328.576456                  BIC             =   71397.58

------------------------------------------------------------------------------------
                   |                 OIM
           wt82_71 | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------------+----------------------------------------------------------------
              qsmk |   2.559594   .8091486     3.16   0.002      .973692    4.145496
               sex |  -1.430272   .4689576    -3.05   0.002    -2.349412   -.5111317
              race |   .5601096   .5818888     0.96   0.336    -.5803714    1.700591
               age |   .3596353   .1633188     2.20   0.028     .0395364    .6797342
                   |
       c.age#c.age |   -.006101   .0017261    -3.53   0.000    -.0094841   -.0027178
                   |
         education |
                1  |    .194977   .7413692     0.26   0.793     -1.25808    1.648034
                2  |   .9854211   .7012116     1.41   0.160    -.3889285    2.359771
                3  |   .7512894   .6339153     1.19   0.236    -.4911617    1.993741
                4  |   1.686547   .8716593     1.93   0.053    -.0218744    3.394967
                   |
    smokeintensity |   .0491365   .0517254     0.95   0.342    -.0522435    .1505165
                   |
  c.smokeintensity#|
  c.smokeintensity |  -.0009907    .000938    -1.06   0.291    -.0028292    .0008479
                   |
          smokeyrs |   .1343686   .0917122     1.47   0.143     -.045384    .3141212
                   |
        c.smokeyrs#|
        c.smokeyrs |  -.0018664   .0015437    -1.21   0.227    -.0048921    .0011592
                   |
          exercise |
                0  |  -.3539128   .5588587    -0.63   0.527    -1.449256    .7414301
                1  |  -.0579374   .4316468    -0.13   0.893    -.9039497    .7880749
                   |
            active |
                0  |   .2613779   .6845577     0.38   0.703     -1.08033    1.603086
                1  |  -.6861916   .6739131    -1.02   0.309    -2.007037    .6346539
                   |
              wt71 |   .0455018   .0833709     0.55   0.585    -.1179022    .2089058
                   |
     c.wt71#c.wt71 |  -.0009653   .0005247    -1.84   0.066    -.0019937    .0000631
                   |
              qsmk |
Smoking cessation  |          0  (omitted)
    smokeintensity |          0  (omitted)
                   |
             qsmk#|
  c.smokeintensity |
```

```
Smoking cessation |   .0466628   .0351448     1.33   0.184    -.0222197    .1155453
                  |
            _cons |  -1.690608   4.388883    -0.39   0.700    -10.29266    6.911444
------------------------------------------------------------------------------------

(option mu assumed; predicted mean wt82_71)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       meanY |      1,566      2.6383    3.034683  -10.87582   9.876489

      +----------+
      |    meanY |
      |----------|
 960. | .3421569 |
      +----------+

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
     wt82_71 |      1,566      2.6383    7.879913  -41.28047   48.53839
```

## Program 13.2

- Standardizing the mean outcome to the baseline confounders
- Data from Table 2.2
- Section 13.3

```
clear
input str10 ID L A Y
"Rheia"      0 0 0
"Kronos"     0 0 1
"Demeter"    0 0 0
"Hades"      0 0 0
"Hestia"     0 1 0
"Poseidon"   0 1 0
"Hera"       0 1 0
"Zeus"       0 1 1
"Artemis"    1 0 1
"Apollo"     1 0 1
"Leto"       1 0 0
"Ares"       1 1 1
"Athena"     1 1 1
"Hephaestus" 1 1 1
"Aphrodite"  1 1 1
"Cyclope"    1 1 1
"Persephone" 1 1 1
"Hermes"     1 1 0
"Hebe"       1 1 0
"Dionysus"   1 1 0
end

/* i. Data set up for standardization:
 - create 3 copies of each subject first,
```

```
 - duplicate the dataset and create a variable `interv` which indicates
which copy is the duplicate (interv =1) */
expand 2, generate(interv)

/* Next, duplicate the original copy (interv = 0) again, and create
another variable 'interv2' to indicate the copy */
expand 2 if interv == 0, generate(interv2)

/* Now, change the value of 'interv' to -1 in one of the copies so that
there are unique values of interv for each copy */
replace interv = -1  if interv2 ==1
drop interv2

/* Check that the data has the structure you want:
 - there should be 1566 people in each of the 3 levels of interv*/
tab interv

/* Two of the copies will be for computing the standardized result
for these two copies (interv = 0 and interv = 1), set the outcome to
missing and force qsmk to either 0 or 1, respectively.
You may need to edit this part of the code for your outcome and exposure variables */
replace Y = . if interv != -1
replace A = 0 if interv == 0
replace A = 1 if interv == 1

/* Check that the data has the structure you want:
for interv = -1, some people quit and some do not;
for interv = 0 or 1, noone quits or everyone quits, respectively */
by interv, sort: summarize A

*ii.Estimation in original sample*
*Now, we do a parametric regression with the covariates we want to adjust for*
*You may need to edit this part of the code for the variables you want.*
*Because the copies have missing Y, this will only run the regression in the
*original copy.*
*The double hash between A & L creates a regression model with A and L and a
* product term between A and L*
regress Y A##L

*Ask Stata for expected values - Stata will give you expected values for all
* copies, not just the original ones*
predict predY, xb

*Now ask for a summary of these values by intervention*
*These are the standardized outcome estimates: you can subtract them to get the
* standardized difference*
by interv, sort: summarize predY

*iii.OPTIONAL: Output standardized point estimates and difference*
*The summary from the last command gives you the standardized estimates*
*We can stop there, or we can ask Stata to calculate the standardized difference
* and display all the results in a simple table*
```

```
*The code below can be used as-is without changing any variable names*
*The option "quietly" asks Stata not to display the output of some intermediate
* calculations*
*You can delete this option if you want to see what is happening step-by-step*
quietly summarize predY if(interv == -1)
matrix input observe = (-1,`r(mean)')
quietly summarize predY if(interv == 0)
matrix observe = (observe \0,`r(mean)')
quietly summarize predY if(interv == 1)
matrix observe = (observe \1,`r(mean)')
matrix observe = (observe \., observe[3,2]-observe[2,2])

*Add some row/column descriptions and print results to screen*
matrix rownames observe = observed E(Y(a=0)) E(Y(a=1)) difference
matrix colnames observe = interv value
matrix list observe

*to interpret these results:*
*row 1, column 2, is the observed mean outcome value in our original sample*
*row 2, column 2, is the mean outcome value if everyone had not quit smoking*
*row 3, column 2, is the mean outcome value if everyone had quit smoking*
*row 4, column 2, is the mean difference outcome value if everyone had quit
* smoking compared to if everyone had not quit smoking*
```

```
              ID           L          A          Y
  1. "Rheia"         0 0 0
  2. "Kronos"        0 0 1
  3. "Demeter"       0 0 0
  4. "Hades"         0 0 0
  5. "Hestia"        0 1 0
  6. "Poseidon"      0 1 0
  7. "Hera"          0 1 0
  8. "Zeus"          0 1 1
  9. "Artemis"       1 0 1
 10. "Apollo"        1 0 1
 11. "Leto"          1 0 0
 12. "Ares"          1 1 1
 13. "Athena"        1 1 1
 14. "Hephaestus" 1 1 1
 15. "Aphrodite" 1 1 1
 16. "Cyclope"       1 1 1
 17. "Persephone" 1 1 1
 18. "Hermes"        1 1 0
 19. "Hebe"          1 1 0
 20. "Dionysus"      1 1     0
 21. end

(20 observations created)

(20 observations created)

(20 real changes made)
```

```
  Expanded observation |
                  type |      Freq.     Percent        Cum.
-----------------------+-----------------------------------
                    -1 |         20       33.33       33.33
  Original observation |         20       33.33       66.67
Duplicated observation |         20       33.33      100.00
-----------------------+-----------------------------------
                 Total |         60      100.00

(40 real changes made, 40 to missing)

(13 real changes made)

(7 real changes made)


-------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           A |         20         .65    .4893605          0          1

-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           A |         20           0           0          0          0

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
           A |         20           1           0          1          1

      Source |       SS           df       MS      Number of obs   =        20
-------------+----------------------------------   F(3, 16)        =      1.07
       Model |  .833333333         3  .277777778   Prob > F        =    0.3909
    Residual |  4.16666667        16  .260416667   R-squared       =    0.1667
-------------+----------------------------------   Adj R-squared   =    0.0104
       Total |           5        19  .263157895   Root MSE        =    .51031

------------------------------------------------------------------------------
           Y | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         1.A |   1.05e-16   .3608439     0.00   1.000    -.7649549    .7649549
         1.L |   .4166667    .389756     1.07   0.301    -.4095791    1.242912
             |
         A#L |
```

```
        1 1  |  -5.83e-17   .4959325    -0.00   1.000     -1.05133     1.05133
             |
       _cons |        .25   .2551552     0.98   0.342    -.2909048    .7909048
------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |         20          .5     .209427        .25   .6666667

-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |         20          .5     .209427        .25   .6666667

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |         20          .5     .209427        .25   .6666667
```

```
observe[4,2]
               interv      value
  observed         -1  .50000001
 E(Y(a=0))          0  .50000001
 E(Y(a=1))          1  .50000001
difference          .          0
```

# Program 13.3

- Standardizing the mean outcome to the baseline confounders:
- Data from NHEFS
- Section 13.3

```
use ./data/nhefs-formatted, clear

*i.Data set up for standardization: create 3 copies of each subject*
*first, duplicate the dataset and create a variable 'interv' which indicates
* which copy is the duplicate (interv =1)
expand 2, generate(interv)

*next, duplicate the original copy (interv = 0) again, and create another
* variable 'interv2' to indicate the copy
expand 2 if interv == 0, generate(interv2)

*now, change the value of 'interv' to -1 in one of the copies so that there are
* unique values of interv for each copy*
replace interv = -1  if interv2 ==1
drop interv2

*check that the data has the structure you want: there should be 1566 people in
* each of the 3 levels of interv*
tab interv

*two of the copies will be for computing the standardized result*
*for these two copies (interv = 0 and interv = 1), set the outcome to missing
* and force qsmk to either 0 or 1, respectively*
*you may need to edit this part of the code for your outcome and exposure variables*
replace wt82_71 = . if interv != -1
replace qsmk = 0 if interv == 0
replace qsmk = 1 if interv == 1

*check that the data has the structure you want: for interv = -1, some people
* quit and some do not; for interv = 0 or 1, noone quits or everyone quits, respectively*
by interv, sort: summarize qsmk

*ii.Estimation in original sample*
*Now, we do a parametric regression with the covariates we want to adjust for*
*You may need to edit this part of the code for the variables you want.*
*Because the copies have missing wt82_71, this will only run the regression in
* the original copy*
regress wt82_71 qsmk sex race c.age##c.age ib(last).education ///
c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
ib(last).exercise ib(last).active c.wt71##c.wt71 qsmk#c.smokeintensity

*Ask Stata for expected values - Stata will give you expected values for all
* copies, not just the original ones*
predict predY, xb

*Now ask for a summary of these values by intervention*
*These are the standardized outcome estimates: you can subtract them to get the
* standardized difference*
by interv, sort: summarize predY

/* iii.OPTIONAL: Output standardized point estimates and difference
- The summary from the last command gives you the
```

```
standardized estimates
- We can stop there, or we can ask Stata to calculate the
standardized difference and display all the results
in a simple table
- The code below can be used as-is without changing any
variable names
- The option `quietly` asks Stata not to display the output of
some intermediate calculations
- You can delete this option if you want to see what is
happening step-by-step */
quietly summarize predY if(interv == -1)
matrix input observe = (-1,`r(mean)')
quietly summarize predY if(interv == 0)
matrix observe = (observe \0,`r(mean)')
quietly summarize predY if(interv == 1)
matrix observe = (observe \1,`r(mean)')
matrix observe = (observe \., observe[3,2]-observe[2,2])

* Add some row/column descriptions and print results to screen
matrix rownames observe = observed E(Y(a=0)) E(Y(a=1)) difference
matrix colnames observe = interv value
matrix list observe

/* To interpret these results:
- row 1, column 2, is the observed mean outcome value
in our original sample
- row 2, column 2, is the mean outcome value
if everyone had not quit smoking
- row 3, column 2, is the mean outcome value
if everyone had quit smoking
- row 4, column 2, is the mean difference outcome value
if everyone had quit smoking compared to if everyone
had not quit smoking */

/* Addition due to way Statamarkdown works
i.e. each code chunk is a separate Stata session */
mata observe = st_matrix("observe")
mata mata matsave ./data/observe observe, replace

*drop the copies*
drop if interv != -1
gen meanY_b =.
qui save ./data/nhefs_std, replace
```

```
(1,566 observations created)

(1,566 observations created)

(1,566 real changes made)



  Expanded observation |
```

```
                  type |      Freq.     Percent        Cum.
-----------------------+-----------------------------------
                    -1 |      1,566       33.33       33.33
  Original observation |      1,566       33.33       66.67
Duplicated observation |      1,566       33.33      100.00
-----------------------+-----------------------------------
                 Total |      4,698      100.00

(3,132 real changes made, 3,132 to missing)

(403 real changes made)

(1,163 real changes made)


--------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566    .2573436    .4373099          0          1

--------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566           0           0          0          0

--------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566           1           0          1          1

      Source |       SS           df       MS      Number of obs   =     1,566
-------------+----------------------------------   F(20, 1545)     =     13.45
       Model |   14412.558        20    720.6279   Prob > F        =    0.0000
    Residual |  82763.0286     1,545  53.5683033   R-squared       =    0.1483
-------------+----------------------------------   Adj R-squared   =    0.1373
       Total |  97175.5866     1,565  62.0930266   Root MSE        =     7.319

------------------------------------------------------------------------------------
           wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------------+----------------------------------------------------------------
              qsmk |   2.559594   .8091486     3.16   0.002     .9724486     4.14674
               sex |  -1.430272   .4689576    -3.05   0.002    -2.350132   -.5104111
              race |   .5601096   .5818888     0.96   0.336    -.5812656    1.701485
               age |   .3596353   .1633188     2.20   0.028     .0392854    .6799851
                   |
       c.age#c.age |   -.006101   .0017261    -3.53   0.000    -.0094868   -.0027151
                   |
```

```
         education |
                1  |    .194977   .7413692     0.26   0.793    -1.259219    1.649173
                2  |   .9854211   .7012116     1.41   0.160     -.390006    2.360848
                3  |   .7512894   .6339153     1.19   0.236    -.4921358    1.994715
                4  |   1.686547   .8716593     1.93   0.053    -.0232138    3.396307
                   |
    smokeintensity |   .0491365   .0517254     0.95   0.342     -.052323    .1505959
                   |
  c.smokeintensity#|
  c.smokeintensity |  -.0009907    .000938    -1.06   0.291    -.0028306    .0008493
                   |
          smokeyrs |   .1343686   .0917122     1.47   0.143     -.045525    .3142621
                   |
        c.smokeyrs#|
        c.smokeyrs |  -.0018664   .0015437    -1.21   0.227    -.0048944    .0011616
                   |
          exercise |
                0  |  -.3539128   .5588587    -0.63   0.527    -1.450114    .7422889
                1  |  -.0579374   .4316468    -0.13   0.893     -.904613    .7887381
                   |
            active |
                0  |   .2613779   .6845577     0.38   0.703    -1.081382    1.604138
                1  |  -.6861916   .6739131    -1.02   0.309    -2.008073    .6356894
                   |
              wt71 |   .0455018   .0833709     0.55   0.585    -.1180303    .2090339
                   |
     c.wt71#c.wt71 |  -.0009653   .0005247    -1.84   0.066    -.0019945    .0000639
                   |
             qsmk#|
  c.smokeintensity |
Smoking cessation  |   .0466628   .0351448     1.33   0.184    -.0222737    .1155993
                   |
             _cons |  -1.690608   4.388883    -0.39   0.700     -10.2994    6.918188
------------------------------------------------------------------------------------


-------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566      2.6383    3.034683  -10.87582   9.876489

-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566    1.756213    2.826271  -11.83737   6.733498

-------------------------------------------------------------------------------------
-> interv = Duplicat
```

```
    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566    5.273587    2.920532  -9.091126    11.0506
```

```
observe[4,2]
                interv      value
  observed          -1  2.6382998
 E(Y(a=0))           0  1.7562131
 E(Y(a=1))           1  5.2735873
difference           .  3.5173742


(saving observe[4,2])
file ./data/observe.mmat saved

(3,132 observations deleted)

(1,566 missing values generated)
```

## Program 13.4

- Computing the 95% confidence interval of the standardized means and their difference: Data from NHEFS
- Section 13.3

```
*Run program 13.3 to obtain point estimates, and then the code below*

capture program drop bootstdz

program define bootstdz, rclass
use ./data/nhefs_std, clear

preserve

* Draw bootstrap sample from original observations
bsample

/* Create copies with each value of qsmk in bootstrap sample.
First, duplicate the dataset and create a variable `interv` which
indicates which copy is the duplicate (interv =1)*/
expand 2, generate(interv_b)
```

```
/* Next, duplicate the original copy (interv = 0) again, and create
another variable `interv2` to indicate the copy*/
expand 2 if interv_b == 0, generate(interv2_b)

/* Now, change the value of interv to -1 in one of the copies so that
there are unique values of interv for each copy*/
replace interv_b = -1  if interv2_b ==1
drop interv2_b

/* Two of the copies will be for computing the standardized result.
For these two copies (interv = 0 and interv = 1), set the outcome to
missing and force qsmk to either 0 or 1, respectively*/
replace wt82_71 = . if interv_b != -1
replace qsmk = 0 if interv_b == 0
replace qsmk = 1 if interv_b == 1

* Run regression
regress wt82_71 qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71 ///
  qsmk#c.smokeintensity

/* Ask Stata for expected values.
Stata will give you expected values for all copies, not just the
original ones*/
predict predY_b, xb
summarize predY_b if interv_b == 0
return scalar boot_0 = r(mean)
summarize predY_b if interv_b == 1
return scalar boot_1 = r(mean)
return scalar boot_diff = return(boot_1) - return(boot_0)
drop meanY_b

restore

end

/* Then we use the `simulate` command to run the bootstraps as many
times as we want.
Start with reps(10) to make sure your code runs, and then change to
reps(1000) to generate your final CIs.*/
simulate EY_a0=r(boot_0) EY_a1 = r(boot_1) ///
  difference = r(boot_diff), reps(10) seed(1): bootstdz

/* Next, format the point estimate to allow Stata to calculate our
standard errors and confidence intervals*/

* Addition: read back in the observe matrix
mata mata matuse ./data/observe, replace
mata st_matrix("observe", observe)

matrix pe = observe[2..4, 2]'
```

```
matrix list pe

/* Finally, the bstat command generates valid 95% confidence intervals
under the normal approximation using our bootstrap results.
The default results use a normal approximation to calcutlate the
confidence intervals.
Note, n contains the original sample size of your data before censoring*/
bstat, stat(pe) n(1629)
```

```
 12.

      Command: bootstdz
        EY_a0: r(boot_0)
        EY_a1: r(boot_1)
   difference: r(boot_diff)

Simulations (10)
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..........

(loading observe[4,2])




pe[1,3]
           r2          r3          r4
c2  1.7562131   5.2735873   3.5173742


Bootstrap results                                       Number of obs = 1,629
                                                        Replications  =    10

------------------------------------------------------------------------------
             |   Observed   Bootstrap                         Normal-based
             | coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       EY_a0 |   1.756213   .2157234     8.14   0.000     1.333403    2.179023
       EY_a1 |   5.273587   .4999001    10.55   0.000     4.293801    6.253374
  difference |   3.517374    .538932     6.53   0.000     2.461087    4.573662
------------------------------------------------------------------------------
```

# 14. G-estimation of Structural Nested Models: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

## Program 14.1

- Ranks of extreme observations
- Data from NHEFS
- Section 14.4

```
/*For Stata 15 or later, first install the extremes function using this code:*/
* ssc install extremes

*Data preprocessing***

use ./data/nhefs, clear
gen byte cens = (wt82 == .)

/*Ranking of extreme observations*/
extremes wt82_71 seqn

/*Estimate unstabilized censoring weights for use in g-estimation models*/
glm cens qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71 ///
  , family(binomial)
predict pr_cens
gen w_cens = 1/(1-pr_cens)
replace w_cens = . if cens == 1
/*observations with cens = 1 contribute to censoring models but not outcome model*/
summarize w_cens

/*Analyses restricted to N=1566*/
drop if wt82 == .
```

```
summarize wt82_71

save ./data/nhefs-wcens, replace
```

```
  |  obs:        wt82_71    seqn |
  |------------------------------|
  | 1329.   -41.28046982   23321 |
  |  527.   -30.50192161   13593 |
  | 1515.   -30.05007421   24363 |
  |  204.   -29.02579305    5412 |
  | 1067.   -25.97055814   21897 |
  +------------------------------+

  +-----------------------------+
  |  205.   34.01779932    5415 |
  | 1145.   36.96925111   22342 |
  |   64.   37.65051215    1769 |
  |  260.   47.51130337    6928 |
  | 1367.   48.53838568   23522 |
  +-----------------------------+


Iteration 0:   log likelihood = -292.45812
Iteration 1:   log likelihood =  -233.5099
Iteration 2:   log likelihood = -232.68635
Iteration 3:   log likelihood =    -232.68
Iteration 4:   log likelihood = -232.67999

Generalized linear models                         Number of obs   =      1,629
Optimization     : ML                             Residual df     =      1,609
                                                  Scale parameter =          1
Deviance         =  465.3599898                   (1/df) Deviance =   .2892231
Pearson          =  1654.648193                   (1/df) Pearson  =   1.028371

Variance function: V(u) = u*(1-u)                 [Bernoulli]
Link function    : g(u) = ln(u/(1-u))             [Logit]

                                                  AIC             =   .3102271
Log likelihood   = -232.6799949                   BIC             =  -11434.36

------------------------------------------------------------------------------------
                 |                 OIM
            cens | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-----------------+------------------------------------------------------------------
            qsmk |   .5168674   .2877162     1.80   0.072    -.0470459    1.080781
             sex |   .0573131   .3302775     0.17   0.862     -.590019    .7046452
            race |  -.0122715   .4524888    -0.03   0.978    -.8991332    .8745902
             age |  -.2697293   .1174647    -2.30   0.022    -.4999558   -.0395027
                 |
     c.age#c.age |   .0028837   .0011135     2.59   0.010     .0007012    .0050661
                 |
       education |
              1  |   .3823818   .5601808     0.68   0.495    -.7155523    1.480316
```

```
           2  |  -.0584066   .5749586    -0.10   0.919    -1.185305    1.068491
           3  |   .2176937   .5225008     0.42   0.677    -.8063891    1.241776
           4  |   .5208288   .6678735     0.78   0.435    -.7881792    1.829837
              |
smokeintensity |   .0157119   .0347319     0.45   0.651    -.0523614    .0837851
              |
c.smokeintensity#|
c.smokeintensity |  -.0001133   .0006058    -0.19   0.852    -.0013007    .0010742
              |
     smokeyrs |   .0785973   .0749576     1.05   0.294     -.068317    .2255116
              |
  c.smokeyrs#|
   c.smokeyrs |  -.0005569   .0010318    -0.54   0.589    -.0025791    .0014653
              |
     exercise |
           0  |    .583989   .3723133     1.57   0.117    -.1457317     1.31371
           1  |  -.3874824   .3439133    -1.13   0.260     -1.06154    .2865753
              |
       active |
           0  |  -.7065829   .3964577    -1.78   0.075    -1.483626    .0704599
           1  |  -.9540614   .3893181    -2.45   0.014    -1.717111   -.1910119
              |
         wt71 |  -.0878871   .0400115    -2.20   0.028    -.1663082   -.0094659
              |
 c.wt71#c.wt71 |   .0006351   .0002257     2.81   0.005     .0001927    .0010775
              |
        _cons |   3.754678   2.651222     1.42   0.157    -1.441622    8.950978
------------------------------------------------------------------------------------

(option mu assumed; predicted mean cens)


(63 real changes made, 63 to missing)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
      w_cens |      1,566    1.039197      .05646   1.001814   1.824624

(63 observations deleted)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
     wt82_71 |      1,566      2.6383    7.879913  -41.28047   48.53839

file ./data/nhefs-wcens.dta saved
```

# Program 14.2

- G-estimation of a 1-parameter structural nested mean model
- Brute force search
- Data from NHEFS
- Section 14.5

```
use ./data/nhefs-wcens, clear

/*Generate test value of Psi = 3.446*/
gen psi = 3.446

/*Generate H(Psi) for each individual using test value of Psi and
their own values of weight change and smoking status*/
gen Hpsi = wt82_71 - psi * qsmk

/*Fit a model for smoking status, given confounders and H(Psi) value,
with censoring weights and display H(Psi) coefficient*/
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71 Hpsi ///
  [pw = w_cens], cluster(seqn)
di _b[Hpsi]

/*G-estimation*/
/*Checking multiple possible values of psi*/
cap noi drop psi Hpsi

local seq_start = 2
local seq_end = 5
local seq_by = 0.1 // Setting seq_by = 0.01 will yield the result 3.46
local seq_len = (`seq_end'-`seq_start')/`seq_by' + 1

matrix results = J(`seq_len', 4, 0)

qui gen psi = .
qui gen Hpsi = .

local j = 0

forvalues i =  `seq_start'(`seq_by')`seq_end' {
    local j = `j' + 1
    qui replace psi = `i'
    qui replace Hpsi = wt82_71 - psi * qsmk
    quietly logit qsmk sex race c.age##c.age ///
      ib(last).education c.smokeintensity##c.smokeintensity ///
      c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
      c.wt71##c.wt71 Hpsi ///
      [pw = w_cens], cluster(seqn)
    matrix p_mat = r(table)
    matrix p_mat = p_mat["pvalue","qsmk:Hpsi"]
    local p = p_mat[1,1]
    local b = _b[Hpsi]
    di "coeff", %6.3f `b', "is generated from psi", %4.1f `i'
    matrix results[`j',1]= `i'
    matrix results[`j',2]= `b'
    matrix results[`j',3]= abs(`b')
    matrix results[`j',4]= `p'
}
```

```
matrix colnames results = "psi" "B(Hpsi)" "AbsB(Hpsi)" "pvalue"
mat li results

mata
res = st_matrix("results")
for(i=1; i<= rows(res); i++) {
  if (res[i,3] == colmin(res[,3])) res[i,1]
}
end
* Setting seq_by = 0.01 will yield the result 3.46
```

```
Iteration 0:   log pseudolikelihood = -936.10067
Iteration 1:   log pseudolikelihood = -879.13942
Iteration 2:   log pseudolikelihood = -877.82647
Iteration 3:   log pseudolikelihood = -877.82423
Iteration 4:   log pseudolikelihood = -877.82423

Logistic regression                                     Number of obs =  1,566
                                                        Wald chi2(19) = 106.13
                                                        Prob > chi2   = 0.0000
Log pseudolikelihood = -877.82423                       Pseudo R2     = 0.0623

                                    (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------------
                  |               Robust
             qsmk | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
------------------+-----------------------------------------------------------------
              sex |  -.5137324   .1536024    -3.34   0.001    -.8147876   -.2126772
             race |  -.8608912   .2099415    -4.10   0.000    -1.272369   -.4494133
              age |   .1151589   .0502116     2.29   0.022      .016746    .2135718
                  |
      c.age#c.age |  -.0007593   .0005297    -1.43   0.152    -.0017976     .000279
                  |
        education |
               1  |  -.4710855   .2247701    -2.10   0.036    -.9116268   -.0305441
               2  |  -.5000231   .2208583    -2.26   0.024    -.9328974   -.0671487
               3  |  -.3833788    .195914    -1.96   0.050    -.7673632    .0006056
               4  |  -.4047116   .2836068    -1.43   0.154    -.9605707    .1511476
                  |
   smokeintensity |  -.0783425    .014645    -5.35   0.000    -.1070461   -.0496389
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0010722   .0002651     4.04   0.000     .0005526    .0015917
                  |
         smokeyrs |  -.0711097    .026398    -2.69   0.007    -.1228488   -.0193705
                  |
       c.smokeyrs#|
       c.smokeyrs |   .0008153   .0004491     1.82   0.069     -.000065    .0016955
                  |
         exercise |
               0  |  -.3800465   .1889205    -2.01   0.044    -.7503238   -.0097692
               1  |  -.0437043   .1372725    -0.32   0.750    -.3127534    .2253447
                  |
```

```
          active |
              0  |  -.2134552   .2122025    -1.01   0.314    -.6293645    .2024541
              1  |  -.1793327    .207151    -0.87   0.387    -.5853412    .2266758
                 |
            wt71 |  -.0076607   .0256319    -0.30   0.765    -.0578983    .0425769
                 |
   c.wt71#c.wt71 |   .0000866   .0001582     0.55   0.584    -.0002236    .0003967
                 |
            Hpsi |  -1.90e-06   .0088414    -0.00   1.000    -.0173307    .0173269
           _cons |  -1.338367   1.359613    -0.98   0.325     -4.00316    1.326426
------------------------------------------------------------------------------------

-1.905e-06
```

```
  6.         matrix p_mat = r(table)
  7.         matrix p_mat = p_mat["pvalue","qsmk:Hpsi"]
  8.         local p = p_mat[1,1]
  9.         local b = _b[Hpsi]
 10.         di "coeff", %6.3f `b', "is generated from psi", %4.1f `i'
 11.         matrix results[`j',1]= `i'
 12.         matrix results[`j',2]= `b'
 13.         matrix results[`j',3]= abs(`b')
 14.         matrix results[`j',4]= `p'
 15. }
coeff  0.027 is generated from psi  2.0
coeff  0.025 is generated from psi  2.1
coeff  0.023 is generated from psi  2.2
coeff  0.021 is generated from psi  2.3
coeff  0.019 is generated from psi  2.4
coeff  0.018 is generated from psi  2.5
coeff  0.016 is generated from psi  2.6
coeff  0.014 is generated from psi  2.7
coeff  0.012 is generated from psi  2.8
coeff  0.010 is generated from psi  2.9
coeff  0.008 is generated from psi  3.0
coeff  0.006 is generated from psi  3.1
coeff  0.005 is generated from psi  3.2
coeff  0.003 is generated from psi  3.3
coeff  0.001 is generated from psi  3.4
coeff -0.001 is generated from psi  3.5
coeff -0.003 is generated from psi  3.6
coeff -0.005 is generated from psi  3.7
coeff -0.007 is generated from psi  3.8
coeff -0.009 is generated from psi  3.9
```

```
coeff -0.011 is generated from psi  4.0
coeff -0.012 is generated from psi  4.1
coeff -0.014 is generated from psi  4.2
coeff -0.016 is generated from psi  4.3
coeff -0.018 is generated from psi  4.4
coeff -0.020 is generated from psi  4.5
coeff -0.022 is generated from psi  4.6
coeff -0.024 is generated from psi  4.7
coeff -0.026 is generated from psi  4.8
coeff -0.028 is generated from psi  4.9
coeff -0.030 is generated from psi  5.0



results[31,4]
            psi     B(Hpsi)  AbsB(Hpsi)      pvalue
 r1           2   .02672188   .02672188   .00177849
 r2         2.1   .02489456   .02489456   .00359089
 r3         2.2   .02306552   .02306552   .00698119
 r4         2.3   .02123444   .02123444   .01305479
 r5         2.4   .01940095   .01940095   .02346121
 r6         2.5   .01756472   .01756472   .04049437
 r7         2.6    .0157254    .0157254   .06710192
 r8         2.7   .01388267   .01388267   .10673812
 r9         2.8    .0120362    .0120362   .16301154
r10         2.9   .01018567   .01018567   .23912864
r11           3   .00833081   .00833081   .33720241
r12         3.1   .00647131   .00647131   .45757692
r13         3.2    .0046069    .0046069   .59835195
r14         3.3   .00273736   .00273736   .75528009
r15         3.4   .00086243   .00086243   .92212566
r16         3.5  -.00101809   .00101809   .90856559
r17         3.6  -.00290439   .00290439    .7444406
r18         3.7  -.00479666   .00479666   .59230593
r19         3.8  -.00669505   .00669505   .45731304
r20         3.9  -.00859969   .00859969    .3425138
r21           4  -.01051072   .01051072    .2488326
r22         4.1  -.01242824   .01242824   .17537691
r23         4.2  -.01435235   .01435235    .1199593
r24         4.3  -.01628313   .01628313   .07967563
r25         4.4  -.01822063   .01822063   .05142147
r26         4.5  -.02016492   .02016492   .03227271
r27         4.6  -.02211603   .02211603   .01971433
r28         4.7  -.02407401   .02407401   .01173271
r29         4.8  -.02603888   .02603888   .00680955
r30         4.9  -.02801063   .02801063   .00385828
r31           5  -.02998926   .02998926   .00213639

------------------------------------------------- mata (type end to exit) ------------
: res = st_matrix("results")

: for(i=1; i<= rows(res); i++) {
>   if (res[i,3] == colmin(res[,3])) res[i,1]
```

```
> }
  3.4

: end
--------------------------------------------------------------------------------------
```

## Program 14.3

- G-estimation for 2-parameter structural nested mean model
- Closed form estimator
- Data from NHEFS
- Section 14.6

```
use ./data/nhefs-wcens, clear

/*create weights*/
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71 ///
  [pw = w_cens], cluster(seqn)
predict pr_qsmk
summarize pr_qsmk

/* Closed form estimator linear mean models  **/
* ssc install tomata
putmata *, replace
mata: diff = qsmk - pr_qsmk
mata: part1 = w_cens :* wt82_71 :* diff
mata: part2 = w_cens :* qsmk :* diff
mata: psi = sum(part1)/sum(part2)

/*** Closed form estimator for 2-parameter model **/
mata
diff = qsmk - pr_qsmk
diff2 = w_cens :* diff

lhs = J(2,2, 0)
lhs[1,1] = sum( qsmk :* diff2)
lhs[1,2] = sum( qsmk :* smokeintensity :* diff2 )
lhs[2,1] = sum( qsmk :* smokeintensity :* diff2)
lhs[2,2] = sum( qsmk :* smokeintensity :* smokeintensity :* diff2 )

rhs = J(2,1,0)
rhs[1] = sum(wt82_71 :* diff2 )
rhs[2] = sum(wt82_71 :* smokeintensity :* diff2 )

psi = (lusolve(lhs, rhs))'
psi
psi = (invsym(lhs'lhs)*lhs'rhs)'
psi
end
```

```
Iteration 0:   log pseudolikelihood = -936.10067
Iteration 1:   log pseudolikelihood = -879.13943
```

```
Iteration 2:   log pseudolikelihood = -877.82647
Iteration 3:   log pseudolikelihood = -877.82423
Iteration 4:   log pseudolikelihood = -877.82423

Logistic regression                                     Number of obs =  1,566
                                                        Wald chi2(18) = 106.13
                                                        Prob > chi2   = 0.0000
Log pseudolikelihood = -877.82423                       Pseudo R2     = 0.0623

                                  (Std. err. adjusted for 1,566 clusters in seqn)
----------------------------------------------------------------------------------
                 |               Robust
            qsmk | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-----------------+----------------------------------------------------------------
             sex |  -.5137295   .1533507    -3.35   0.001    -.8142913   -.2131677
            race |  -.8608919   .2099555    -4.10   0.000    -1.272397   -.4493867
             age |   .1151581   .0503079     2.29   0.022     .0165564    .2137598
                 |
     c.age#c.age |  -.0007593     .00053    -1.43   0.152    -.0017981    .0002795
                 |
       education |
              1  |  -.4710854   .2247796    -2.10   0.036    -.9116454   -.0305255
              2  |  -.5000247    .220776    -2.26   0.024    -.9327378   -.0673116
              3  |  -.3833802   .1954991    -1.96   0.050    -.7665515   -.0002089
              4  |  -.4047148   .2833093    -1.43   0.153    -.9599908    .1505613
                 |
  smokeintensity |  -.0783426   .0146634    -5.34   0.000    -.1070824   -.0496029
                 |
c.smokeintensity#|
c.smokeintensity |   .0010722   .0002655     4.04   0.000     .0005518    .0015925
                 |
        smokeyrs |  -.0711099   .0263523    -2.70   0.007    -.1227596   -.0194602
                 |
      c.smokeyrs#|
      c.smokeyrs |   .0008153   .0004486     1.82   0.069    -.0000639    .0016945
                 |
        exercise |
              0  |  -.3800461   .1890123    -2.01   0.044    -.7505034   -.0095887
              1  |  -.0437044    .137269    -0.32   0.750    -.3127467     .225338
                 |
          active |
              0  |  -.2134564   .2121759    -1.01   0.314    -.6293135    .2024007
              1  |  -.1793322   .2070848    -0.87   0.386    -.5852109    .2265466
                 |
            wt71 |  -.0076609   .0255841    -0.30   0.765    -.0578048     .042483
                 |
   c.wt71#c.wt71 |   .0000866   .0001572     0.55   0.582    -.0002216    .0003947
                 |
           _cons |  -1.338358   1.359289    -0.98   0.325    -4.002516      1.3258
----------------------------------------------------------------------------------

(option pr assumed; Pr(qsmk))
```

```
    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
     pr_qsmk |      1,566    .2607709    .1177584   .0514466   .7891403

(68 vectors posted)




------------------------------------------------- mata (type end to exit) ------------
: diff = qsmk - pr_qsmk

: diff2 = w_cens :* diff

:
: lhs = J(2,2, 0)

: lhs[1,1] = sum( qsmk :* diff2)

: lhs[1,2] = sum( qsmk :* smokeintensity :* diff2 )

: lhs[2,1] = sum( qsmk :* smokeintensity :* diff2)

: lhs[2,2] = sum( qsmk :* smokeintensity :* smokeintensity :* diff2 )

:
: rhs = J(2,1,0)

: rhs[1] = sum(wt82_71 :* diff2 )

: rhs[2] = sum(wt82_71 :* smokeintensity :* diff2 )

:
: psi = (lusolve(lhs, rhs))'

: psi
                 1             2
    +-----------------------------+
  1 |  2.859470362   .0300412816  |
    +-----------------------------+

: psi = (invsym(lhs'lhs)*lhs'rhs)'

: psi
                 1             2
    +-----------------------------+
  1 |  2.859470362   .0300412816  |
    +-----------------------------+

: end
---------------------------------------------------------------------------------------
```

# 15. Outcome regression and propensity scores: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

## Program 15.1

- Estimating the average causal effect within levels of confounders under the assumption of effect-measure modification by smoking intensity ONLY
- Data from NHEFS
- Section 15.1

```
use ./data/nhefs-formatted, clear

/* Generate smoking intensity among smokers product term */
gen qsmkintensity = qsmk*smokeintensity

* Regression on covariates, allowing for some effect modfication
regress wt82_71 qsmk qsmkintensity ///
  c.smokeintensity##c.smokeintensity sex race c.age##c.age ///
  ib(last).education c.smokeyrs##c.smokeyrs ///
  ib(last).exercise ib(last).active c.wt71##c.wt71

/* Display the estimated mean difference between quitting and
  not quitting value when smoke intensity = 5 cigarettes/ day */
lincom 1*_b[qsmk] + 5*1*_b[qsmkintensity]

/* Display the estimated mean difference between quitting and
  not quitting value when smoke intensity = 40 cigarettes/ day */
lincom 1*_b[qsmk] + 40*1*_b[qsmkintensity]

/* Regression on covariates, with no product terms */
regress wt82_71 qsmk c.smokeintensity##c.smokeintensity ///
  sex race c.age##c.age ///
  ib(last).education c.smokeyrs##c.smokeyrs ///
```

```
  ib(last).exercise ib(last).active c.wt71##c.wt71

      Source |       SS           df       MS      Number of obs   =     1,566
-------------+----------------------------------   F(20, 1545)     =     13.45
       Model |   14412.558        20  720.6279     Prob > F        =    0.0000
    Residual |  82763.0286     1,545  53.5683033   R-squared       =    0.1483
-------------+----------------------------------   Adj R-squared   =    0.1373
       Total |  97175.5866     1,565  62.0930266   Root MSE        =     7.319

------------------------------------------------------------------------------------
           wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------------+----------------------------------------------------------------
              qsmk |   2.559594   .8091486     3.16   0.002     .9724486     4.14674
     qsmkintensity |   .0466628   .0351448     1.33   0.184    -.0222737    .1155993
    smokeintensity |   .0491365   .0517254     0.95   0.342     -.052323    .1505959
                   |
c.smokeintensity#|
  c.smokeintensity |  -.0009907    .000938    -1.06   0.291    -.0028306    .0008493
                   |
               sex |  -1.430272   .4689576    -3.05   0.002    -2.350132   -.5104111
              race |   .5601096   .5818888     0.96   0.336    -.5812656    1.701485
               age |   .3596353   .1633188     2.20   0.028     .0392854    .6799851
                   |
       c.age#c.age |   -.006101   .0017261    -3.53   0.000    -.0094868   -.0027151
                   |
         education |
               1   |    .194977   .7413692     0.26   0.793    -1.259219    1.649173
               2   |   .9854211   .7012116     1.41   0.160     -.390006    2.360848
               3   |   .7512894   .6339153     1.19   0.236    -.4921358    1.994715
               4   |   1.686547   .8716593     1.93   0.053    -.0232138    3.396307
                   |
          smokeyrs |   .1343686   .0917122     1.47   0.143     -.045525    .3142621
                   |
      c.smokeyrs#|
        c.smokeyrs |  -.0018664   .0015437    -1.21   0.227    -.0048944    .0011616
                   |
          exercise |
               0   |  -.3539128   .5588587    -0.63   0.527    -1.450114    .7422889
               1   |  -.0579374   .4316468    -0.13   0.893     -.904613    .7887381
                   |
            active |
               0   |   .2613779   .6845577     0.38   0.703    -1.081382    1.604138
               1   |  -.6861916   .6739131    -1.02   0.309    -2.008073    .6356894
                   |
              wt71 |   .0455018   .0833709     0.55   0.585    -.1180303    .2090339
                   |
     c.wt71#c.wt71 |  -.0009653   .0005247    -1.84   0.066    -.0019945    .0000639
                   |
             _cons |  -1.690608   4.388883    -0.39   0.700     -10.2994    6.918188
------------------------------------------------------------------------------------


 ( 1)  qsmk + 5*qsmkintensity = 0
```

```
------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         (1) |   2.792908   .6682596     4.18   0.000     1.482117      4.1037
------------------------------------------------------------------------------


 ( 1)  qsmk + 40*qsmkintensity = 0

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         (1) |   4.426108   .8477818     5.22   0.000     2.763183    6.089032
------------------------------------------------------------------------------

      Source |       SS           df       MS      Number of obs   =     1,566
-------------+----------------------------------   F(19, 1546)     =     14.06
       Model |  14318.1239        19  753.58547   Prob > F        =    0.0000
    Residual |  82857.4627     1,546  53.5947365   R-squared       =    0.1473
-------------+----------------------------------   Adj R-squared   =    0.1369
       Total |  97175.5866     1,565  62.0930266   Root MSE        =    7.3208

-----------------------------------------------------------------------------------
          wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
------------------+----------------------------------------------------------------
             qsmk |   3.462622   .4384543     7.90   0.000     2.602594     4.32265
   smokeintensity |   .0651533   .0503115     1.29   0.196    -.0335327    .1638392
                  |
c.smokeintensity#|
 c.smokeintensity |  -.0010468   .0009373    -1.12   0.264    -.0028853    .0007918
                  |
              sex |   -1.46505    .468341    -3.13   0.002      -2.3837   -.5463989
             race |   .5864117   .5816949     1.01   0.314    -.5545827    1.727406
              age |   .3626624   .1633431     2.22   0.027     .0422649    .6830599
                  |
      c.age#c.age |  -.0061377   .0017263    -3.56   0.000    -.0095239   -.0027515
                  |
        education |
               1  |   .1708264   .7413289     0.23   0.818     -1.28329    1.624943
               2  |   .9893527   .7013784     1.41   0.159    -.3864007    2.365106
               3  |   .7423268   .6340357     1.17   0.242     -.501334    1.985988
               4  |   1.679344   .8718575     1.93   0.054    -.0308044    3.389492
                  |
        smokeyrs |   .1333931   .0917319     1.45   0.146    -.0465389    .3133252
                  |
     c.smokeyrs#|
       c.smokeyrs |   -.001827   .0015438    -1.18   0.237    -.0048552    .0012012
                  |
         exercise |
               0  |  -.3628786   .5589557    -0.65   0.516     -1.45927    .7335129
               1  |  -.0421962   .4315904    -0.10   0.922    -.8887606    .8043683
                  |
```

```
         active |
             0  |   .2580374   .6847219     0.38   0.706    -1.085044    1.601119
             1  |    -.68492   .6740787    -1.02   0.310    -2.007125    .6372851
                |
           wt71 |   .0373642   .0831658     0.45   0.653    -.1257655     .200494
                |
    c.wt71#c.wt71 |  -.0009158   .0005235    -1.75   0.080    -.0019427    .0001111
                |
          _cons |  -1.724603   4.389891    -0.39   0.694    -10.33537    6.886166
------------------------------------------------------------------------------------
```

## Prorgam 15.2

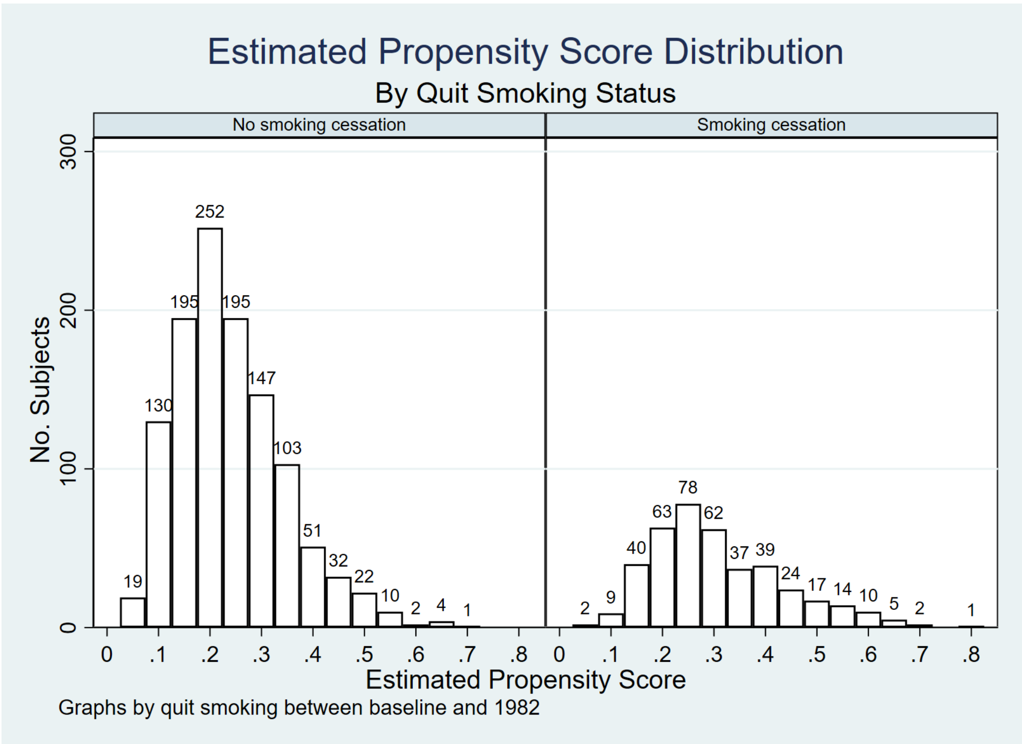
- Estimating and plotting the propensity score
- Data from NHEFS
- Section 15.2

```
use ./data/nhefs-formatted, clear

/*Fit a model for the exposure, quitting smoking*/
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity ///
  c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
  c.wt71##c.wt71

/*Estimate the propensity score, P(Qsmk|Covariates)*/
predict ps, pr

/*Check the distribution of the propensity score*/
bys qsmk: summarize ps

/*Return extreme values of propensity score:
  note, for Stata versions 15 and above, start by installing extremes*/
* ssc install extremes
extremes ps seqn
bys qsmk: extremes ps seqn

save ./data/nhefs-ps, replace

/*Plotting the estimated propensity score*/
histogram ps, width(0.05) start(0.025) ///
  frequency fcolor(none) lcolor(black) ///
  lpattern(solid) addlabel ///
  addlabopts(mlabcolor(black) mlabposition(12) ///
  mlabangle(zero)) ///
  ytitle(No. Subjects) ylabel(#4) ///
  xtitle(Estimated Propensity Score) xlabel(#15) ///
  by(, title(Estimated Propensity Score Distribution) ///
  subtitle(By Quit Smoking Status)) ///
  by(, legend(off)) ///
  by(qsmk, style(compact) colfirst) ///
  subtitle(, size(small) box bexpand)
qui gr export ./figs/stata-fig-15-2.png, replace
```

```
Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
             qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
------------------+-----------------------------------------------------------------
              sex |  -.5274782   .1540497    -3.42   0.001      -.82941   -.2255463
             race |  -.8392636   .2100668    -4.00   0.000    -1.250987   -.4275404
              age |   .1212052   .0512663     2.36   0.018     .0207251    .2216853
                  |
      c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753    .0002262
                  |
        education |
               1  |  -.4759606   .2262238    -2.10   0.035    -.9193511   -.0325701
               2  |  -.5047361    .217597    -2.32   0.020    -.9312184   -.0782538
               3  |  -.3895288   .1914353    -2.03   0.042    -.7647351   -.0143226
               4  |  -.4123596   .2772868    -1.49   0.137    -.9558318    .1311126
                  |
   smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                  |
         smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                  |
       c.smokeyrs#|
       c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
                  |
         exercise |
               0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
               1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
                  |
           active |
               0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
               1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
                  |
             wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
                  |
    c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
                  |
            _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------
```

```
------------------------------------------------------------------------------------------
-> qsmk = No smoking cessation

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |      1,163    .2392928    .1056545   .0510008   .6814955

------------------------------------------------------------------------------------------
-> qsmk = Smoking cessation

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        403    .3094353    .1290642   .0598799   .7768887



  +--------------------------+
  |  obs:         ps    seqn |
  |--------------------------|
  |  979.   .0510008   22941 |
  |  945.   .0527126    1769 |
  | 1023.   .0558418   21140 |
  |  115.   .0558752    2522 |
  |  478.   .0567372   12639 |
  +--------------------------+

  +--------------------------+
  | 1173.   .6659576   22272 |
  | 1033.   .6814955   22773 |
  | 1551.   .7166381   14983 |
  | 1494.   .7200644   24817 |
  | 1303.   .7768887   24949 |
  +--------------------------+


------------------------------------------------------------------------------------------
-> qsmk = No smoking cessation

  +--------------------------+
  |  obs:         ps    seqn |
  |--------------------------|
  |  979.   .0510008   22941 |
  |  945.   .0527126    1769 |
  | 1023.   .0558418   21140 |
  |  115.   .0558752    2522 |
  |  478.   .0567372   12639 |
  +--------------------------+

  +--------------------------+
  |  463.   .6337243   17096 |
  |  812.   .6345721   17768 |
  |  707.   .6440308   19147 |
  |  623.   .6566707   21983 |
```

```
| 1033.   .6814955   22773 |
+--------------------------+

-------------------------------------------------------------------------------------
-> qsmk = Smoking cessation

+--------------------------+
|  obs:         ps     seqn |
|--------------------------|
| 1223.   .0598799     4289 |
| 1283.   .0600822    23550 |
| 1253.   .0806089    24306 |
| 1467.   .0821677    22904 |
| 1165.   .1021875    24584 |
+--------------------------+

+--------------------------+
| 1399.    .635695    17738 |
| 1173.   .6659576    22272 |
| 1551.   .7166381    14983 |
| 1494.   .7200644    24817 |
| 1303.   .7768887    24949 |
+--------------------------+

file ./data/nhefs-ps.dta saved
```




## Program 15.3

- Stratification and outcome regression using deciles of the propensity score
- Data from NHEFS
- Section 15.3

- Note: Stata decides borderline cutpoints differently from SAS, so, despite identically distributed propensity scores, the results of regression using deciles are not an exact match with the book.

```
use ./data/nhefs-ps, clear

/*Calculation of deciles of ps*/
xtile ps_dec = ps, nq(10)
by ps_dec, sort: summarize ps

/*Stratification on PS deciles, allowing for effect modification*/
/*Note: Stata compares qsmk 0 vs qsmk 1, so the coefficients are reversed
relative to the book*/
by ps_dec: ttest wt82_71, by(qsmk)

/*Regression on PS deciles, with no product terms*/
regress wt82_71 qsmk ib(last).ps_dec
```

```
-> ps_dec = 1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157    .0976251    .0185215    .0510008   .1240482

--------------------------------------------------------------------------------------
-> ps_dec = 2

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157    .1430792    .0107751    .1241923   .1603558

--------------------------------------------------------------------------------------
-> ps_dec = 3

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        156    .1750423     .008773    .1606041   .1893271

--------------------------------------------------------------------------------------
-> ps_dec = 4

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157    .2014066    .0062403     .189365   .2121815

--------------------------------------------------------------------------------------
-> ps_dec = 5

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        156    .2245376    .0073655    .2123068    .237184

--------------------------------------------------------------------------------------
-> ps_dec = 6
```

```
    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157    .2515298    .0078777   .2377578   .2655718

-------------------------------------------------------------------------------------
-> ps_dec = 7

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157    .2827476    .0099986   .2655724   .2994968

-------------------------------------------------------------------------------------
-> ps_dec = 8

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        156    .3204104    .0125102   .2997581   .3438773

-------------------------------------------------------------------------------------
-> ps_dec = 9

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        157     .375637    .0221347   .3439862   .4174631

-------------------------------------------------------------------------------------
-> ps_dec = 10

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          ps |        156    .5026508    .0733494   .4176717   .7768887



-------------------------------------------------------------------------------------
-> ps_dec = 1

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     146     3.74236    .6531341    7.891849    2.451467    5.033253
 Smoking |      11    3.949703    2.332995    7.737668   -1.248533     9.14794
---------+--------------------------------------------------------------------
Combined |     157    3.756887    .6270464    7.856869     2.51829    4.995484
---------+--------------------------------------------------------------------
    diff |           -.2073431    2.464411               -5.075509    4.660822
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -0.0841
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.4665         Pr(|T| > |t|) = 0.9331          Pr(T > t) = 0.5335
```

```
------------------------------------------------------------------------------------------
-> ps_dec = 2

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     134    2.813019     .589056    6.818816    1.647889    3.978149
 Smoking |      23    7.726944    1.260784    6.046508    5.112237    10.34165
---------+--------------------------------------------------------------------
Combined |     157    3.532893    .5519826    6.916322    2.442569    4.623217
---------+--------------------------------------------------------------------
    diff |           -4.913925    1.515494               -7.907613   -1.920237
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -3.2425
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0007         Pr(|T| > |t|) = 0.0015          Pr(T > t) = 0.9993

------------------------------------------------------------------------------------------
-> ps_dec = 3

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     128     3.25684    .5334655    6.035473    2.201209    4.312472
 Smoking |      28    7.954974    1.418184    7.504324    5.045101    10.86485
---------+--------------------------------------------------------------------
Combined |     156    4.100095    .5245749    6.551938    3.063857    5.136334
---------+--------------------------------------------------------------------
    diff |           -4.698134    1.318074               -7.301973   -2.094294
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -3.5644
H0: diff = 0                                     Degrees of freedom =      154

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0002         Pr(|T| > |t|) = 0.0005          Pr(T > t) = 0.9998

------------------------------------------------------------------------------------------
-> ps_dec = 4

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     121    3.393929    .5267602    5.794362    2.350981    4.436877
 Smoking |      36    5.676072    1.543143    9.258861    2.543324    8.808819
---------+--------------------------------------------------------------------
Combined |     157    3.917223    .5412091     6.78133    2.848179    4.986266
---------+--------------------------------------------------------------------
```

```
    diff |          -2.282143    1.278494               -4.807663    .2433778
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -1.7850
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0381         Pr(|T| > |t|) = 0.0762          Pr(T > t) = 0.9619

--------------------------------------------------------------------------------------
-> ps_dec = 5

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     119    1.368438    .8042619    8.773461   -.2242199    2.961095
 Smoking |      37    5.195421    1.388723     8.44727    2.378961    8.011881
---------+--------------------------------------------------------------------
Combined |     156     2.27612    .7063778    8.822656    .8807499    3.671489
---------+--------------------------------------------------------------------
    diff |          -3.826983    1.637279               -7.061407    -.592559
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -2.3374
H0: diff = 0                                     Degrees of freedom =      154

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0104         Pr(|T| > |t|) = 0.0207          Pr(T > t) = 0.9896

--------------------------------------------------------------------------------------
-> ps_dec = 6

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     112     2.25564    .6850004    7.249362    .8982664    3.613014
 Smoking |      45    7.199088    1.724899    11.57097    3.722782    10.67539
---------+--------------------------------------------------------------------
Combined |     157    3.672552    .7146582    8.954642    2.260897    5.084207
---------+--------------------------------------------------------------------
    diff |          -4.943447    1.535024               -7.975714   -1.911181
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -3.2204
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0008         Pr(|T| > |t|) = 0.0016          Pr(T > t) = 0.9992

--------------------------------------------------------------------------------------
-> ps_dec = 7

Two-sample t test with equal variances
------------------------------------------------------------------------------
```

```
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     116    .7948483    .7916172    8.525978    -.773193     2.36289
 Smoking |      41    6.646091     1.00182    6.414778    4.621337    8.670844
---------+--------------------------------------------------------------------
Combined |     157     2.32288    .6714693    8.413486    .9965349    3.649225
---------+--------------------------------------------------------------------
    diff |           -5.851242     1.45977               -8.734853   -2.967632
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -4.0083
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0001          Pr(T > t) = 1.0000

--------------------------------------------------------------------------------------
-> ps_dec = 8

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     107    1.063848    .5840159    6.041107   -.0940204    2.221716
 Smoking |      49    3.116263    1.113479    7.794356    .8774626    5.355063
---------+--------------------------------------------------------------------
Combined |     156    1.708517    .5352016    6.684666    .6512864    2.765747
---------+--------------------------------------------------------------------
    diff |           -2.052415    1.144914                -4.31418    .2093492
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -1.7926
H0: diff = 0                                     Degrees of freedom =      154

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0375         Pr(|T| > |t|) = 0.0750          Pr(T > t) = 0.9625

--------------------------------------------------------------------------------------
-> ps_dec = 9

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |     100   -.0292906    .7637396    7.637396   -1.544716    1.486134
 Smoking |      57    .9112647    .9969309    7.526663   -1.085828    2.908357
---------+--------------------------------------------------------------------
Combined |     157    .3121849    .6054898    7.586766   -.8838316    1.508201
---------+--------------------------------------------------------------------
    diff |           -.9405554     1.26092                -3.43136    1.550249
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -0.7459
H0: diff = 0                                     Degrees of freedom =      155

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
```

```
 Pr(T < t) = 0.2284         Pr(|T| > |t|) = 0.4568          Pr(T > t) = 0.7716

-------------------------------------------------------------------------------------
-> ps_dec = 10

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
No smoki |      80    -.768504    .9224756    8.250872   -2.604646    1.067638
 Smoking |      76     2.39532    1.053132    9.180992    .2973737    4.493267
---------+--------------------------------------------------------------------
Combined |     156    .7728463    .7071067    8.831759   -.6239631    2.169656
---------+--------------------------------------------------------------------
    diff |           -3.163824    1.396178               -5.921957    -.405692
------------------------------------------------------------------------------
    diff = mean(No smoki) - mean(Smoking)                         t =  -2.2661
H0: diff = 0                                     Degrees of freedom =      154

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0124         Pr(|T| > |t|) = 0.0248          Pr(T > t) = 0.9876

      Source |       SS           df       MS      Number of obs   =     1,566
-------------+----------------------------------   F(10, 1555)     =      9.87
       Model |   5799.7817        10   579.97817   Prob > F        =    0.0000
    Residual |  91375.8049     1,555  58.7625755   R-squared       =    0.0597
-------------+----------------------------------   Adj R-squared   =    0.0536
       Total |  97175.5866     1,565  62.0930266   Root MSE        =    7.6657

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   3.356927   .4580399     7.33   0.000     2.458486    4.255368
             |
      ps_dec |
          1  |   4.384269   .8873947     4.94   0.000     2.643652    6.124885
          2  |   3.903694   .8805212     4.43   0.000      2.17656    5.630828
          3  |    4.36015   .8793345     4.96   0.000     2.635343    6.084956
          4  |   4.010061   .8745966     4.59   0.000     2.294548    5.725575
          5  |   2.342505   .8754878     2.68   0.008     .6252438    4.059766
          6  |   3.572955   .8714389     4.10   0.000     1.863636    5.282275
          7  |    2.30881   .8727462     2.65   0.008     .5969261    4.020693
          8  |   1.516677   .8715796     1.74   0.082    -.1929182    3.226273
          9  |  -.0439923   .8684465    -0.05   0.960    -1.747442    1.659457
             |
       _cons |  -.8625798   .6530529    -1.32   0.187    -2.143537    .4183773
------------------------------------------------------------------------------
```

# Program 15.4

- Standardization and outcome regression using the propensity score
- Data from NHEFS

- Section 15.3

```
use ./data/nhefs-formatted, clear

/*Estimate the propensity score*/
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity ///
  c.smokeyrs##c.smokeyrs ib(last).exercise ///
  ib(last).active c.wt71##c.wt71
predict ps, pr

/*Expand the dataset for standardization*/
expand 2, generate(interv)
expand 2 if interv == 0, generate(interv2)
replace interv = -1 if interv2 ==1
drop interv2
tab interv
replace wt82_71 = . if interv != -1
replace qsmk = 0 if interv == 0
replace qsmk = 1 if interv == 1
by interv, sort: summarize qsmk

/*Regression on the propensity score, allowing for effect modification*/
regress wt82_71 qsmk##c.ps
predict predY, xb
by interv, sort: summarize predY

quietly summarize predY if(interv == -1)
matrix input observe = (-1,`r(mean)')
quietly summarize predY if(interv == 0)
matrix observe = (observe \0,`r(mean)')
quietly summarize predY if(interv == 1)
matrix observe = (observe \1,`r(mean)')
matrix observe = (observe \., observe[3,2]-observe[2,2])
matrix rownames observe = observed E(Y(a=0)) E(Y(a=1)) difference
matrix colnames observe = interv value
matrix list observe

/*bootstrap program*/
drop if interv != -1
gen meanY_b =.
qui save ./data/nhefs_std, replace

capture program drop bootstdz

program define bootstdz, rclass
use ./data/nhefs_std, clear
preserve
bsample
/*Create 2 new copies of the data.
Set the outcome AND the exposure to missing in the copies*/
expand 2, generate(interv_b)
expand 2 if interv_b == 0, generate(interv2_b)
```

```
qui replace interv_b = -1 if interv2_b ==1
qui drop interv2_b
qui replace wt82_71 = . if interv_b != -1
qui replace qsmk = . if interv_b != -1

/*Fit the propensity score in the original data
(where qsmk is not missing) and generate predictions for everyone*/
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity ///
    c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
    c.wt71##c.wt71
predict ps_b, pr

/*Set the exposure to 0 for everyone in copy 0,
and 1 to everyone for copy 1*/
qui replace qsmk = 0 if interv_b == 0
qui replace qsmk = 1 if interv_b == 1

/*Fit the outcome regression in the original data
(where wt82_71 is not missing) and
generate predictions for everyone*/
regress wt82_71 qsmk##c.ps
predict predY_b, xb

/*Summarize the predictions in each set of copies*/
summarize predY_b if interv_b == 0
return scalar boot_0 = r(mean)
summarize predY_b if interv_b == 1
return scalar boot_1 = r(mean)
return scalar boot_diff = return(boot_1) - return(boot_0)
qui drop meanY_b
restore
end

/*Then we use the `simulate` command to run the bootstraps
as many times as we want.
Start with reps(10) to make sure your code runs,
and then change to reps(1000) to generate your final CIs*/
simulate EY_a0=r(boot_0) EY_a1 = r(boot_1) ///
  difference = r(boot_diff), reps(500) seed(1): bootstdz

matrix pe = observe[2..4, 2]'
matrix list pe
bstat, stat(pe) n(1629)
estat bootstrap, p
```

```
Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
```

```
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
            qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-----------------+------------------------------------------------------------------
             sex |  -.5274782   .1540497    -3.42   0.001      -.82941   -.2255463
            race |  -.8392636   .2100668    -4.00   0.000    -1.250987   -.4275404
             age |   .1212052   .0512663     2.36   0.018     .0207251    .2216853
                 |
     c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753    .0002262
                 |
       education |
              1  |  -.4759606   .2262238    -2.10   0.035    -.9193511   -.0325701
              2  |  -.5047361    .217597    -2.32   0.020    -.9312184   -.0782538
              3  |  -.3895288   .1914353    -2.03   0.042    -.7647351   -.0143226
              4  |  -.4123596   .2772868    -1.49   0.137    -.9558318    .1311126
                 |
  smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                 |
c.smokeintensity#|
c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                 |
        smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                 |
     c.smokeyrs#|
      c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
                 |
        exercise |
              0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
              1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
                 |
          active |
              0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
              1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
                 |
            wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
                 |
   c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
                 |
           _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------

(1,566 observations created)

(1,566 observations created)

(1,566 real changes made)
```

```
  Expanded observation |
                  type |      Freq.     Percent        Cum.
-----------------------+-----------------------------------
                    -1 |      1,566       33.33       33.33
  Original observation |      1,566       33.33       66.67
Duplicated observation |      1,566       33.33      100.00
-----------------------+-----------------------------------
                 Total |      4,698      100.00

(3,132 real changes made, 3,132 to missing)

(403 real changes made)

(1,163 real changes made)


-------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566    .2573436    .4373099          0          1

-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566           0           0          0          0

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
        qsmk |      1,566           1           0          1          1

      Source |       SS           df       MS      Number of obs   =     1,566
-------------+----------------------------------   F(3, 1562)      =     29.96
       Model |  5287.31428         3  1762.43809   Prob > F        =    0.0000
    Residual |  91888.2723     1,562   58.827319   R-squared       =    0.0544
-------------+----------------------------------   Adj R-squared   =    0.0526
       Total |  97175.5866     1,565  62.0930266   Root MSE        =    7.6699

-----------------------------------------------------------------------------------
           wt82_71 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------------+---------------------------------------------------------------
              qsmk |
Smoking cessation  |   4.036457    1.13904     3.54   0.000      1.80225    6.270665
                ps |   -12.3319   2.129602    -5.79   0.000    -16.50908   -8.154716
                   |
         qsmk#c.ps |
Smoking cessation  |  -2.038829   3.649684    -0.56   0.576    -9.197625    5.119967
```

```
                 |
           _cons |   4.935432   .5570216     8.86   0.000     3.842843    6.028021
------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------
-> interv = -1

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566      2.6383    1.838063    -3.4687   8.111371

-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566    1.761898    1.433264  -4.645079   4.306496

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       predY |      1,566    5.273676    1.670225  -2.192565   8.238971
```

```
observe[4,2]
               interv      value
  observed         -1  2.6382998
 E(Y(a=0))          0  1.7618979
 E(Y(a=1))          1  5.2736757
difference          .  3.5117778

(3,132 observations deleted)

(1,566 missing values generated)
```

```
 11. predict ps_b, pr
 12.
```

```
      Command: bootstdz
        EY_a0: r(boot_0)
        EY_a1: r(boot_1)
   difference: r(boot_diff)

Simulations (500)
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..................................................    50
..................................................   100
..................................................   150
..................................................   200
..................................................   250
..................................................   300
..................................................   350
..................................................   400
..................................................   450
..................................................   500



pe[1,3]
        E(Y(a=0))   E(Y(a=1))  difference
value   1.7618979   5.2736757   3.5117778


Bootstrap results                                       Number of obs = 1,629
                                                        Replications  =   500

------------------------------------------------------------------------------
             |   Observed   Bootstrap                         Normal-based
             | coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       EY_a0 |   1.761898   .2255637     7.81   0.000     1.319801    2.203995
       EY_a1 |   5.273676   .4695378    11.23   0.000     4.353399    6.193953
  difference |   3.511778   .4970789     7.06   0.000     2.537521    4.486035
------------------------------------------------------------------------------


Bootstrap results                               Number of obs     =      1,629
                                                Replications      =        500

------------------------------------------------------------------------------
             |    Observed               Bootstrap
             | coefficient       Bias    std. err.  [95% conf. interval]
-------------+----------------------------------------------------------------
       EY_a0 |   1.7618979   .0026735   .22556365    1.269908   2.186845   (P)
       EY_a1 |   5.2736757  -.0049491   .46953779     4.34944   6.109205   (P)
  difference |   3.5117778  -.0076226   .49707894    2.466025   4.424034   (P)
------------------------------------------------------------------------------
Key: P: Percentile
```

# 16. Instrumental variables estimation: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

## Program 16.1

- Estimating the average causal effect using the standard IV estimator via the calculation of sample averages
- Data from NHEFS
- Section 16.2

```
use ./data/nhefs-formatted, clear

summarize price82

/* ignore subjects with missing outcome or missing instrument for simplicity*/
foreach var of varlist wt82 price82 {
  drop if `var'==.
}

/*Create categorical instrument*/
gen byte highprice = (price82 > 1.5 & price82 < .)

save ./data/nhefs-highprice, replace

/*Calculate P[Z|A=a]*/
tab highprice qsmk, row

/*Calculate P[Y|Z=z]*/
ttest wt82_71, by(highprice)

/*Final IV estimate, OPTION 1: Hand calculations*/
/*Numerator: num = E[Y|Z=1] - E[Y|Z=0] = 2.686 - 2.536 = 0.150*/
/*Denominator: denom = P[A=1|Z=1] - P[A=1|Z=0] = 0.258 - 0.195 = 0.063 */
```

```
/*IV estimator: E[Ya=1] - E[Ya=0] =
(E[Y|Z=1]-E[Y|Z=0])/(P[A=1|Z=1]-P[A=1|Z=0]) = 0.150/0.063 = 2.397*/
display "Numerator, E[Y|Z=1] - E[Y|Z=0] =", 2.686 - 2.536
display "Denominator: denom = P[A=1|Z=1] - P[A=1|Z=0] =", 0.258 - 0.195
display "IV estimator =", 0.150/0.063

/*OPTION 2 2: automated calculation of instrument*/
/*Calculate P[A=1|Z=z], for each value of the instrument,
and store in a matrix*/
quietly summarize qsmk if (highprice==0)
matrix input pa = (`r(mean)')
quietly summarize qsmk if (highprice==1)
matrix pa = (pa ,`r(mean)')
matrix list pa

/*Calculate P[Y|Z=z], for each value of the instrument,
and store in a second matrix*/
quietly summarize wt82_71 if (highprice==0)
matrix input ey = (`r(mean)')
quietly summarize wt82_71 if (highprice==1)
matrix ey = (ey ,`r(mean)')
matrix list ey

/*Using Stata's built-in matrix manipulation feature (Mata),
calculate numerator, denominator and IV estimator*/
*Numerator: num = E[Y|Z=1] - E[Y|Z=0]*mata
*Denominator: denom = P[A=1|Z=1] - P[A=1|Z=0]*
*IV estimator: iv_est = IV estimate of E[Ya=1] - E[Ya=0] *
mata
pa = st_matrix("pa")
ey = st_matrix("ey")
num = ey[1,2] - ey[1,1]
denom = pa[1,2] - pa[1,1]
iv_est = num / denom
num
denom
st_numscalar("iv_est", iv_est)
end
di scalar(iv_est)
```

```
    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
     price82 |      1,476    1.805989    .1301703   1.451904   2.103027

(0 observations deleted)
(90 observations deleted)


file ./data/nhefs-highprice.dta saved


+-----------------+
| Key             |
```

```
|---------------┤
|   frequency    |
| row percentage |
+----------------+

           | quit smoking between
           |   baseline and 1982
 highprice | No smokin  Smoking c |     Total
-----------+----------------------+----------
         0 |        33          8 |        41 
           |     80.49      19.51 |    100.00 
-----------+----------------------+----------
         1 |     1,065        370 |     1,435 
           |     74.22      25.78 |    100.00 
-----------+----------------------+----------
     Total |     1,098        378 |     1,476 
           |     74.39      25.61 |    100.00 


Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
       0 |      41    2.535729    1.461629    9.358993   -.4183336    5.489792
       1 |   1,435    2.686018    .2084888    7.897848    2.277042    3.094994
---------+--------------------------------------------------------------------
Combined |   1,476    2.681843    .2066282    7.938395    2.276527    3.087159
---------+--------------------------------------------------------------------
    diff |           -.1502887    1.257776               -2.617509    2.316932
------------------------------------------------------------------------------
    diff = mean(0) - mean(1)                                      t =  -0.1195
H0: diff = 0                                     Degrees of freedom =     1474

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.4525         Pr(|T| > |t|) = 0.9049          Pr(T > t) = 0.5475

Numerator, E[Y|Z=1] - E[Y|Z=0] = .15

Denominator: denom = P[A=1|Z=1] - P[A=1|Z=0] = .063

IV estimator = 2.3809524
```

```
pa[1,2]
           c1          c2
r1  .19512195   .25783972
```

```
ey[1,2]
           c1          c2
r1   2.535729   2.6860178

------------------------------------------------- mata (type end to exit) ------------
: pa = st_matrix("pa")

: ey = st_matrix("ey")

: num = ey[1,2] - ey[1,1]

: denom = pa[1,2] - pa[1,1]

: iv_est = num / denom

: num
  .1502887173

: denom
  .06271777

: st_numscalar("iv_est", iv_est)

: end
--------------------------------------------------------------------------------------

2.3962701
```

# Program 16.2

- Estimating the average causal effect using the standard IV estimator via two-stage-least-squares regression
- Data from NHEFS
- Section 16.2

```
use ./data/nhefs-highprice, clear

/* ivregress fits the model in two stages:
- first model: qsmk = highprice
- second model: wt82_71 = predicted_qsmk */
ivregress 2sls wt82_71 (qsmk = highprice)
```

```
Instrumental variables 2SLS regression            Number of obs   =      1,476
                                                  Wald chi2(1)    =       0.01
                                                  Prob > chi2     =     0.9038
                                                  R-squared       =     0.0213
                                                  Root MSE        =     7.8508

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
```

```
-------------+----------------------------------------------------------------
        qsmk |    2.39627   19.82659     0.12   0.904    -36.46313    41.25567
       _cons |   2.068164   5.081652     0.41   0.684     -7.89169    12.02802
------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: highprice
```

# Program 16.3

- Estimating the average causal effect using the standard IV estimator via an additive marginal structural model
- Data from NHEFS
- Checking one possible value of psi.
- See Chapter 14 for program that checks several values and computes 95% confidence intervals

- Section 16.2

```
use ./data/nhefs-highprice, clear

gen psi = 2.396
gen hspi = wt82_71 - psi*qsmk

logit highprice hspi
```

```
Iteration 0:   log likelihood = -187.34948
Iteration 1:   log likelihood = -187.34948

Logistic regression                                     Number of obs =  1,476
                                                        LR chi2(1)    =   0.00
                                                        Prob > chi2   = 1.0000
Log likelihood = -187.34948                             Pseudo R2     = 0.0000

------------------------------------------------------------------------------
   highprice | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        hspi |   2.75e-07   .0201749     0.00   1.000    -.0395419    .0395424
       _cons |   3.555347   .1637931    21.71   0.000     3.234319    3.876376
------------------------------------------------------------------------------
```

# Program 16.4

- Estimating the average causal effect using the standard IV estimator based on alternative proposed instruments
- Data from NHEFS
- Section 16.5

```
use ./data/nhefs-highprice, clear

/*Instrument cut-point: 1.6*/
replace highprice = .
replace highprice = (price82 >1.6 & price82 < .)

ivregress 2sls wt82_71 (qsmk = highprice)
```

```
/*Instrument cut-point: 1.7*/
replace highprice = .
replace highprice = (price82 >1.7 & price82 < .)

ivregress 2sls wt82_71 (qsmk = highprice)

/*Instrument cut-point: 1.8*/
replace highprice = .
replace highprice = (price82 >1.8 & price82 < .)

ivregress 2sls wt82_71 (qsmk = highprice)

/*Instrument cut-point: 1.9*/
replace highprice = .
replace highprice = (price82 >1.9 & price82 < .)

ivregress 2sls wt82_71 (qsmk = highprice)
```

```
(1,476 real changes made, 1,476 to missing)

(1,476 real changes made)


Instrumental variables 2SLS regression          Number of obs     =      1,476
                                                Wald chi2(1)      =       0.06
                                                Prob > chi2       =     0.8023
                                                R-squared         =          .
                                                Root MSE          =     18.593

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |   41.28124   164.8417     0.25   0.802    -281.8026     364.365
       _cons |  -7.890182   42.21833    -0.19   0.852    -90.63659    74.85623
------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: highprice

(1,476 real changes made, 1,476 to missing)

(1,476 real changes made)


Instrumental variables 2SLS regression          Number of obs     =      1,476
                                                Wald chi2(1)      =       0.05
                                                Prob > chi2       =     0.8274
                                                R-squared         =          .
                                                Root MSE          =     20.577

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |  -40.91185   187.6162    -0.22   0.827    -408.6328    326.8091
```

```
       _cons |   13.15927   48.05103     0.27   0.784    -81.01901    107.3375
------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: highprice

(1,476 real changes made, 1,476 to missing)

(1,476 real changes made)


Instrumental variables 2SLS regression            Number of obs   =      1,476
                                                  Wald chi2(1)    =       0.55
                                                  Prob > chi2     =     0.4576
                                                  R-squared       =          .
                                                  Root MSE        =      13.01

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |  -21.10342   28.40885    -0.74   0.458    -76.78374    34.57691
       _cons |   8.086377   7.283314     1.11   0.267    -6.188657    22.36141
------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: highprice

(1,476 real changes made, 1,476 to missing)

(1,476 real changes made)


Instrumental variables 2SLS regression            Number of obs   =      1,476
                                                  Wald chi2(1)    =       0.29
                                                  Prob > chi2     =     0.5880
                                                  R-squared       =          .
                                                  Root MSE        =     10.357

------------------------------------------------------------------------------
     wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
        qsmk |  -12.81141   23.65099    -0.54   0.588    -59.16649    33.54368
       _cons |   5.962813   6.062956     0.98   0.325    -5.920362    17.84599
------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: highprice
```

## Program 16.5

- Estimating the average causal effect using the standard IV estimator conditional on baseline covariates
- Data from NHEFS
- Section 16.5

```
use ./data/nhefs-highprice, clear

replace highprice = .
replace highprice = (price82 >1.5 & price82 < .)

ivregress 2sls wt82_71 sex race c.age c.smokeintensity ///
  c.smokeyrs i.exercise i.active c.wt7 ///
  (qsmk = highprice)
```

```
(1,476 real changes made, 1,476 to missing)

(1,476 real changes made)


Instrumental variables 2SLS regression          Number of obs   =      1,476
                                                Wald chi2(11)   =     135.18
                                                Prob > chi2     =     0.0000
                                                R-squared       =     0.0622
                                                Root MSE        =     7.6848

--------------------------------------------------------------------------------
       wt82_71 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
---------------+----------------------------------------------------------------
          qsmk |  -1.042295   29.86522    -0.03   0.972    -59.57705    57.49246
           sex |  -1.644393   2.620115    -0.63   0.530    -6.779724    3.490938
          race |  -.1832546   4.631443    -0.04   0.968    -9.260716    8.894207
           age |    -.16364   .2395678    -0.68   0.495    -.6331844    .3059043
smokeintensity |   .0057669    .144911     0.04   0.968    -.2782534    .2897872
      smokeyrs |   .0258357   .1607639     0.16   0.872    -.2892558    .3409271
               |
      exercise |
            1  |   .4987479   2.162395     0.23   0.818    -3.739469    4.736964
            2  |   .5818337   2.174255     0.27   0.789    -3.679628    4.843296
               |
        active |
            1  |  -1.170145   .6049921    -1.93   0.053    -2.355908    .0156176
            2  |  -.5122842   1.303121    -0.39   0.694    -3.066355    2.041787
               |
          wt71 |  -.0979493    .036123    -2.71   0.007     -.168749   -.0271496
         _cons |   17.28033    2.32589     7.43   0.000     12.72167    21.83899
--------------------------------------------------------------------------------
Instrumented: qsmk
 Instruments: sex race age smokeintensity smokeyrs 1.exercise 2.exercise
              1.active 2.active wt71 highprice
```

# 17. Causal survival analysis: Stata

```
library(Statamarkdown)
```

```
/***************************************************************
Stata code for Causal Inference: What If by Miguel Hernan & Jamie Robins
Date: 10/10/2019
Author: Eleanor Murray
For errors contact: ejmurray@bu.edu
***************************************************************/
```

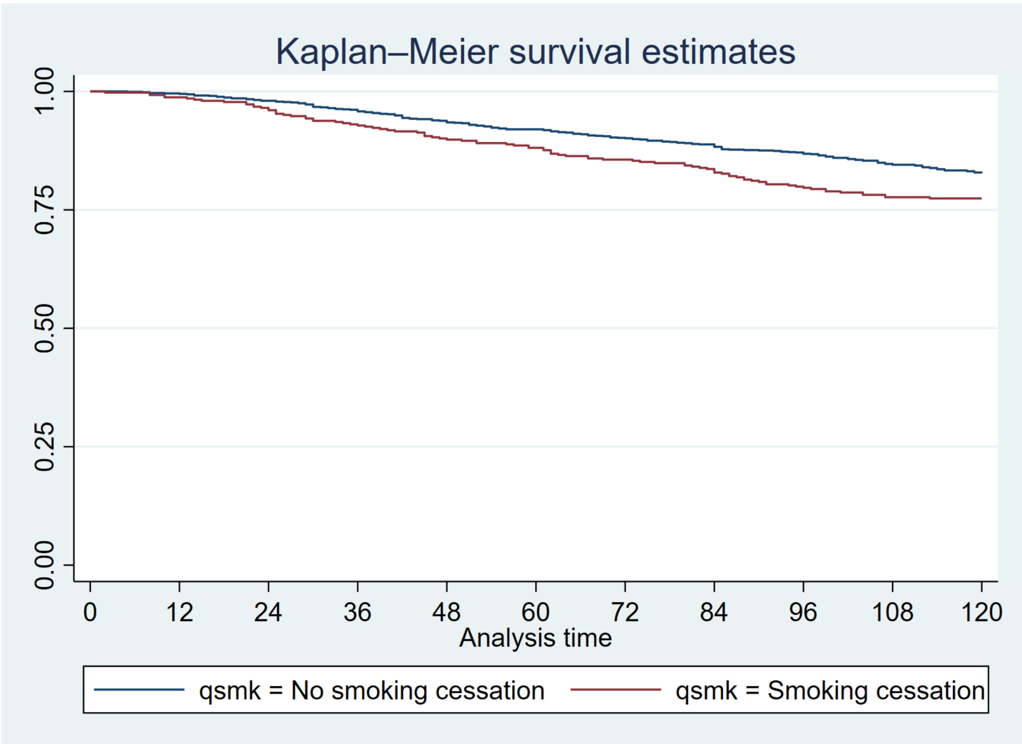
## Program 17.1

- Nonparametric estimation of survival curves
- Data from NHEFS
- Section 17.1

```
use ./data/nhefs-formatted, clear

/*Some preprocessing of the data*/
gen survtime = .
replace survtime = 120 if death == 0
replace survtime = (yrdth - 83)*12 + modth if death ==1
* yrdth ranges from 83 to 92*

tab death qsmk

/*Kaplan-Meier graph of observed survival over time, by quitting smoking*/
*For now, we use the stset function in Stata*
stset survtime, failure(death=1)
sts graph, by(qsmk) xlabel(0(12)120)
qui gr export ./figs/stata-fig-17-1.png, replace
```

```
(1,566 missing values generated)

(1,275 real changes made)

(291 real changes made)

     death |
   between | quit smoking between
  1983 and |   baseline and 1982
      1992 | No smokin  Smoking c |     Total
-----------+----------------------+----------
```

```
         0 |       963         312 |     1,275
         1 |       200          91 |       291
-----------+----------------------+----------
     Total |     1,163         403 |     1,566


Survival-time data settings

         Failure event: death==1
Observed time interval: (0, survtime]
     Exit on or before: failure

--------------------------------------------------------------------------
      1,566  total observations
          0  exclusions
--------------------------------------------------------------------------
      1,566  observations remaining, representing
        291  failures in single-record/single-failure data
    171,076  total analysis time at risk and under observation
                                                At risk from t =         0
                                     Earliest observed entry t =         0
                                          Last observed exit t =       120

        Failure _d: death==1
  Analysis time _t: survtime
```




## Program 17.2

- Parametric estimation of survival curves via hazards model
- Data from NHEFS
- Section 17.1

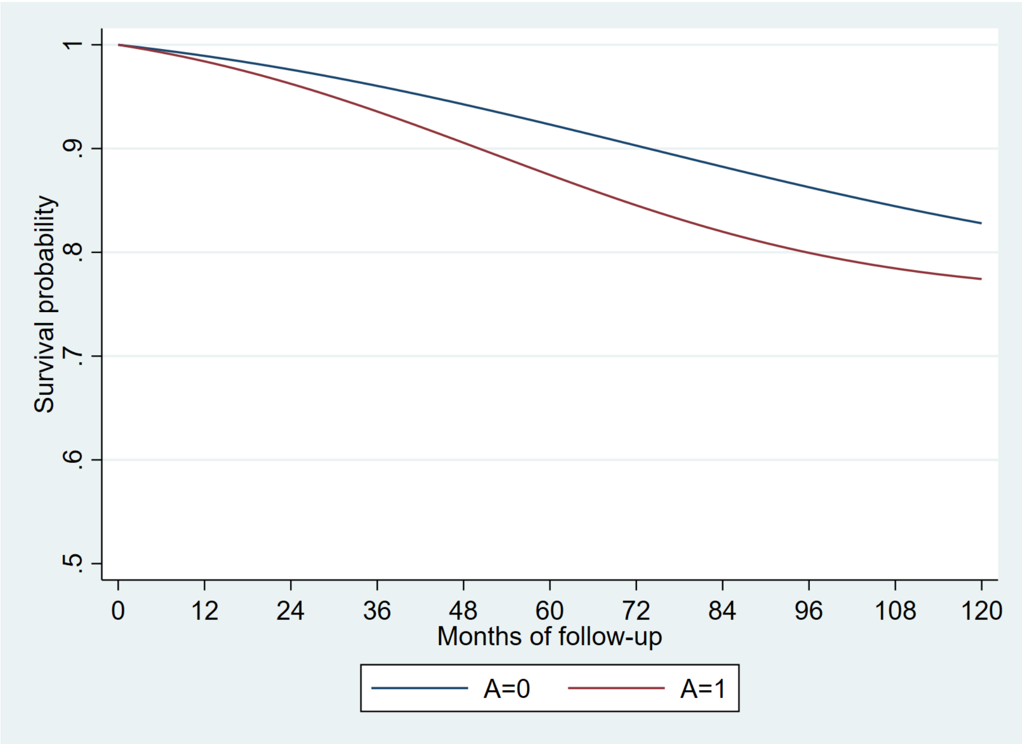
- Generates Figure 17.4

```
/**Create person-month dataset for survival analyses**/

/* We want our new dataset to include 1 observation per person
per month alive, starting at time = 0.
Individuals who survive to the end of follow-up will have
119 time points
Individuals who die will have survtime - 1 time points*/

use ./data/nhefs-formatted, clear

gen survtime = .
replace survtime = 120 if death == 0
replace survtime = (yrdth - 83)*12 + modth if death ==1

*expand data to person-time*
gen time = 0
expand survtime if time == 0
bysort seqn: replace time = _n - 1

*Create event variable*
gen event = 0
replace event = 1 if time == survtime - 1 & death == 1
tab event

*Create time-squared variable for analyses*
gen timesq = time*time

*Save the dataset to your working directory for future use*
qui save ./data/nhefs_surv, replace

/**Hazard ratios**/
use ./data/nhefs_surv, clear

*Fit a pooled logistic hazards model *
logistic event qsmk qsmk#c.time qsmk#c.time#c.time ///
  c.time c.time#c.time

/**Survival curves: run regression then do:**/

*Create a dataset with all time points under each treatment level*
*Re-expand data with rows for all timepoints*
drop if time != 0
expand 120 if time ==0
bysort seqn: replace time = _n - 1

/*Create 2 copies of each subject, and set outcome to missing
and treatment -- use only the newobs*/
expand 2 , generate(interv)
replace qsmk = interv

/*Generate predicted event and survival probabilities
```

```
for each person each month in copies*/
predict pevent_k, pr
gen psurv_k = 1-pevent_k
keep seqn time qsmk interv psurv_k

*Within copies, generate predicted survival over time*
*Remember, survival is the product of conditional survival probabilities in each interval*
sort seqn interv time
gen _t = time + 1
gen psurv = psurv_k if _t ==1
bysort seqn interv: replace psurv = psurv_k*psurv[_t-1] if _t >1

*Display 10-year standardized survival, under interventions*
*Note: since time starts at 0, month 119 is 10-year survival*
by interv, sort: summarize psurv if time == 119

*Graph of standardized survival over time, under interventions*
/*Note, we want our graph to start at 100% survival,
so add an extra time point with P(surv) = 1*/
expand 2 if time ==0, generate(newtime)
replace psurv  = 1 if newtime == 1
gen time2 = 0 if newtime ==1
replace time2 = time + 1 if newtime == 0

/*Separate the survival probabilities to allow plotting by
intervention on qsmk*/
separate psurv, by(interv)

*Plot the curves*
twoway (line psurv0 time2, sort) ///
  (line psurv1 time2, sort) if interv > -1 ///
  , ylabel(0.5(0.1)1.0) xlabel(0(12)120) ///
  ytitle("Survival probability") xtitle("Months of follow-up") ///
  legend(label(1 "A=0") label(2 "A=1"))
qui gr export ./figs/stata-fig-17-2.png, replace
```

```
(1,566 missing values generated)

(1,275 real changes made)

(291 real changes made)


(169,510 observations created)

(169510 real changes made)


(291 real changes made)

      event |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |    170,785       99.83       99.83
```

```
         1 |        291        0.17      100.00
------------+-----------------------------------
      Total |    171,076      100.00


file ./data/nhefs_surv.dta cannot be modified or erased; likely cause is read-only
    directory or file
r(608);

end of do-file
r(608);
```




## Program 17.3

- Estimation of survival curves via IP weighted hazards model
- Data from NHEFS
- Section 17.4
- Generates Figure 17.6

```
use ./data/nhefs_surv, clear

keep seqn event qsmk time sex race age education ///
  smokeintensity smkintensity82_71 smokeyrs ///
  exercise active wt71
preserve

*Estimate weights*
logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity ///
  c.smokeyrs##c.smokeyrs ib(last).exercise ///
  ib(last).active c.wt71##c.wt71 if time == 0
```

```
predict p_qsmk, pr

logit qsmk if time ==0
predict num, pr
gen sw=num/p_qsmk if qsmk==1
replace sw=(1-num)/(1-p_qsmk) if qsmk==0
summarize sw

*IP weighted survival by smoking cessation*
logit event qsmk qsmk#c.time qsmk#c.time#c.time ///
  c.time c.time#c.time [pweight=sw] , cluster(seqn)

*Create a dataset with all time points under each treatment level*
*Re-expand data with rows for all timepoints*
drop if time != 0
expand 120 if time ==0
bysort seqn: replace time = _n - 1

/*Create 2 copies of each subject, and set outcome
to missing and treatment -- use only the newobs*/
expand 2 , generate(interv)
replace qsmk = interv

/*Generate predicted event and survival probabilities
for each person each month in copies*/
predict pevent_k, pr
gen psurv_k = 1-pevent_k
keep seqn time qsmk interv psurv_k

*Within copies, generate predicted survival over time*
/*Remember, survival is the product of conditional survival
probabilities in each interval*/
sort seqn interv time
gen _t = time + 1
gen psurv = psurv_k if _t ==1
bysort seqn interv: replace psurv = psurv_k*psurv[_t-1] if _t >1

*Display 10-year standardized survival, under interventions*
*Note: since time starts at 0, month 119 is 10-year survival*
by interv, sort: summarize psurv if time == 119

quietly summarize psurv if(interv==0 & time ==119)
matrix input observe = (0,`r(mean)')
quietly summarize psurv if(interv==1 & time ==119)
matrix observe = (observe \1,`r(mean)')
matrix observe = (observe \3, observe[2,2]-observe[1,2])
matrix list observe

*Graph of standardized survival over time, under interventions*
/*Note: since our outcome model has no covariates,
we can plot psurv directly.
If we had covariates we would need to stratify or average across the values*/
```

```
expand 2 if time ==0, generate(newtime)
replace psurv  = 1 if newtime == 1
gen time2 = 0 if newtime ==1
replace time2 = time + 1 if newtime == 0
separate psurv, by(interv)
twoway (line psurv0 time2, sort) ///
  (line psurv1 time2, sort) if interv > -1 ///
  , ylabel(0.5(0.1)1.0) xlabel(0(12)120) ///
  ytitle("Survival probability") xtitle("Months of follow-up") ///
  legend(label(1 "A=0") label(2 "A=1"))
qui gr export ./figs/stata-fig-17-3.png, replace

*remove extra timepoint*
drop if newtime == 1
drop time2

restore

**Bootstraps**
qui save ./data/nhefs_std1 , replace

capture program drop bootipw_surv

program define bootipw_surv , rclass
use ./data/nhefs_std1 , clear
preserve
bsample, cluster(seqn) idcluster(newseqn)

logit qsmk sex race c.age##c.age ib(last).education ///
  c.smokeintensity##c.smokeintensity ///
    c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
    c.wt71##c.wt71 if time == 0
predict p_qsmk, pr

logit qsmk if time ==0
predict num, pr

gen sw=num/p_qsmk if qsmk==1
replace sw=(1-num)/(1-p_qsmk) if qsmk==0

logit event qsmk qsmk#c.time qsmk#c.time#c.time ///
  c.time c.time#c.time [pweight=sw], cluster(newseqn)

drop if time != 0
expand 120 if time ==0
bysort newseqn: replace time = _n - 1
expand 2 , generate(interv_b)
replace qsmk = interv_b

predict pevent_k, pr
gen psurv_k = 1-pevent_k
keep newseqn time qsmk interv_b psurv_k
```

```
sort newseqn interv_b time
gen _t = time + 1
gen psurv = psurv_k if _t ==1
bysort newseqn interv_b: ///
  replace psurv = psurv_k*psurv[_t-1] if _t >1
drop if time != 119
bysort interv_b: egen meanS_b = mean(psurv)
keep newseqn qsmk  meanS_b
drop if newseqn != 1  /* only need one pair */

drop newseqn

return scalar boot_0 = meanS_b[1]
return scalar boot_1 = meanS_b[2]
return scalar  boot_diff = return(boot_1) - return(boot_0)
restore
end

set rmsg on
simulate PrY_a0 = r(boot_0) PrY_a1 = r(boot_1) ///
  difference=r(boot_diff), reps(10) seed(1): bootipw_surv
set rmsg off

matrix pe = observe[1..3, 2]'
bstat, stat(pe) n(1629)
```

```
Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -839.70016
Iteration 2:   log likelihood = -838.45045
Iteration 3:   log likelihood = -838.44842
Iteration 4:   log likelihood = -838.44842

Logistic regression                                     Number of obs =  1,566
                                                        LR chi2(18)   = 109.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -838.44842                             Pseudo R2     = 0.0611

------------------------------------------------------------------------------------
            qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-----------------+------------------------------------------------------------------
             sex |  -.5274782   .1540497    -3.42   0.001      -.82941    -.2255463
            race |  -.8392636   .2100668    -4.00   0.000    -1.250987    -.4275404
             age |   .1212052   .0512663     2.36   0.018     .0207251     .2216853
                 |
     c.age#c.age |  -.0008246   .0005361    -1.54   0.124    -.0018753     .0002262
                 |
       education |
              1  |  -.4759606   .2262238    -2.10   0.035    -.9193511    -.0325701
              2  |  -.5047361    .217597    -2.32   0.020    -.9312184    -.0782538
              3  |  -.3895288   .1914353    -2.03   0.042    -.7647351    -.0143226
              4  |  -.4123596   .2772868    -1.49   0.137    -.9558318     .1311126
                 |
```

```
   smokeintensity |  -.0772704   .0152499    -5.07   0.000    -.1071596   -.0473812
                  |
 c.smokeintensity#|
 c.smokeintensity |   .0010451   .0002866     3.65   0.000     .0004835    .0016068
                  |
         smokeyrs |  -.0735966   .0277775    -2.65   0.008    -.1280395   -.0191538
                  |
       c.smokeyrs#|
       c.smokeyrs |   .0008441   .0004632     1.82   0.068    -.0000637    .0017519
                  |
         exercise |
               0  |   -.395704   .1872401    -2.11   0.035    -.7626878   -.0287201
               1  |  -.0408635   .1382674    -0.30   0.768    -.3118627    .2301357
                  |
           active |
               0  |   -.176784   .2149721    -0.82   0.411    -.5981215    .2445535
               1  |  -.1448395   .2111472    -0.69   0.493    -.5586806    .2690015
                  |
             wt71 |  -.0152357   .0263161    -0.58   0.563    -.0668144     .036343
                  |
    c.wt71#c.wt71 |   .0001352   .0001632     0.83   0.407    -.0001846     .000455
                  |
            _cons |   -1.19407   1.398493    -0.85   0.393    -3.935066    1.546925
------------------------------------------------------------------------------------


Iteration 0:   log likelihood = -893.02712
Iteration 1:   log likelihood = -893.02712

Logistic regression                                     Number of obs =   1,566
                                                        LR chi2(0)    =   -0.00
                                                        Prob > chi2   =       .
Log likelihood = -893.02712                             Pseudo R2     = -0.0000

------------------------------------------------------------------------------
        qsmk | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
       _cons |  -1.059822   .0578034   -18.33   0.000    -1.173114    -.946529
------------------------------------------------------------------------------


(128,481 missing values generated)

(128,481 real changes made)

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
          sw |    171,076    1.000509    .2851505   .3312489   4.297662


Iteration 0:   log pseudolikelihood = -2136.3671
Iteration 1:   log pseudolikelihood = -2127.0974
```

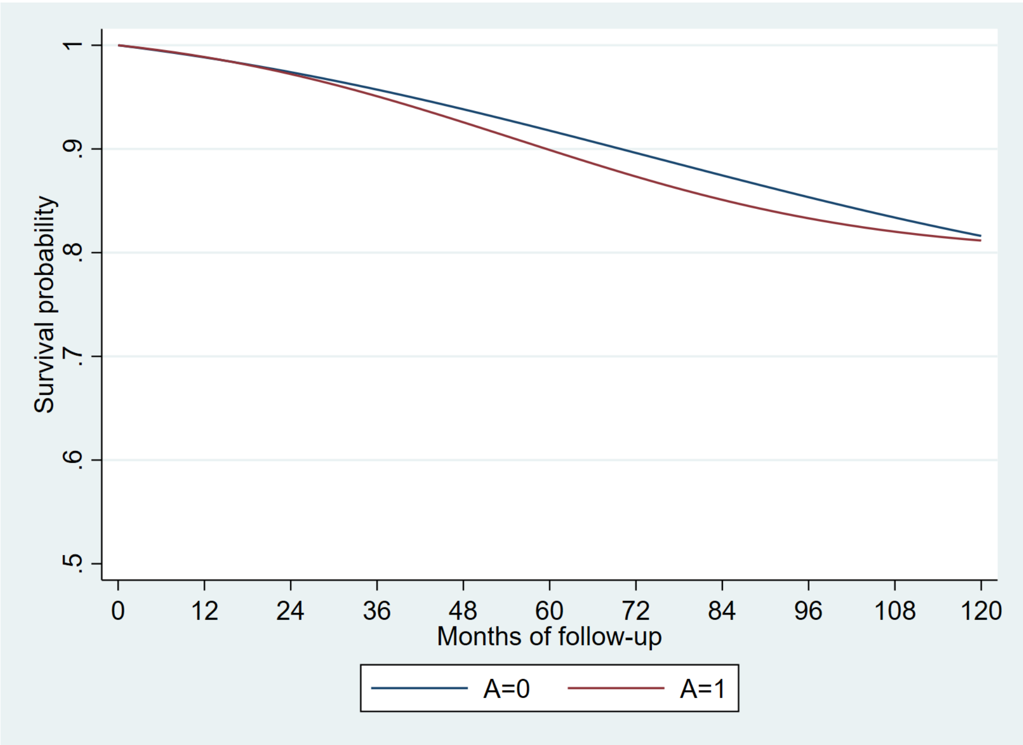
```
Iteration 2:   log pseudolikelihood = -2126.8556
Iteration 3:   log pseudolikelihood = -2126.8554

Logistic regression                                     Number of obs = 171,076
                                                        Wald chi2(5)  =   22.74
                                                        Prob > chi2   =  0.0004
Log pseudolikelihood = -2126.8554                       Pseudo R2     =  0.0045

                                     (Std. err. adjusted for 1,566 clusters in seqn)
------------------------------------------------------------------------------------
                   |               Robust
             event | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------------+----------------------------------------------------------------
              qsmk |  -.1301273   .4186673    -0.31   0.756    -.9507002    .6904456
                   |
       qsmk#c.time |
Smoking cessation  |     .01916   .0151318     1.27   0.205    -.0104978    .0488178
                   |
qsmk#c.time#c.time |
Smoking cessation  |  -.0002152   .0001213    -1.77   0.076    -.0004528    .0000225
                   |
              time |   .0208179   .0077769     2.68   0.007     .0055754    .0360604
                   |
     c.time#c.time |  -.0001278   .0000643    -1.99   0.047    -.0002537   -1.84e-06
                   |
             _cons |  -7.038847   .2142855   -32.85   0.000    -7.458839   -6.618855
------------------------------------------------------------------------------------

(169,510 observations deleted)

(186,354 observations created)

(186354 real changes made)

(187,920 observations created)

(187,920 real changes made)




(372,708 missing values generated)

(372708 real changes made)


--------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
```

```
       psurv |      1,566    .8161003           0   .8161003   .8161003

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       psurv |      1,566    .8116784           0   .8116784   .8116784
```

```
observe[3,2]
            c1          c2
r1           0    .8161003
r2           1   .81167841
r3           3  -.00442189

(3,132 observations created)

(3,132 real changes made)

(375,840 missing values generated)

(375,840 real changes made)


Variable      Storage   Display    Value
    name         type    format    label      Variable label
-------------------------------------------------------------------------------------
psurv0          float   %9.0g                 psurv, interv == Original observation
psurv1          float   %9.0g                 psurv, interv == Duplicated observation



(3,132 observations deleted)
```

```
  5. predict p_qsmk, pr
  6. 
 11. 
 23. drop if time ≠ 119
 24. bysort interv_b: egen meanS_b = mean(psurv)
 25. keep newseqn qsmk  meanS_b
 26. drop if newseqn ≠ 1  /* only need one pair */
 27. 
```

```
r; t=0.00 10:07:59

      Command: bootipw_surv
       PrY_a0: r(boot_0)
       PrY_a1: r(boot_1)
   difference: r(boot_diff)

Simulations (10)
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..........
r; t=19.02 10:08:18



Bootstrap results                                       Number of obs = 1,629
                                                        Replications  =    10

------------------------------------------------------------------------------
             |   Observed   Bootstrap                         Normal-based
             | coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
      PrY_a0 |   .8161003   .0093124    87.64   0.000     .7978484    .8343522
      PrY_a1 |   .8116784   .0237581    34.16   0.000     .7651133    .8582435
  difference |  -.0044219   .0225007    -0.20   0.844    -.0485224    .0396786
------------------------------------------------------------------------------
```




## Program 17.4

- Estimating of survival curves via g-formula

- Data from NHEFS
- Section 17.5
- Generates Figure 17.7

```
use ./data/nhefs_surv, clear

keep seqn event qsmk time sex race age education ///
  smokeintensity smkintensity82_71  smokeyrs exercise ///
  active wt71
preserve

quietly logistic event qsmk qsmk#c.time ///
  qsmk#c.time#c.time time c.time#c.time  ///
    sex race c.age##c.age ib(last).education ///
    c.smokeintensity##c.smokeintensity ///
    c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
    c.wt71##c.wt71 , cluster(seqn)

drop if time != 0
expand 120 if time ==0
bysort seqn: replace time = _n - 1
expand 2 , generate(interv)
replace qsmk = interv
predict pevent_k, pr
gen psurv_k = 1-pevent_k
keep seqn  time qsmk interv psurv_k
sort seqn interv time
gen _t = time + 1
gen psurv = psurv_k if _t ==1
bysort seqn interv: replace psurv = psurv_k*psurv[_t-1] if _t >1
by interv, sort: summarize psurv if time == 119

keep qsmk interv psurv time

bysort interv : egen meanS = mean(psurv) if time == 119
by interv: summarize meanS

quietly summarize meanS if(qsmk==0  & time ==119)
matrix input observe = ( 0,`r(mean)')
quietly summarize meanS if(qsmk==1  & time ==119)
matrix observe = (observe \1,`r(mean)')
matrix observe = (observe \2, observe[2,2]-observe[1,2])
*Add some row/column descriptions and print results to screen*
matrix rownames observe =  P(Y(a=0)=1) P(Y(a=1)=1) difference
matrix colnames observe = interv survival

*Graph standardized survival over time, under interventions*
/*Note: unlike in Program 17.3, we now have covariates
so we first need to average survival across strata*/
bysort interv time : egen meanS_t = mean(psurv)

*Now we can continue with the graph*
expand 2 if time ==0, generate(newtime)
```

```
replace meanS_t  = 1 if newtime == 1
gen time2 = 0 if newtime ==1
replace time2 = time + 1 if newtime == 0
separate meanS_t, by(interv)

twoway (line meanS_t0 time2, sort) ///
  (line meanS_t1 time2, sort) ///
  , ylabel(0.5(0.1)1.0) xlabel(0(12)120) ///
  ytitle("Survival probability") xtitle("Months of follow-up") ///
  legend(label(1 "A=0") label(2 "A=1"))
gr export ./figs/stata-fig-17-4.png, replace

*remove extra timepoint*
drop if newtime == 1

restore

*Bootstraps*
qui save ./data/nhefs_std2 , replace

capture program drop bootstdz_surv

program define bootstdz_surv , rclass
use ./data/nhefs_std2 , clear
preserve

bsample, cluster(seqn) idcluster(newseqn)
logistic event qsmk qsmk#c.time qsmk#c.time#c.time ///
  time c.time#c.time ///
    sex race c.age##c.age ib(last).education ///
    c.smokeintensity##c.smokeintensity c.smkintensity82_71 ///
    c.smokeyrs##c.smokeyrs ib(last).exercise ib(last).active ///
    c.wt71##c.wt71
drop if time != 0
/*only predict on new version of data */
expand 120 if time ==0
bysort newseqn: replace time = _n - 1
expand 2 , generate(interv_b)
replace qsmk = interv_b
predict pevent_k, pr
gen psurv_k = 1-pevent_k
keep newseqn  time qsmk psurv_k
sort newseqn qsmk time
gen _t = time + 1
gen psurv = psurv_k if _t ==1
bysort newseqn  qsmk: replace psurv = psurv_k*psurv[_t-1] if _t >1
drop  if time != 119   /* keep only last observation */
keep newseqn qsmk psurv
/* if time is in data for complete graph add time to bysort */
bysort qsmk  : egen meanS_b = mean(psurv)
keep newseqn qsmk  meanS_b
drop if newseqn != 1  /* only need one pair */
```

```
drop newseqn

return scalar boot_0 = meanS_b[1]
return scalar boot_1 = meanS_b[2]
return scalar boot_diff = return(boot_1) - return(boot_0)
restore
end

set rmsg on
simulate PrY_a0 = r(boot_0) PrY_a1 = r(boot_1) ///
  difference=r(boot_diff), reps(10) seed(1): bootstdz_surv
set rmsg off

matrix pe = observe[1..3, 2]'
bstat, stat(pe) n(1629)
```

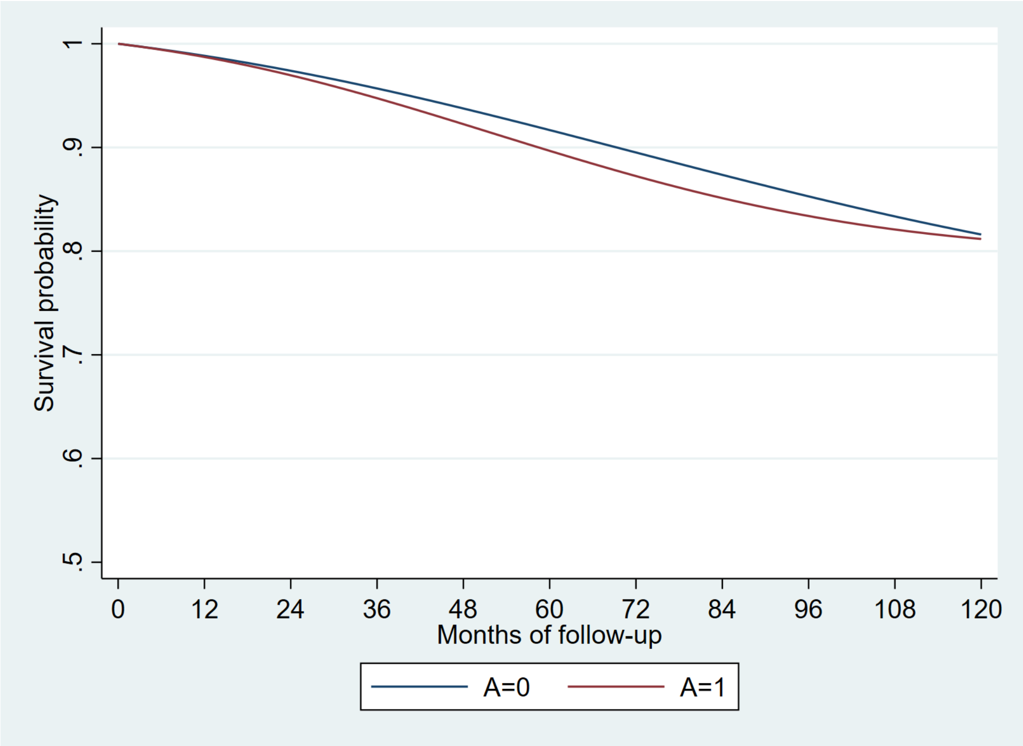
```
(169,510 observations deleted)

(186,354 observations created)

(186354 real changes made)

(187,920 observations created)

(187,920 real changes made)




(372,708 missing values generated)

(372708 real changes made)


-------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       psurv |      1,566    .8160697    .2014345    .014127   .9903372

-------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       psurv |      1,566     .811763    .2044758   .0123403   .9900259



(372,708 missing values generated)
```

```
--------------------------------------------------------------------------------------
-> interv = Original

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       meanS |      1,566    .8160697           0   .8160697   .8160697

--------------------------------------------------------------------------------------
-> interv = Duplicat

    Variable |        Obs        Mean    Std. dev.       Min        Max
-------------+---------------------------------------------------------
       meanS |      1,566    .8117629           0   .8117629   .8117629
```

```
(3,132 observations created)

(3,132 real changes made)

(375,840 missing values generated)

(375,840 real changes made)


Variable      Storage   Display    Value
    name         type    format    label      Variable label
--------------------------------------------------------------------------------------
meanS_t0        float   %9.0g                 meanS_t, interv == Original observation
meanS_t1        float   %9.0g                 meanS_t, interv == Duplicated
                                                observation


file ./figs/stata-fig-17-4.png saved as PNG format

(3,132 observations deleted)
```

```
  5. drop if time != 0
  6. /*only predict on new version of data */

r; t=0.00 10:08:24
```

```
      Command: bootstdz_surv
        PrY_a0: r(boot_0)
        PrY_a1: r(boot_1)
    difference: r(boot_diff)

Simulations (10)
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..........
r; t=22.14 10:08:46



Bootstrap results                                         Number of obs = 1,629
                                                          Replications  =    10

------------------------------------------------------------------------------
             |   Observed   Bootstrap                         Normal-based
             | coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
      PrY_a0 |   .8160697   .0087193    93.59   0.000     .7989802    .8331593
      PrY_a1 |   .8117629   .0292177    27.78   0.000     .7544973    .8690286
  difference |  -.0043068   .0307674    -0.14   0.889    -.0646099    .0559963
------------------------------------------------------------------------------
```



# Session information: Stata

```r
library(Statamarkdown)
```

For reproducibility.

```stata
about
```

```
Stata/MP 17.0 for Windows (64-bit x86-64)
Revision 29 Aug 2023
Copyright 1985-2021 StataCorp LLC

Total physical memory:       32.00 GB
Available physical memory:   21.12 GB

Stata license: Unlimited-user 2-core network, expiring 21 Jan 2024
Serial number: 501709378202
  Licensed to: Tom Palmer
               University of Bristol
```

```r
# install.packages("sessioninfo")
sessioninfo::session_info()
- Session info ------------------------------------------------------------------
 setting  value
 version  R version 4.3.2 (2023-10-31 ucrt)
 os       Windows 11 x64 (build 22621)
 system   x86_64, mingw32
 ui       RTerm
 language (EN)
 collate  English_United Kingdom.utf8
 ctype    English_United Kingdom.utf8
 tz       Europe/London
 date     2023-11-01
 pandoc   3.1.1 @ C:/Program Files/RStudio/resources/app/bin/quarto/bin/tools/ (via rmarkdown)

- Packages ----------------------------------------------------------------------
 package      * version date (UTC) lib source
 bookdown       0.36    2023-10-16 [1] CRAN (R 4.3.1)
 cli            3.6.1   2023-03-23 [1] CRAN (R 4.3.0)
 digest         0.6.33  2023-07-07 [1] CRAN (R 4.3.1)
 evaluate       0.22    2023-09-29 [1] CRAN (R 4.3.1)
 fastmap        1.1.1   2023-02-24 [1] CRAN (R 4.3.0)
 htmltools      0.5.6.1 2023-10-06 [1] CRAN (R 4.3.1)
 knitr          1.45    2023-10-30 [1] CRAN (R 4.3.1)
 rlang          1.1.1   2023-04-28 [1] CRAN (R 4.3.0)
```

```
 rmarkdown       2.25    2023-09-18 [1] CRAN (R 4.3.1)
 rstudioapi      0.15.0  2023-07-07 [1] CRAN (R 4.3.1)
 sessioninfo     1.2.2   2021-12-06 [1] CRAN (R 4.3.0)
 Statamarkdown * 0.8.0   2023-06-01 [1] CRAN (R 4.3.1)
 xfun            0.40    2023-08-09 [1] CRAN (R 4.3.1)
 yaml            2.3.7   2023-01-23 [1] CRAN (R 4.3.0)

 [1] C:/Users/tom/AppData/Local/R/win-library/4.3
 [2] C:/Program Files/R/R-4.3.2/library

------------------------------------------------------------------------------
```

# Bibliography

Miguel A Hernán and James M Robins. *Causal Inference: What If.* Boca Raton: Chapman & Hall/CRC, 2020.