

# **Session 4: loglinear regression part 1**

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# Learning objectives and outline

# Learning objectives

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Conclusions

- 1 Define log-linear models in GLM framework
- 2 Identify situations that motivate use of log-linear models
- 3 Assess model fit of log-linear models
- 4 Define multi-collinearity

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Conclusions

- ① brief review of GLMs
- ② Motivating example for log-linear models
  - Poisson regression
- ③ Checking model assumptions and fit: Residual Analysis
- ④ Note on collinearity

Reading: Vittinghoff textbook chapter 8.1-8.3

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# Review

# Components of GLM

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- **Random component** specifies the conditional distribution for the response variable - it doesn't have to be normal but can be any distribution that belongs to the “exponential” family of distributions
- **Systematic component** specifies linear function of predictors (linear predictor)
- **Link** [denoted by  $g(\cdot)$ ] specifies the relationship between the expected value of the random component and the systematic component, can be linear or nonlinear

# Linear Regression as GLM

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- **The model:**

$$y_i = E[y|x] + \epsilon_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi} + \epsilon_i$$

- **Random component** of  $y_i$  is normally distributed:

$$\epsilon_i \stackrel{iid}{\sim} N(0, \sigma_\epsilon^2)$$

- **Systematic component** (linear predictor):

$$\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi}$$

- **Link function** here is the *identity link*:

$g(E(y|x)) = E(y|x)$ . We are modeling the mean directly, no transformation.

# Logistic Regression as GLM

- **The model:**

$$\text{Logit}(P(x)) = \log \left( \frac{P(x)}{1 - P(x)} \right) = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi}$$

- **Random component:**  $y_i$  follows a Binomial distribution (outcome is a binary variable)
- **Systematic component:** linear predictor

$$\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi}$$

- **Link function:** *logit* (Converts Prob  $\rightarrow$  log-odds)

$$g(P(x)) = \text{logit}(P(x)) = \log \left( \frac{P(x)}{1 - P(x)} \right)$$

$$P(x) = g^{-1}(\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi})$$



# Additive vs. Multiplicative models

- Linear regression is an *additive* model
  - e.g. for two binary variables  $\beta_1 = 1.5$ ,  $\beta_2 = 1.5$ .
  - If  $x_1 = 1$  and  $x_2 = 1$ , this adds 3.0 to  $E(y|x)$
- Logistic regression is a *multiplicative* model
  - If  $x_1 = 1$  and  $x_2 = 1$ , this adds 3.0 to  $\log(\frac{P}{1-P})$
  - Odds-ratio  $\frac{P}{1-P}$  increases 20-fold:  $\exp(1.5 + 1.5)$  or  $\exp(1.5) * \exp(1.5)$

# Motivating example for log-linear models

# Effectiveness of a depression case-management program

- Research question: can a new treatment reduce the number of needed visits to the emergency room, compared to standard care?
- *outcome*: # of emergency room visits for each patient in the year following initial treatment
- *predictors*:
  - *race* (white or nonwhite)
  - *treatment* (treated or control)
  - *amount of alcohol consumption* (numerical measure)
  - *drug use* (numerical measure)

# Statistical issues

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- 1 about  $1/3$  of observations are exactly 0 (did not return to the emergency room within the year)
- 2 highly nonnormal and cannot be transformed to be approximately normal
- 3 even  $\log(y_i + 1)$  transformation will have a “lump” at zero + over  $1/2$  the transformed data would have values of 0 or  $\log(2)$
- 4 a linear regression model would give negative predictions for some covariate combinations
- 5 some subjects die or cannot be followed up on for a whole year

# Towards a reasonable model

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- A *multiplicative* model will allow us to make inference on *ratios* of mean emergency room usage
- Modeling *log* of the *mean* emergency usage ensures positive means, and does not suffer from  $\log(0)$  problem
- Random component of GLM, or residuals (was  $\epsilon_i \stackrel{iid}{\sim} N(0, \sigma_\epsilon^2)$  for linear regression) may still not be normal, but we can choose from other distributions

## Proposed model without time

$$\log(E[Y_i]) = \beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i$$

Or equivalently:

$$E[Y_i] = \exp(\beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i)$$

where  $E[Y_i]$  is the expected number of emergency room visits for patient  $i$ .

- Important note: Modeling  $\log(E[Y_i])$  is *not* equivalent to modeling  $E(\log(Y_i))$

# Accounting for follow-up time

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Instead, model mean count per unit time:

$$\log(E[Y_i]/t_i) = \beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i$$

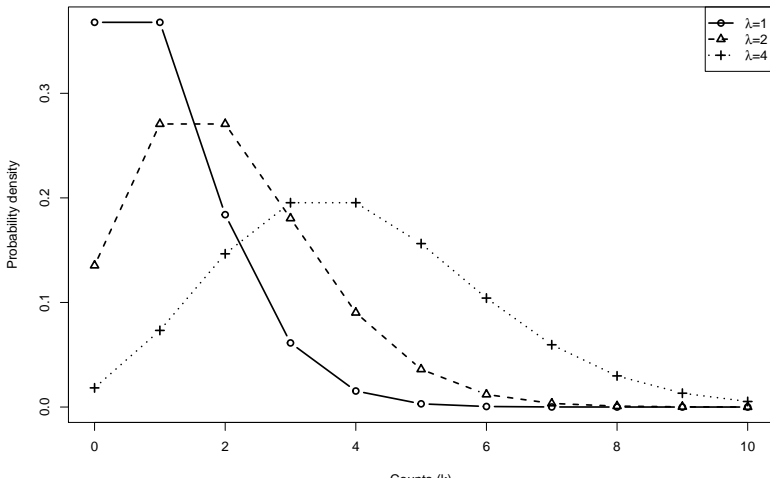
Or equivalently:

$$\log(E[Y_i]) = \beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i + \log(t_i)$$

- $\log(t_i)$  is not a covariate, it is called an *offset*

# The Poisson distribution

- Count data are often modeled as Poisson distributed:
  - mean  $\lambda$  is greater than 0
  - variance is also  $\lambda$
  - Probability density  $P(k, \lambda) = \frac{\lambda^k}{k!} e^{-\lambda}$





# When the Poisson distribution works

- Individual events are low-probability (small  $p$ ), but many opportunities (large  $n$ )
  - e.g. # 911 calls per day
  - e.g. # emergency room visits
- Approximates the binomial distribution when  $n$  is large and  $p$  is small
  - e.g.  $n > 20$ ,  $np < 5$  or  $n(1 - p) < 5$
- When mean of residuals is approx. equal to variance

# GLM with log-linear link and Poisson error model

- Model the number of counts per unit time as Poisson-distributed + so the expected number of counts per time is  $\lambda_i$

$$E[Y_i]/t_i = \lambda_i$$

$$\log(E[Y_i]/t_i) = \log(\lambda_i)$$

$$\log(E[Y_i]) = \log(\lambda_i) + \log(t_i)$$

Recalling the log-linear model systematic component:

$$\log(E[Y_i]) = \beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i + \log(t_i)$$

# GLM with log-linear link and Poisson error model (cont'd)

Then the systematic part of the GLM is:

$$\log(\lambda_i) = \beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i$$

Or alternatively:

$$\lambda_i = \exp(\beta_0 + \beta_1 \text{RACE}_i + \beta_2 \text{TRT}_i + \beta_3 \text{ALCH}_i + \beta_4 \text{DRUG}_i)$$

## Interpretation of coefficients

- Suppose that  $\hat{\beta}_1 = -0.5$  in the fitted model, where  $RACE_i = 0$  for white and  $RACE_i = 1$  for non-white.
- The mean rate of emergency room visits per unit time for white relative to non-white, all else held equal, is estimated to be:

$$\begin{aligned} & \frac{\exp(\beta_0 + 0 + \beta_2 TRT_i + \beta_3 ALCH_i + \beta_4 DRUG_i)}{\exp(\beta_0 - 0.5 + \beta_2 TRT_i + \beta_3 ALCH_i + \beta_4 DRUG_i)} \\ &= \frac{e^{\beta_0} e^0 e^{\beta_2 TRT_i} e^{\beta_3 ALCH_i} e^{\beta_4 DRUG_i}}{e^{\beta_0} e^{-0.5} e^{\beta_2 TRT_i} e^{\beta_3 ALCH_i} e^{\beta_4 DRUG_i}} \\ &= \frac{e^0}{e^{-0.5}} \\ &= e^{0.5} \approx 1.65 \end{aligned}$$

# Interpretation of coefficients (cont'd)

- If  $\hat{\beta}_1 = -0.5$  with whites as the reference group: - after adjustment for treatment group, alcohol and drug usage, whites tend to use the emergency room at a rate 1.65 times higher than non-whites. - equivalently, the average rate of usage for whites is 65% higher than that for non-whites
- Multiplicative rules apply for other coefficients as well, because they are exponentiated to estimate the mean rate.

# Multi-collinearity

# Note on Multicollinearity

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- 1 *Multicollinearity* exists when two or more of the independent variables in regression are moderately or highly correlated.
- 2 Multicollinearity implies near-linear relationship among the predictors
- 3 The presence of near-linear dependence dramatically impacts the ability to estimate regression coefficients
- 4 High multicollinearity results in larger standard errors for regression coefficients
  - estimates of such regression coefficients will tend to be less stable over repeated sampling

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# Conclusions

- ① Log-linear models are appropriate for non-negative, skewed count data
  - probability of each event is low
- ② The coefficients of log-linear models are *multiplicative*
- ③ An *offset* term can account for varying follow-up time or otherwise varying opportunity to be counted
- ④ Poisson distribution is limit of binomial distribution with high number of trials, low probability
- ⑤ Inference from log-linear models is sensitive to the choice of error model (assumption on the distribution of residuals)
- ⑥ We will cover other options next week for when the Poisson error model doesn't fit:
  - Variance proportional to mean, instead of equal
  - Negative Binomial
  - Zero Inflation