Biost 518
Applied Biostatistics II

Scott S. Emerson, M.D., Ph.D.
Professor of Biostatistics
University of Washington

Lecture 6:
Adjustment for Covariates

January 25, 2008

1

Scientific Questions

- Most times:
  - Comparing distribution of response across groups defined by predictor of interest
- Very often, other variables also need to be considered because
  - Comparison is different in strata
  - Groups being compared differ in other ways
  - Less variability of response if we control for other variables

2

Adjustment for Covariates

- We "adjust" for other covariates
  - Define groups according to
    - Predictor of interest, and
    - Other covariates
  - Compare the distribution of response across groups which
    - differ with respect to the Predictor of Interest, but
    - are the same with respect to the other covariates
      - "holding other variables constant"

3

Statistical Role

- Covariates other than the POI are included in the model as
  - Effect modifiers
  - Confounders
  - Precision variables

4

Statistical Methods

- Adjustment for additional covariates
  - Stratified analyses
  - Multiple regression

5

Statistical Methods

- Adjustment for additional covariates
  - Stratified analyses
    - Combines information about association between response and POI across strata
    - Will not borrow information about (or even estimate) about association between response and adjustment variables
  - Multiple regression
    - Can (but does not have to) borrow information about associations between response and all modeled variables

6

Stratified Analyses

7

Stratified Analyses

- Divide the data into strata based on all combinations of the “adjustment” covariates
  - E.g., every combination of sex, age, race, etc.
- In each stratum, perform an analysis comparing response across POI groups
- Use (weighted) average of estimated associations across groups

8

Stratified Estimates

- This is easy, if estimates are independent and approximately normally distributed

For independent strata $k = 1, \ldots, K$

Estimate in stratum k: $\hat{\theta}_k \sim N\left(\theta_k, se_k^2\right)$

Weight for stratum k: w_k

Stratified estimate:

$$\hat{\theta} = \frac{\sum_{k=1}^{K} w_k \hat{\theta}_k}{\sum_{k=1}^{K} w_k} \sim N\left(\theta = \frac{\sum_{k=1}^{K} w_k \theta_k}{\sum_{k=1}^{K} w_k}, \frac{\sum_{k=1}^{K} w_k^2 se_k^2}{\left(\sum_{k=1}^{K} w_k\right)^2}\right)$$

9

Choosing Weights

- Criteria
  - Scientific relevance of stratified estimate
  - Statistical precision of stratified estimate
- Should be based on statistical role of "adjustment" variables
  - Effect modifiers
  - Confounding
  - Precision

10

Presence of Effect Modification

- Scientific Criteria
  - Sometimes we anticipate effect modification by some variables, but
  - We do not choose to report estimate of association between response and POI in each stratum separately
    - E.g., political polls, age adjusted incidence rates
  - We want to estimate an "average association" for a population

11

Presence of Effect Modification

- Choose weights according to importance
  - Size of the corresponding stratum in a population of interest
    - The real population, or
    - Some standard population used for comparisons
      - E.g., in ecologic studies comparing incidence of hip fracture across countries
        - » Hip fracture rates increase with age
        - » Industrialized countries and developing world have very different age distributions
        - » Choose a standard age distribution to remove confounding by age

12

Aside: Oversampling

- In political polls or epidemiologic studies, we sometimes oversample some strata in order to gain precision
  - For fixed maximal sample size, we gain most precision if stratum sample size is proportional to weight times standard deviation of measurements in the stratum

13

Aside: Oversampling

- Typical case for stratified estimates

For independent strata $k = 1, \ldots, K$

Sample size in stratum k: n_k

Estimate in stratum k: $\hat{\theta}_k \dot{\sim} N\left(\theta_k, se_k^2 = \frac{V_k}{n_k}\right)$

Importance weight for stratum k: w_k

Optimal sample size when fixed $N = \sum_{k=1}^{K} n_k$:

$$\frac{w_1\sqrt{V_1}}{n_1} = \frac{w_2\sqrt{V_2}}{n_2} = \cdots = \frac{w_K\sqrt{V_K}}{n_K}$$

14

Confounders, Precision

- Scientific Criteria
  - The true association is the same in each stratum
    - We are free to consider statistical criteria
- Statistical Criteria
  - Maximize precision of stratified estimate by minimizing standard error

15

Confounders, Precision

- Association between response and POI is the same in every stratum

For independent strata $k = 1, \ldots, K$

Estimate in stratum k: $\hat{\theta}_k \dot{\sim} N\left(\theta_k = \theta, se_k^2\right)$

Weight for stratum k: w_k

Stratified estimate:

$$\hat{\theta} = \frac{\sum_{k=1}^{K} w_k \hat{\theta}_k}{\sum_{k=1}^{K} w_k} \dot{\sim} N\left(\theta, \frac{\sum_{k=1}^{K} w_k^2 se_k^2}{\left(\sum_{k=1}^{K} w_k\right)^2}\right)$$

16

Optimal Weights for Small SE

- Typical case for stratified estimates

For independent strata $k = 1, \ldots, K$

Sample size in stratum k: n_k

Estimate in stratum k: $\hat{\theta}_k \sim N\left(\theta_k, se_k^2 = \frac{V_k}{n_k}\right)$

Importance weight for stratum k: w_k

Optimal sample size when fixed $N = \sum_{k=1}^{K} n_k$:

$$\frac{w_1\sqrt{V_1}}{n_1} = \frac{w_2\sqrt{V_2}}{n_2} = \cdots = \frac{w_K\sqrt{V_K}}{n_K}$$

17

Confounders, Precision

- Often we ignore the aspect that variability might differ across strata
  - Just choose weights by sample size for each stratum
    - Note that if we sampled randomly from the population of interest, this would also be appropriate for importance weights in the presence of effect modification

18

Ex: Mantel-Haenszel Statistic

- Hypothesis test comparing odds (proportions) across two groups
  - Adjust for confounding in a stratified analysis
  - Weights chosen for statistical precision
    - (Not quite the most optimal weights but close)
    - (Actual statistic uses stratum specific standard errors computed using hypergeometric distribution rather than binomial distribution)

19

Ex: Mantel-Haenszel Statistic

- Approximate weighting of difference in proportions based on harmonic means of sample sizes in each stratum
  - Usually viewed as weighted odds ratios

Sample size in stratum k: n_{1k}, n_{0k}

Estimates in stratum k: $\hat{p}_{1k}, \hat{p}_{0k}$

Precision weight for stratum k:

$$w_k = \frac{\frac{n_{1k}n_{0k}}{n_{1k}+n_{0k}}}{\sum_{k=1}^{K} \frac{n_{1k}n_{0k}}{n_{1k}+n_{0k}}}$$

20

Ex: Stata Mantel-Haenszel

- Odds of being full professor by sex

```
. cc full female if year==95, by(field)

field |     OR      [95% ConfInt]       M-H Weight
 Arts |   .538      .293    .984       16.545 (exact)
Other |   .254      .187    .344       91.645 (exact)
 Prof |   .343      .164    .705       14.426 (exact)
Crude |   .290      .227    .372                (exact)
  M-H |   .303      .238    .386
Test of homogeneity: chi2(2)= 5.47  Pr>chi2 = 0.0648
Test that OR =1    :         MH chi2(1) =     99.10
                             Pr>chi2    =    0.0000
```

21

Multiple Regression

22

Types of Variables

- Binary data
  - E.g., sex, death
- Nominal data: unordered, categorical data
  - E.g., race, marital status
- Ordinal categorical data
  - E.g., stage of disease
- Quantitative data
  - E.g., age, blood pressure
- Right censored data
  - E.g., time to death (when not everyone has died)

23

Summary Measures

- The measures commonly used to summarize and compare distributions vary according to the types of data
  - Means: binary; quantitative
  - Medians: ordered; quantitative; censored
  - Proportions: binary; nominal
  - Odds: binary; nominal
  - Hazards: censored
    - hazard = instantaneous rate of failure

24

Regression Models

- According to the parameter compared across groups
  - Means → Linear regression
  - Geom Means → Linear regression on logs
  - Odds → Logistic regression
  - Rates → Poisson regression
  - Hazards → Proportional Hazards regr
  - Quantiles → Parametric survival regr

25

General Regression

- General notation for variables and parameter

Y_i	Response measured on the ith subject
X_i	Value of the POI for the ith subject
$W_{1i}, W_{2i}, \ldots$	Value of adjustment variables for the ith subject
θ_i	Parameter of distribution of Y_i

  - The parameter might be the mean, geometric mean, odds, rate, instantaneous risk of an event (hazard), etc.

26

Multiple Regression

- General notation for simple regression model

$$g(\theta_i) = \beta_0 + \beta_1 \times X_i + \beta_2 \times W_{1i} + \beta_3 \times W_{2i} + \cdots$$

$g(\ )$	"link" function used for modeling
β_0	"Intercept"
β_1	"Slope for Pred of Interest X)"
β_j	"Slope for covariate W_{j-1}"

  - The link function is usually either none (means) or log (geom mean, odds, hazard)

27

Borrowing Information

- Use other groups to make estimates in groups with sparse data
  - Intuitively: 67 and 69 year olds would provide some relevant information about 68 year olds
  - Assuming straight line relationship tells us how to adjust data from other (even more distant) age groups
    - If we do not know about the exact functional relationship, we might want to borrow information only close to each group

28

Defining "Contrasts"

- Define a comparison across groups to use when answering scientific question
  - If straight line relationship in parameter, slope for POI is difference in parameter between groups differing by 1 unit in X when all other covariates in model are equal
  - If nonlinear relationship in parameter, slope is average difference in parameter between groups differing by 1 unit in X "holding covariates constant"
    - Statistical jargon: a "contrast" across the groups

29

Comparison of Models

- The major difference between regression models is interpretation of the parameters
  - Summary: Mean, geometric mean, odds, hazards
  - Comparison of groups: Difference, ratio
- Issues related to inclusion of covariates remain the same
  - Address the scientific question
    - Predictor of interest; Effect modifiers
  - Address confounding
  - Increase precision

30

Interpretation of Parameters

- Intercept
  - Corresponds to a population with <u>all</u> modeled covariates equal to zero
    - Most often outside range of data; quite often impossible; very rarely of interest by itself
- Slope
  - A comparison between groups differing by 1 unit in corresponding covariate, but agreeing on all other modeled covariates
    - Sometimes impossible to use this definition when modeling interactions or complex curves

31

Stratification vs Regression

- Generally, any stratified analysis could be performed as a regression model
  - But stratification adjusts for covariates and all interactions among those covariates
    - E.g, sex, race, and the sex-race interaction
  - Our habit in regression is to just adjust for the covariates (the "main effect"), and consider interactions less often

32

Stata: Multiple Regression

- In Stata, we use the same commands as were used for simple regression
  - We just list more variable names
  - Interpretation of CI, P values for coefficient estimates now relate to new scientific interpretation of intercept and slopes
  - Test of entire regression model also provided
    - A test that all slopes are equal to 0

33

Ex: FEV and Smoking

```
. regress logfev smoker if age>=9, robust

                                   Number of obs =     439
                                   F(  1,   437) =   10.45
                                   Prob > F      =  0.0013
                                   R-squared     =  0.0212
                                   Root MSE      =  .24765
------------------------------------------------------------------------------
       |          Robust
logfev |   Coef.  St Err     t    P>|t|    [95% CI]
-------+----------------------------------------------------------------------
smoker |   .102   .0317   3.23  0.001   .040    .165
 _cons |  1.058   .0129  81.82  0.000  1.033   1.084
```

34

Ex: Adjusted for Age

```
. regress logfev smoker age if age>=9, robust

                                   Number of obs =     439
                                   F(  2,   437) =   82.28
                                   Prob > F      =  0.0000
                                   R-squared     =  0.3012
                                   Root MSE      =  .20949
------------------------------------------------------------------------------
       |          Robust
logfev |   Coef.  St Err     t    P>|t|    [95% CI]
-------+----------------------------------------------------------------------
smoker |  -.051   .0344  -1.49  0.136  -.119    .016
   age |   .064   .0051  12.37  0.000   .053    .074
 _cons |  0.352   .0575   6.12  0.000   .239    .465
```

35

Ex: Adjusted for Age, Height

```
. regress logfev smoker age loght if age>=9, robust

                                   Number of obs =     439
                                   F(  3,   437) =  284.22
                                   Prob > F      =  0.0000
                                   R-squared     =  0.6703
                                   Root MSE      =  .14407
------------------------------------------------------------------------------
       |          Robust
logfev |   Coef.  St Err     t    P>|t|     [95% CI]
-------+----------------------------------------------------------------------
smoker |  -.054   .0241  -2.22  0.027   -.101    -.006
   age |   .022   .0035   6.18  0.000    .015     .028
 loght |  2.870   .1280  22.42  0.000   2.618    3.121
 _cons |-11.095   .5153 -21.53  0.000 -12.107 -10.082
```

36