

432 Classes 15 and 16

<https://thomaseLove.github.io/432-2023/>

2023-03-07

This Week's Topic

Regression Models for Count Outcomes

- Modeling approaches illustrated in these slides
 - Poisson Regression
 - Negative Binomial Regression
 - Two types of Zero-inflated model
 - ZIP (Zero-inflated Poisson)
 - ZINB (Zero-inflated Neg. Binomial)
- The slides also discuss
 - Two types of Hurdle model
 - using a Poisson approach
 - using a Negative Binomial approach

Chapters 24-26 of the Course Notes describe this material.

Installing the countreg package

The countreg package is available on R-Forge.

To build rootograms to visualize the results of regression models on count outcomes, I have decided for the moment to continue to use the countreg package, which is currently available on R-Forge only.

To install countreg, type

```
install.packages("countreg",  
                  repos="http://R-Forge.R-project.org")
```

into the R Console within R Studio. I will not be loading countreg in this work, though.

Setup

Again, we assume you have already installed the countreg package from R-Forge.

```
knitr::opts_chunk$set(comment=NA)
options(width = 60)

library(janitor); library(knitr)
library(conflicted)
library(MASS)
library(pscl)
library(VGAM)
library(broom); library(rsample); library(yardstick)
library(tidyverse)

conflict_prefer("select", "dplyr")
conflict_prefer("filter", "dplyr")
theme_set(theme_bw())
```

Section 1

An Overview

Generalized Linear Models for Count Outcomes

We want to build a generalized linear model to predict count data using one or more predictors.

In count data, the observations are non-negative integers (0, 1, 2, 3, ...)

- the number of COVID-19 hospitalizations in Ohio yesterday
- the number of mutations within a particular search grid
- the number of days in the past 30 where your mental health was poor

The Poisson and the Negative Binomial probability distributions will be useful.

The Poisson Probability Distribution

The Poisson probability model describes the probability of a given number of events occurring in a fixed interval of time or space.

- If events occur with a constant mean rate, and independently of the time since the last event, the Poisson model is appropriate.
- The probability mass function for a discrete random variable with Poisson distribution follows.

$$Pr(Y = k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

- k is the number of times an event occurs in an interval, and k can take the values 0, 1, 2, 3, ...
- The parameter λ (lambda) is equal to the expected value (mean) of Y and is also equal to the variance of Y .

The Negative Binomial Probability Distribution

The Negative Binomial distribution models the number of failures in a sequence of independent and identically distributed Bernoulli trials before a specified number of successes occurs.

- The probability mass function for a discrete random variable with a negative binomial distribution follows.

$$Pr(Y = k) = \binom{k + r - 1}{k} p^r (1 - p)^k$$

- k is the number of failures (units of time) before the r th event occurs, and k can take the values 0, 1, 2, 3, ...
- The mean of the random variable Y which follows a negative binomial distribution is $rp/(1 - p)$ and the variance is $rp/(1 - p)^2$.

Poisson Regression and the possibility of overdispersion

- Poisson regression assumes that the outcome Y follows a Poisson distribution, and that the logarithm of the expected value of Y (its mean) can be modeled by a linear combination of a set of predictors.
 - A Poisson regression makes the strong assumption that the variance of Y is equal to its mean.
 - A Poisson model might fit poorly due to **overdispersion**, where the variance of Y is larger than we'd expect based on the mean of Y .
 - Quasipoisson models are available which estimate an overdispersion parameter, but we'll skip those.

We will show the use of `glm` to fit Poisson models, by using `family = "Poisson"`.

Negative Binomial Regression to generalize the Poisson

- Negative binomial regression is a generalization of Poisson regression which loosens the assumption that the variance of Y is equal to its mean, and thus produces models which fit a broader class of data.

We will demonstrate the use of `glm.nb` from the MASS package to fit negative binomial regression models.

Zero-inflated approaches

- Both the Poisson and Negative Binomial regression approaches may under-estimate the number of zeros compared to the data.
- To better match up the counts of zero, zero-inflated models fit:
 - a logistic regression to predict the extra zeros, along with
 - a Poisson or Negative Binomial model to predict the counts, including some zeros.

We will demonstrate the use of `zeroinfl` from the `pscl` package to fit zero-inflated Poisson (or ZIP) and zero-inflated negative binomial (or ZINB) regressions.

Hurdle models (in the slides, but not today's focus)

A hurdle model predicts the count outcome by making an assumption that there are two processes at work:

- a process that determines whether the count is zero or not zero (usually using logistic regression), and
- a process that determines the count when we know the subject has a positive count (usually using a truncated Poisson or Negative Binomial model where no zeros are predicted)

These slides use the `hurdle` function from the `pscl` package to fit these models.

Comparing Models

- 1 A key tool will be a graphical representation of the fit of the models to the count outcome, called a **rootogram**. We'll use the rootograms produced by the `countreg` package to help us.
- 2 We'll also demonstrate a Vuong hypothesis testing approach (from the `lmtest` package) to help us make decisions between various types of Poisson models or various types of Negative Binomial models on the basis of improvement in fit of things like bias-corrected AIC or BIC.
- 3 We'll also demonstrate the calculation of pseudo-R square statistics for comparing models, which can be compared in a validation sample as well as in the original modeling sample.

Section 2

The medicare data

The medicare example

The data we will use come from the NMES1988 data set in R's AER package, although I have built a cleaner version for you in the `medicare.csv` file on our web site. These are essentially the same data as are used in [my main resource](#) from the University of Virginia for hurdle models.

These data are a cross-section originating from the US National Medical Expenditure Survey (NMES) conducted in 1987 and 1988. The NMES is based upon a representative, national probability sample of the civilian non-institutionalized population and individuals admitted to long-term care facilities during 1987. The data are a subsample of individuals ages 66 and over all of whom are covered by Medicare (a public insurance program providing substantial protection against health-care costs), and some of whom also have private supplemental insurance.

The medicare code book

Variable	Description
subject	subject number (code)
visits	outcome of interest: number of physician office visits
hospital	number of hospital stays
health	self-perceived health status (poor, average, excellent)
chronic	number of chronic conditions
sex	male or female
school	number of years of education
insurance	is the subject (also) covered by private insurance? (yes or no)

Today's Goal

Predict visits using main effects of the 6 predictors (excluding subject)






Skimming the medicare tibble

```
> skimr::skim(medicare)
-- Data Summary -----
Name                Values
Number of rows      4406
Number of columns    8

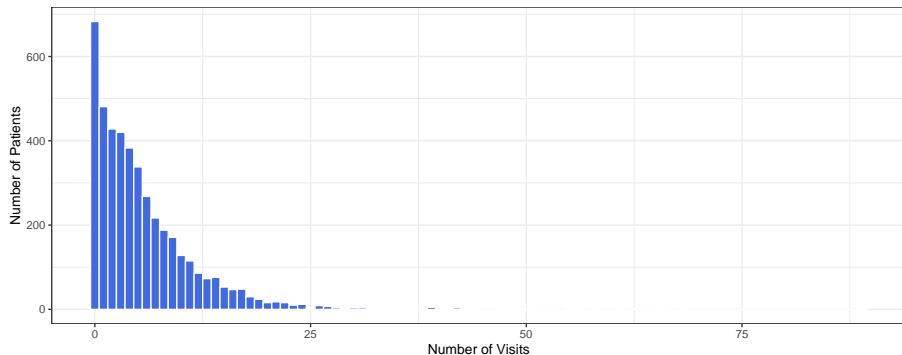
Column type frequency:
  factor            3
  numeric           5

Group variables      None

-- Variable type: factor -----
# A tibble: 3 x 6
  skim_variable n_missing complete_rate ordered n_unique top_counts
* <chr>         <int>         <dbl> <lg1>      <int> <chr>
1 health         0             1 FALSE         3 ave: 3509, poo: 554, exc: 343
2 sex            0             1 FALSE         2 fem: 2628, mal: 1778
3 insurance      0             1 FALSE         2 yes: 3421, no: 985

-- Variable type: numeric -----
# A tibble: 5 x 11
  skim_variable n_missing complete_rate mean      sd      p0      p25      p50      p75      p100 hist
* <chr>         <int>         <dbl>  <dbl>  <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <chr>
1 subject         0             1 2204. 1272.  1 1102. 2204. 3305. 4406 
2 visits          0             1   5.77   6.76   0    1    4    8    89 
3 hospital         0             1  0.296  0.746   0    0    0    0    8 
4 chronic          0             1   1.54   1.35   0    1    1    2    8 
5 school           0             1  10.3   3.74   0    8   11   12   18 
```

Our outcome, visits



```
mosaic::favstats(~ visits, data = medicare)
```

min	Q1	median	Q3	max	mean	sd	n	missing
0	1	4	8	89	5.774399	6.759225	4406	0

visits numerical summaries

```
Hmisc::describe(medicare$visits)
```

```
medicare$visits
```

n	missing	distinct	Info	Mean	Gmd
4406	0	60	0.992	5.774	6.227
.05	.10	.25	.50	.75	.90
0	0	1	4	8	13
.95					
17					

```
lowest : 0 1 2 3 4, highest: 63 65 66 68 89
```

Reiterating the Goal

Predict visits using some combination of these 6 predictors...

Predictor	Description
hospital	number of hospital stays
health	self-perceived health status (poor, average, excellent)
chronic	number of chronic conditions
sex	male or female
school	number of years of education
insurance	is the subject (also) covered by private insurance? (yes or no)

We'll build separate training and test samples to help us validate.

Partitioning the Data into Training vs. Test Samples

```
set.seed(432)
med_split <- initial_split(medicare, prop = 0.75)

med_train = training(med_split)
med_test = testing(med_split)
```

I've held out 25% of the medicare data for the test sample.

```
dim(med_train)
```

```
[1] 3304    8
```

```
dim(med_test)
```

```
[1] 1102    8
```

Section 3

mod_1: A Poisson Regression

Poisson Regression

Assume our count data (`visits`) follows a Poisson distribution with a mean conditional on our predictors.

```
mod_1 <- glm(visits ~ hospital + health + chronic +  
              sex + school + insurance,  
              data = med_train, family = "poisson")
```

The Poisson model uses a logarithm as its link function, so the model is actually predicting $\log(\text{visits})$.

Note that we're fitting the model here using the training sample alone.

mod_1 (Poisson) model coefficients

```
tidy(mod_1) |>  
  select(term, estimate, std.error, p.value) |>  
  kable(digits = 3)
```

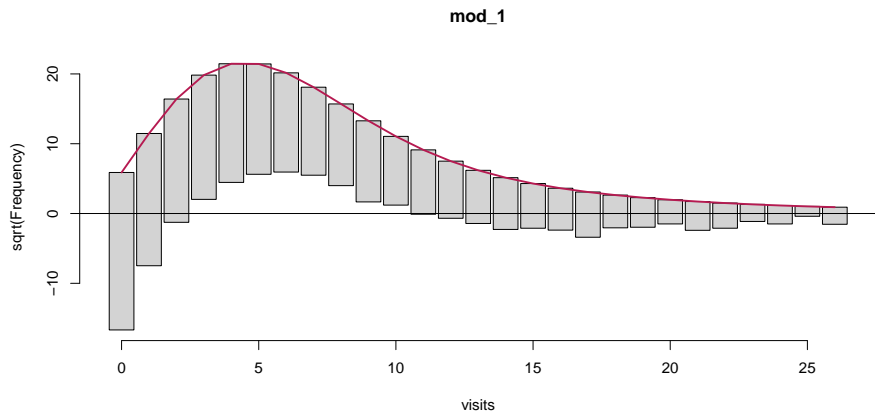
term	estimate	std.error	p.value
(Intercept)	0.985	0.027	0
hospital	0.164	0.007	0
healthexcellent	-0.359	0.035	0
healthpoor	0.310	0.020	0
chronic	0.137	0.005	0
sexmale	-0.098	0.015	0
school	0.031	0.002	0
insuranceyes	0.200	0.019	0

Interpretation

If Harry and Larry have the same values for all other predictors but only Harry has private insurance, the model predicts Harry to have a value of $\log(\text{visits})$ that is 0.2 larger than Larry's $\log(\text{visits})$.

Visualize fit with a (Hanging) Rootogram

```
countreg::rootogram(mod_1)
```



See the next slide for details on how to interpret this...

Interpreting the Rootogram

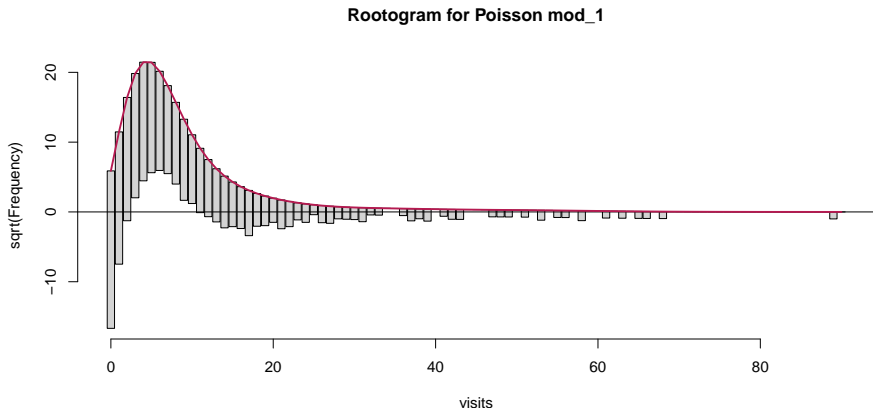
- The red curved line is the theoretical Poisson fit.
- “Hanging” from each point on the red line is a bar, the height of which represents the observed counts.
 - A bar hanging below 0 indicates that the model under-predicts that value. (Model predicts fewer values than the data show.)
 - A bar hanging above 0 indicates over-prediction of that value. (Model predicts more values than the data show.)
- The counts have been transformed with a square root transformation to prevent smaller counts from getting obscured and overwhelmed by larger counts.

For more information on rootograms, check out

<https://arxiv.org/pdf/1605.01311>.

The Complete Rootogram for mod_1

```
countreg::rootogram(mod_1, max = 90,  
                      main = "Rootogram for Poisson mod_1")
```



This shows what happens with the subject with 89 visits.

Interpreting the Rootogram for `mod_1`

In `mod_1`, we see a great deal of under-prediction for counts of 0 and 1, then over-prediction for visit counts in the 3-10 range, with some under-prediction again at more than a dozen or so visits.

- Our Poisson model (`mod_1`) doesn't fit enough zeros or ones, and fits too many 3-12 values, then not enough of the higher values.

Store Training Sample mod_1 Predictions

We'll use the `augment` function to store the predictions within our training sample. Note the use of "response" to predict visits, not `log(visits)`.

```
mod_1_aug <- augment(mod_1, med_train,  
                      type.predict = "response")  
  
mod_1_aug |> select(subject, visits, .fitted) |>  
  head(3)
```

```
# A tibble: 3 x 3  
  subject visits .fitted  
    <int>   <int>   <dbl>  
1     355     19    5.02  
2    2661      3    4.21  
3    2895      0    4.65
```

Summarizing Training Sample mod_1 Fit

Within our training sample, `mod_1_aug` now contains both the actual counts (`visits`) and the predicted counts (in `.fitted`) from `mod_1`. We'll summarize the fit...

```
mets <- metric_set(rsq, rmse, mae)
mod_1_summary <-
  mets(mod_1_aug, truth = visits, estimate = .fitted) |>
  mutate(model = "mod_1") |> relocate(model)
mod_1_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_1	rsq	standard	0.100
mod_1	rmse	standard	6.594
mod_1	mae	standard	4.189

These will become interesting as we build additional models.

Section 4

mod_2: A Negative Binomial Regression

Fitting the Negative Binomial Model

The negative binomial model requires the estimation of an additional parameter, called θ (theta). The default link for this generalized linear model is also a logarithm, like the Poisson.

```
mod_2 <- MASS::glm.nb(visits ~ hospital + health + chronic +  
                      sex + school + insurance,  
                      data = med_train)
```

The estimated dispersion parameter value θ is...

```
summary(mod_2)$theta
```

```
[1] 1.21109
```

The Poisson model is essentially the negative binomial model assuming a known $\theta = 1$.

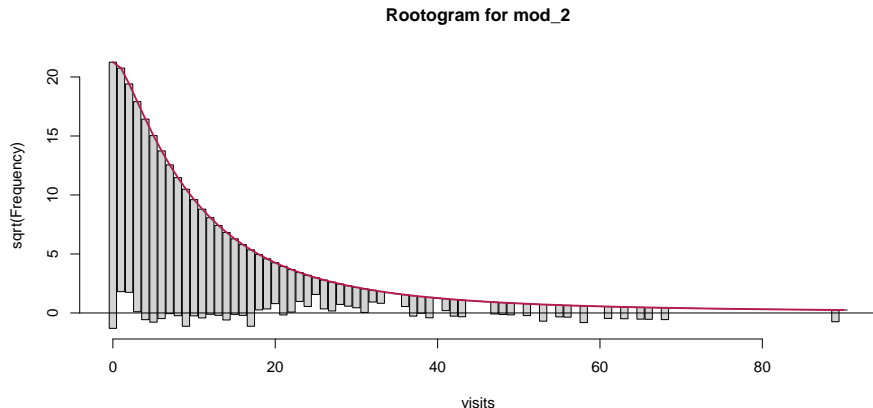
mod_2 (Negative Binomial) coefficients

```
tidy(mod_2) |> kable(digits = c(0, 3, 3, 1, 3))
```

term	estimate	std.error	statistic	p.value
(Intercept)	0.875	0.063	14.0	0.000
hospital	0.224	0.023	9.9	0.000
healthexcellent	-0.336	0.070	-4.8	0.000
healthpoor	0.360	0.056	6.5	0.000
chronic	0.169	0.014	12.2	0.000
sexmale	-0.109	0.036	-3.0	0.002
school	0.031	0.005	6.1	0.000
insuranceyes	0.237	0.046	5.2	0.000

Rootogram for Negative Binomial Model

```
countreg::rootogram(mod_2, max = 90,  
                     main = "Rootogram for mod_2")
```



Does this look better than the Poisson rootogram?

Store Training Sample mod_2 Predictions

```
mod_2_aug <- augment(mod_2, med_train,  
                      type.predict = "response")  
  
mod_2_aug |> select(subject, visits, .fitted) |>  
  head(3)
```

```
# A tibble: 3 x 3  
  subject visits .fitted  
    <int>   <int>   <dbl>  
1     355     19    5.22  
2    2661      3    4.08  
3    2895      0    4.39
```

- Note that this may throw a warning about who maintains tidiers for negbin models. I'd silence it.

Summarizing Training Sample mod_2 Fit

As before, `mod_2_aug` now has actual (`visits`) and predicted counts (in `.fitted`) from `mod_2`.

```
mod_2_summary <-  
  mets(mod_2_aug, truth = visits, estimate = .fitted) |>  
  mutate(model = "mod_2") |> relocate(model)  
mod_2_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_2	rsq	standard	0.078
mod_2	rmse	standard	6.941
mod_2	mae	standard	4.252

So Far in our Training Sample

The reasonable things to summarize in sample look like the impressions from the rootograms and the summaries we've prepared so far.

```
bind_rows(mod_1_summary, mod_2_summary) |>
  pivot_wider(names_from = model,
              values_from = .estimate) |> kable(dig = 3)
```

.metric	.estimator	mod_1	mod_2
rsq	standard	0.100	0.078
rmse	standard	6.594	6.941
mae	standard	4.189	4.252

Model	Rootogram impressions
mod_1 (P)	Many problems. Data appear overdispersed.
mod_2 (NB)	Still not enough zeros; some big predictions.

Section 5

mod_3: Zero-Inflated Poisson (ZIP) Model

Zero-Inflated Poisson (ZIP) model

The zero-inflated Poisson model describes count data with an excess of zero counts.

The model posits that there are two processes involved:

- a logistic regression model is used to predict excess zeros
- while a Poisson model is used to predict the counts

We'll use the `pscl` package to fit zero-inflated models.

```
mod_3 <- pscl::zeroinfl(visits ~ hospital + health +  
                        chronic + sex + school + insurance,  
                        data = med_train)
```


mod_3 ZIP coefficients

Sadly, there's no broom tidying functions for these zero-inflated models.

```
summary(mod_3)
```

Screenshot on next slide...

```
> summary(mod_3)
```

```
Call:
```

```
pscl::zeroinfl(formula = visits ~ hospital + health + chronic + sex + school +  
insurance, data = med_train)
```

```
Pearson residuals:
```

	Min	1Q	Median	3Q	Max
	-5.2755	-1.1549	-0.4718	0.5539	24.7634

```
Count model coefficients (poisson with log link):
```

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	1.426024	0.028059	50.822	< 2e-16 ***
hospital	0.146820	0.006916	21.229	< 2e-16 ***
healthexcellent	-0.279266	0.034575	-8.077	6.63e-16 ***
healthpoor	0.251422	0.020563	12.227	< 2e-16 ***
chronic	0.103175	0.005446	18.945	< 2e-16 ***
sexmale	-0.048790	0.015043	-3.243	0.001181 **
school	0.017484	0.002147	8.142	3.88e-16 ***
insuranceyes	0.071434	0.019867	3.596	0.000324 ***

```
Zero-inflation model coefficients (binomial with logit link):
```

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.07633	0.16394	0.466	0.64149
hospital	-0.31378	0.10685	-2.937	0.00332 **
healthexcellent	0.01029	0.18319	0.056	0.95519
healthpoor	0.06277	0.18668	0.336	0.73669
chronic	-0.55244	0.05352	-10.323	< 2e-16 ***
sexmale	0.42526	0.10327	4.118	3.82e-05 ***
school	-0.06617	0.01404	-4.711	2.46e-06 ***
insuranceyes	-0.79835	0.11806	-6.762	1.36e-11 ***

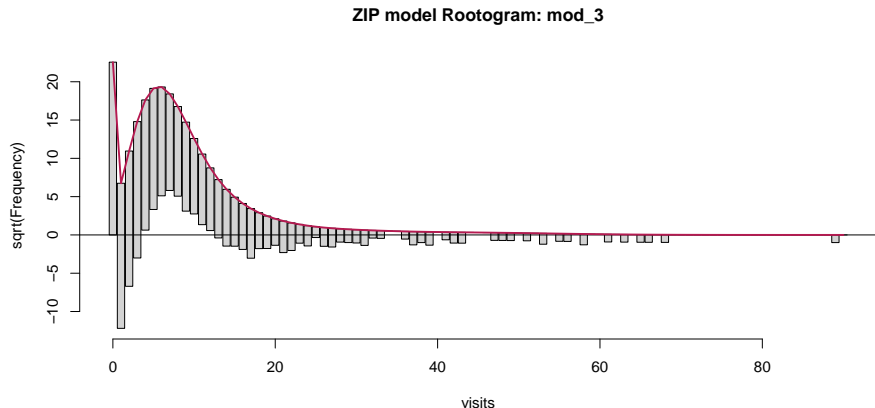
```
---  
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Number of iterations in BFGS optimization: 19
```

```
Log-likelihood: -1.205e+04 on 16 Df
```

Rootogram for ZIP model

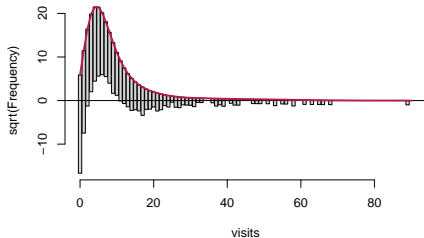
```
countreg::rootogram(mod_3, max = 90,  
                      main = "ZIP model Rootogram: mod_3")
```



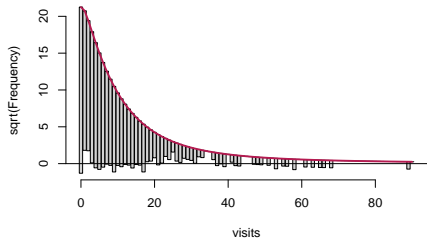
What do you think? Next slide shows all models so far.

First Three Rootograms - Which Looks Best?

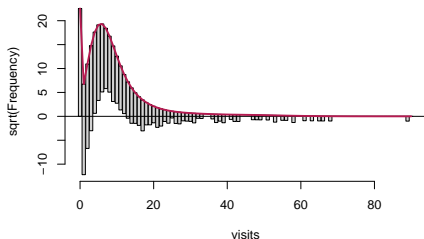
Poisson mod_1



Negative Binomial mod_2



ZIP mod_3



Store Training Sample mod_3 Predictions

We have no `augment` or other broom functions available for zero-inflated models, so ...

```
mod_3_aug <- med_train |>
  mutate(".fitted" = predict(mod_3, type = "response"),
         ".resid" = resid(mod_3, type = "response"))

mod_3_aug |> select(subject, visits, .fitted, .resid) |>
  head(3)
```

```
# A tibble: 3 x 4
  subject visits .fitted .resid
  <int>   <int>   <dbl>  <dbl>
1     355     19     5.31   13.7
2    2661      3     4.21   -1.21
3    2895      0     4.59   -4.59
```

Summarizing Training Sample mod_3 Fit

`mod_3_aug` now has actual (`visits`) and predicted counts (in `.fitted`) from `mod_3`, just as we set up for the previous two models.

```
mod_3_summary <-  
  mets(mod_3_aug, truth = visits, estimate = .fitted) |>  
  mutate(model = "mod_3") |> relocate(model)  
mod_3_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_3	rsq	standard	0.108
mod_3	rmse	standard	6.560
mod_3	mae	standard	4.164

Training Sample Results through mod_3

```
bind_rows(mod_1_summary, mod_2_summary, mod_3_summary) |>
  pivot_wider(names_from = model,
              values_from = .estimate) |> kable(dig = 3)
```

.metric	.estimator	mod_1	mod_2	mod_3
rsq	standard	0.100	0.078	0.108
rmse	standard	6.594	6.941	6.560
mae	standard	4.189	4.252	4.164

Remember we want a larger R^2 and smaller values of RMSE and MAE.

Comparing models with Vuong's procedure

Vuong's test compares predicted probabilities (for each count) in two non-nested models. How about Poisson vs. ZIP?

```
vuong(mod_1, mod_3)
```

Vuong Non-Nested Hypothesis Test-Statistic:

(test-statistic is asymptotically distributed $N(0,1)$ under the null that the models are indistinguishable)

	Vuong z-statistic	H_A	p-value
Raw	-14.59671	model2 > model1 <	2.22e-16
AIC-corrected	-14.51271	model2 > model1 <	2.22e-16
BIC-corrected	-14.25638	model2 > model1 <	2.22e-16

The large negative z-statistic indicates mod_3 (ZIP) fits detectably better than mod_1 (Poisson) in our training sample.

Reference: Vuong, QH (1989) Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica*. 57:307-333.

Section 6

mod_4: Zero-Inflated Negative Binomial (ZINB) Model

Zero-Inflated Negative Binomial (ZINB) model

As in the ZIP, we assume there are two processes involved:

- a logistic regression model is used to predict excess zeros
- while a negative binomial model is used to predict the counts

We'll use the `pscl` package again and the `zeroinfl` function.

```
mod_4 <- zeroinfl(visits ~ hospital + health + chronic +  
                  sex + school + insurance,  
                  dist = "negbin", data = med_train)
```

`summary(mod_4)` results on next slide...

```
> summary(mod_4)
```

```
Call:
zeroinfl(formula = visits ~ hospital + health + chronic + sex + school + insurance,
  data = med_train, dist = "negbin")
```

```
Pearson residuals:
```

	Min	1Q	Median	3Q	Max
	-1.2103	-0.7038	-0.2759	0.3266	17.2261

```
Count model coefficients (negbin with log link):
```

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.200177	0.065972	18.192	< 2e-16	***
hospital	0.193561	0.023208	8.340	< 2e-16	***
healthexcellent	-0.279277	0.069924	-3.994	6.50e-05	***
healthpoor	0.298912	0.052710	5.671	1.42e-08	***
chronic	0.132141	0.013550	9.752	< 2e-16	***
sexmale	-0.064602	0.035463	-1.822	0.0685	.
school	0.021115	0.004987	4.234	2.29e-05	***
insuranceyes	0.110006	0.048189	2.283	0.0224	*
Log(theta)	0.418977	0.040758	10.280	< 2e-16	***

```
Zero-inflation model coefficients (binomial with logit link):
```

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	0.08053	0.29852	0.270	0.78735	
hospital	-0.73882	0.49978	-1.478	0.13934	
healthexcellent	-0.24399	0.41885	-0.583	0.56021	
healthpoor	0.32305	0.41910	0.771	0.44081	
chronic	-1.16999	0.18230	-6.418	1.38e-10	***
sexmale	0.66582	0.22345	2.980	0.00289	**
school	-0.08895	0.02892	-3.075	0.00210	**
insuranceyes	-1.29494	0.24416	-5.304	1.14e-07	***

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

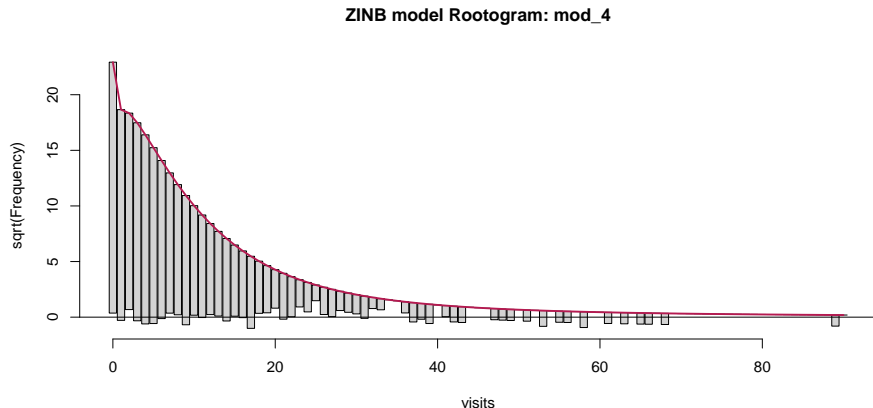
```
Theta = 1.5204
```

```
Number of iterations in BFGS optimization: 28
```

```
Log-likelihood: -9057 on 17 Df
```

Rootogram for ZINB model

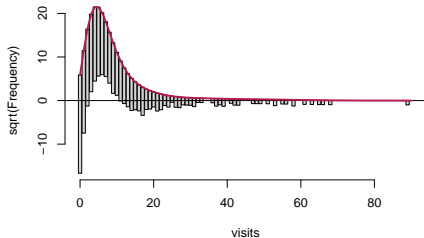
```
countreg::rootogram(mod_4, max = 90,  
                      main = "ZINB model Rootogram: mod_4")
```



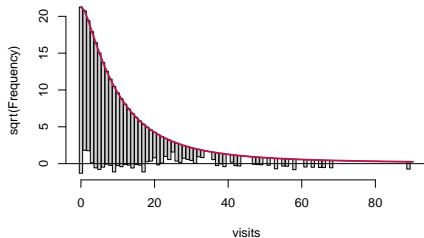
Again, next slide shows all models so far.

First Four Rootograms - Which Looks Best?

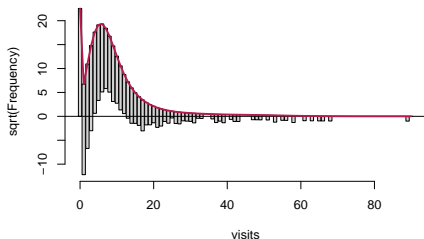
Poisson mod_1



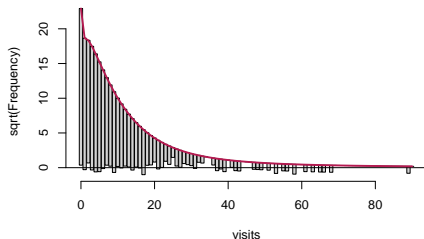
Negative Binomial mod_2



ZIP mod_3



ZINB mod_4



Store Training Sample mod_4 Predictions

Again, there is no `augment` or other broom functions available for zero-inflated models, so ...

```
mod_4_aug <- med_train |>
  mutate(".fitted" = predict(mod_4, type = "response"),
         ".resid" = resid(mod_4, type = "response"))

mod_4_aug |> select(subject, visits, .fitted, .resid) |>
  head(3)
```

```
# A tibble: 3 x 4
  subject visits .fitted .resid
  <int>   <int>   <dbl>  <dbl>
1     355     19    5.29   13.7
2    2661      3    4.47   -1.47
3    2895      0    4.57   -4.57
```

Summarizing Training Sample mod_4 Fit

mod_4_aug now has actual (visits) and predicted counts (in .fitted) from mod_4.

```
mod_4_summary <-  
  mets(mod_4_aug, truth = visits, estimate = .fitted) |>  
  mutate(model = "mod_4") |> relocate(model)  
mod_4_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_4	rsq	standard	0.094
mod_4	rmse	standard	6.709
mod_4	mae	standard	4.191

Training Sample Results through mod_4

```
bind_rows(mod_1_summary, mod_2_summary,  
          mod_3_summary, mod_4_summary) |>  
  pivot_wider(names_from = model,  
              values_from = .estimate) |> kable(dig = 3)
```

.metric	.estimator	mod_1	mod_2	mod_3	mod_4
rsq	standard	0.100	0.078	0.108	0.094
rmse	standard	6.594	6.941	6.560	6.709
mae	standard	4.189	4.252	4.164	4.191

What do you think?

Comparing models with Vuong's procedure

Vuong's test compares predicted probabilities (for each count) in two non-nested models. How about Negative Binomial vs. ZINB?

```
vuong(mod_4, mod_2)
```

Vuong Non-Nested Hypothesis Test-Statistic:

(test-statistic is asymptotically distributed $N(0,1)$ under the null that the models are indistinguishable)

```
-----
              Vuong z-statistic              H_A      p-value
Raw              4.808258 model1 > model2 7.6126e-07
AIC-corrected    4.081965 model1 > model2 2.2328e-05
BIC-corrected    1.865724 model1 > model2 0.03104
```

The large positive z-statistics indicate mod_4 (ZINB) fits detectably better than mod_2 (Negative Binomial) in our training sample.

Section 7

Validation in the Test Sample for our Four Models?

Validation: Test Sample Predictions

Predict the visit counts for each subject in our test sample.

```
test_1 <- predict(mod_1, newdata = med_test,  
                  type.predict = "response")  
test_2 <- predict(mod_2, newdata = med_test,  
                  type.predict = "response")  
test_3 <- predict(mod_3, newdata = med_test,  
                  type.predict = "response")  
test_4 <- predict(mod_4, newdata = med_test,  
                  type.predict = "response")
```

Create a Tibble with Predictions

Combine the various predictions into a tibble with the original data.

```
test_res <- bind_cols(med_test,  
  pre_m1 = test_1, pre_m2 = test_2,  
  pre_m3 = test_3, pre_m4 = test_4)  
  
names(test_res)
```

```
[1] "subject"    "visits"      "hospital"    "health"  
[5] "chronic"    "sex"         "school"      "insurance"  
[9] "pre_m1"     "pre_m2"      "pre_m3"      "pre_m4"
```

Summarize fit in test sample for each model

```
m1_sum <- mets(test_res, truth = visits, estimate = pre_m1) |>
  mutate(model = "mod_1")
m2_sum <- mets(test_res, truth = visits, estimate = pre_m2) |>
  mutate(model = "mod_2")
m3_sum <- mets(test_res, truth = visits, estimate = pre_m3) |>
  mutate(model = "mod_3")
m4_sum <- mets(test_res, truth = visits, estimate = pre_m4) |>
  mutate(model = "mod_4")

test_sum <- bind_rows(m1_sum, m2_sum, m3_sum, m4_sum)
```

Validation Results in Test Sample: Four Models

```
test_sum <- bind_rows(m1_sum, m2_sum, m3_sum, m4_sum) |>
  pivot_wider(names_from = model,
              values_from = .estimate)

test_sum |>
  select(-.estimator) |> kable(dig = 3)
```

.metric	mod_1	mod_2	mod_3	mod_4
rsq	0.103	0.108	0.099	0.097
rmse	7.212	7.205	5.907	5.967
mae	4.455	4.450	3.994	4.009

- Which model would you choose based on test sample performance?
- Is there an obvious choice?

Section 8

Hurdle Models

The Hurdle Model

The hurdle model is a two-part model that specifies one process for zero counts and another process for positive counts. The idea is that positive counts occur once a threshold is crossed, or put another way, a hurdle is cleared. If the hurdle is not cleared, then we have a count of 0.

- The first part of the model is typically a **binary logistic regression** model. This models whether an observation takes a positive count or not.
- The second part of the model is usually a truncated Poisson or Negative Binomial model. Truncated means we're only fitting positive counts, and not zeros.

Section 9

mod_5: Poisson-Logistic Hurdle Model

Fitting a Hurdle Model / Poisson-Logistic

In fitting a hurdle model to our medicare training data, the interpretation would be that one process governs whether a patient visits a doctor or not, and another process governs how many visits are made.

```
mod_5 <- hurdle(visits ~ hospital + health + chronic +  
                sex + school + insurance,  
                dist = "poisson", zero.dist = "binomial",  
                data = med_train)
```

summary(mod_5) results follow...

```
> summary(mod_5)
```

```
Call:
hurdle(formula = visits ~ hospital + health + chronic + sex + school + insurance,
       data = med_train, dist = "poisson", zero.dist = "binomial")
```

```
Pearson residuals:
```

Min	1Q	Median	3Q	Max
-5.279	-1.155	-0.472	0.554	24.756

```
Count model coefficients (truncated poisson with log link):
```

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.426528	0.028060	50.838	< 2e-16	***
hospital	0.146777	0.006917	21.219	< 2e-16	***
healthexcellent	-0.279153	0.034594	-8.069	7.07e-16	***
healthpoor	0.251479	0.020565	12.228	< 2e-16	***
chronic	0.103080	0.005444	18.935	< 2e-16	***
sexmale	-0.048598	0.015043	-3.231	0.001235	**
school	0.017433	0.002146	8.122	4.57e-16	***
insuranceyes	0.071653	0.019863	3.607	0.000309	***

```
Zero hurdle model coefficients (binomial with logit link):
```

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-0.10797	0.16128	-0.669	0.50323	
hospital	0.32226	0.10663	3.022	0.00251	**
healthexcellent	-0.06488	0.17362	-0.374	0.70861	
healthpoor	-0.05085	0.18596	-0.273	0.78451	
chronic	0.55612	0.05281	10.530	< 2e-16	***
sexmale	-0.42500	0.10149	-4.187	2.82e-05	***
school	0.06744	0.01378	4.894	9.90e-07	***
insuranceyes	0.79196	0.11630	6.810	9.79e-12	***

```
---
```

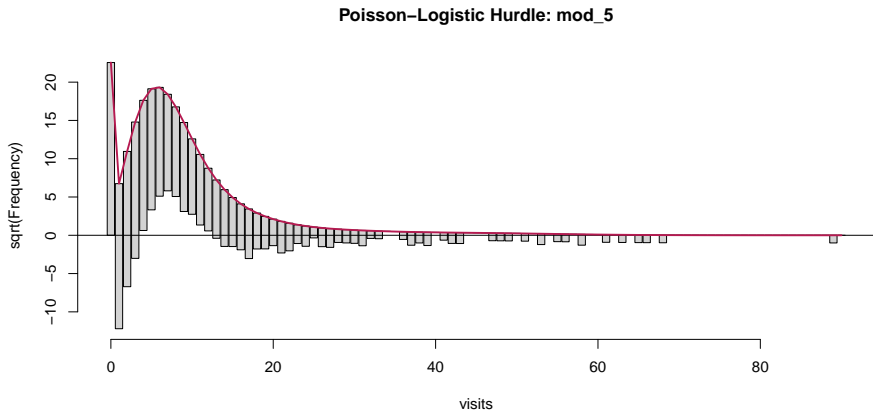
```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Number of iterations in BFGS optimization: 13
```

```
Log-likelihood: -1.205e+04 on 16 Df
```

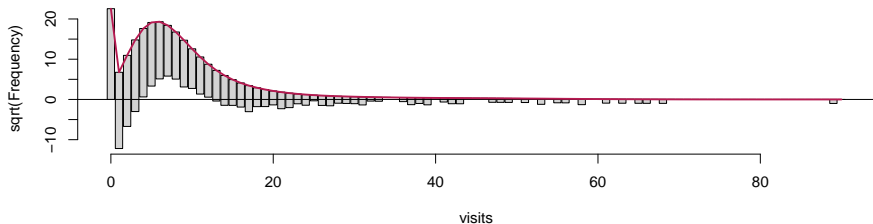
Rootogram for Poisson-Logistic Hurdle model

```
countreg::rootogram(mod_5, max = 90,  
  main = "Poisson-Logistic Hurdle: mod_5")
```

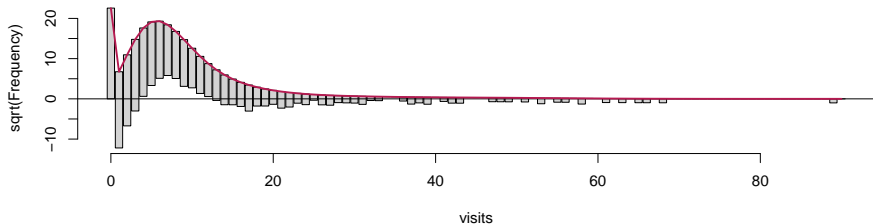


Poisson-Based Rootograms - Which Looks Best?

ZIP mod_3



Poisson-Logistic Hurdle mod_5



Store Training Sample mod_5 Predictions

No augment or other broom functions for hurdle models, so ...

```
mod_5_aug <- med_train |>
  mutate(".fitted" = predict(mod_5, type = "response"),
         ".resid" = resid(mod_5, type = "response"))

mod_5_aug |> select(subject, visits, .fitted, .resid) |>
  head(3)
```

A tibble: 3 x 4

	subject	visits	.fitted	.resid
	<int>	<int>	<dbl>	<dbl>
1	355	19	5.32	13.7
2	2661	3	4.20	-1.20
3	2895	0	4.59	-4.59

Summarizing Training Sample mod_5 Fit

```
mod_5_summary <-  
  mets(mod_5_aug, truth = visits, estimate = .fitted) |>  
  mutate(model = "mod_5") |> relocate(model)  
mod_5_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_5	rsq	standard	0.108
mod_5	rmse	standard	6.560
mod_5	mae	standard	4.164

Training Sample Results through mod_5

```
bind_rows(mod_1_summary, mod_2_summary, mod_3_summary,  
          mod_4_summary, mod_5_summary) |>  
  pivot_wider(names_from = model,  
              values_from = .estimate) |> kable(dig = 3)
```

.metric	.estimator	mod_1	mod_2	mod_3	mod_4	mod_5
rsq	standard	0.100	0.078	0.108	0.094	0.108
rmse	standard	6.594	6.941	6.560	6.709	6.560
mae	standard	4.189	4.252	4.164	4.191	4.164

What do you think?

Are ZIP and Poisson-Logistic Hurdle the Same?

```
temp_check <- tibble(  
  subject = mod_3_aug$subject,  
  visits = mod_3_aug$visits,  
  pred_zip = mod_3_aug$.fitted,  
  pred_hur = mod_5_aug$.fitted,  
  diff = pred_hur - pred_zip)  
  
mosaic::favstats(~ diff, data = temp_check)
```

min	Q1	median	Q3
-0.02412392	-0.0004090414	0.0003037249	0.0009281458
max	mean	sd	n missing
0.03270803	0.000330143	0.003049981	3304 0

Vuong test: Comparing mod_3 and mod_5

```
vuong(mod_3, mod_5)
```

Vuong Non-Nested Hypothesis Test-Statistic:

(test-statistic is asymptotically distributed $N(0,1)$ under the null that the models are indistinguishable)

	Vuong z-statistic	H_A	p-value
Raw	1.913251 model1 > model2		0.027858
AIC-corrected	1.913251 model1 > model2		0.027858
BIC-corrected	1.913251 model1 > model2		0.027858

There's some evidence mod_3 (ZIP) fits a bit better than mod_5 (Hurdle) in our training sample, though the p value (barely) exceeds 0.05.

Section 10

mod_6: Negative Binomial-Logistic Hurdle Model

Fitting a Hurdle Model / NB-Logistic

```
mod_6 <- hurdle(visits ~ hospital + health + chronic +  
                sex + school + insurance,  
                dist = "negbin", zero.dist = "binomial",  
                data = med_train)
```

summary(mod_6) results follow...

```
> summary(mod_6)
```

```
Call:
hurdle(formula = visits ~ hospital + health + chronic + sex + school + insurance,
       data = med_train, dist = "negbin", zero.dist = "binomial")
```

```
Pearson residuals:
```

	Min	1Q	Median	3Q	Max
	-1.1795	-0.7086	-0.2709	0.3255	17.4285

```
Count model coefficients (truncated negbin with log link):
```

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	1.205406	0.068361	17.633	< 2e-16 ***
hospital	0.203515	0.024298	8.376	< 2e-16 ***
healthexcellent	-0.302424	0.073635	-4.107	4.01e-05 ***
healthpoor	0.324407	0.055347	5.861	4.59e-09 ***
chronic	0.129937	0.014151	9.182	< 2e-16 ***
sexmale	-0.052089	0.037161	-1.402	0.16100
school	0.019541	0.005177	3.774	0.00016 ***
insuranceyes	0.091958	0.049304	1.865	0.06217 .
Log(theta)	0.347515	0.049274	7.053	1.76e-12 ***

```
Zero hurdle model coefficients (binomial with logit link):
```

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-0.10797	0.16128	-0.669	0.50323
hospital	0.32226	0.10663	3.022	0.00251 **
healthexcellent	-0.06488	0.17362	-0.374	0.70861
healthpoor	-0.05085	0.18596	-0.273	0.78451
chronic	0.55612	0.05281	10.530	< 2e-16 ***
sexmale	-0.42500	0.10149	-4.187	2.82e-05 ***
school	0.06744	0.01378	4.894	9.90e-07 ***
insuranceyes	0.79196	0.11630	6.810	9.79e-12 ***

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

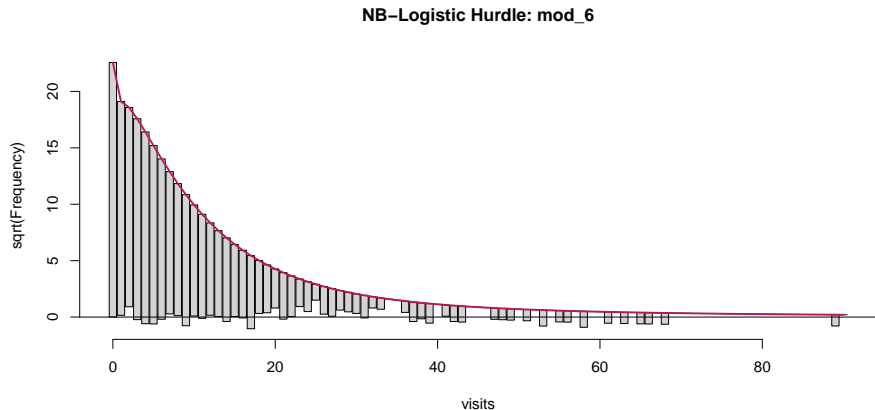
```
Theta: count = 1.4155
```

```
Number of iterations in BFGS optimization: 15
```

```
Log-likelihood: -9053 on 17 Df
```

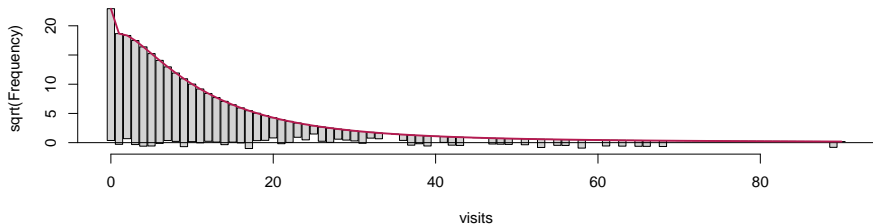
Rootogram for NB-Logistic Hurdle model

```
countreg::rootogram(mod_6, max = 90,  
  main = "NB-Logistic Hurdle: mod_6")
```

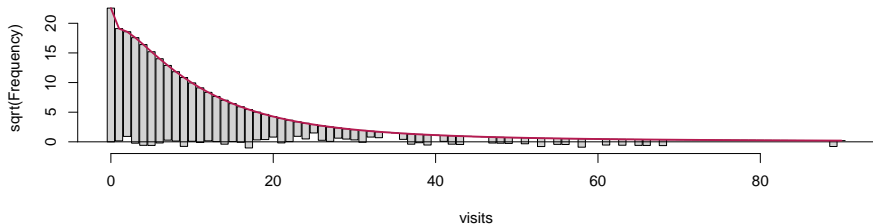


NB-Based Rootograms - Which Looks Best?

ZINB mod_4



NB-Logistic Hurdle mod_6



Store Training Sample mod_6 Predictions

```
mod_6_aug <- med_train |>
  mutate(".fitted" = predict(mod_6, type = "response"),
         ".resid" = resid(mod_6, type = "response"))

mod_6_aug |> select(subject, visits, .fitted, .resid) |>
  head(3)
```

```
# A tibble: 3 x 4
  subject visits .fitted .resid
  <int>   <int>   <dbl>  <dbl>
1     355     19     5.35   13.6
2    2661      3     4.16   -1.16
3    2895      0     4.49   -4.49
```


Summarizing Training Sample mod_6 Fit

```
mod_6_summary <-  
  mets(mod_6_aug, truth = visits, estimate = .fitted) |>  
  mutate(model = "mod_6") |> relocate(model)  
mod_6_summary |> kable(digits = 3)
```

model	.metric	.estimator	.estimate
mod_6	rsq	standard	0.089
mod_6	rmse	standard	6.772
mod_6	mae	standard	4.209

Training Sample Results through mod_6

```
bind_rows(mod_1_summary, mod_2_summary, mod_3_summary,  
          mod_4_summary, mod_5_summary, mod_6_summary) |>  
pivot_wider(names_from = model, values_from = .estimate) |>  
select(-.estimator) |> kable(dig = 3)
```

.metric	mod_1	mod_2	mod_3	mod_4	mod_5	mod_6
rsq	0.100	0.078	0.108	0.094	0.108	0.089
rmse	6.594	6.941	6.560	6.709	6.560	6.772
mae	4.189	4.252	4.164	4.191	4.164	4.209

Vuong test: Comparing mod_4 and mod_6

```
vuong(mod_4, mod_6)
```

Vuong Non-Nested Hypothesis Test-Statistic:

(test-statistic is asymptotically distributed $N(0,1)$ under the null that the models are indistinguishable)

```
-----  
                Vuong z-statistic                H_A p-value  
Raw                0.02994935 model1 > model2 0.48805  
AIC-corrected      0.02994935 model1 > model2 0.48805  
BIC-corrected      0.02994935 model1 > model2 0.48805
```

There's some evidence mod_4 (ZINB) fits better than mod_6 (NB Hurdle) in our training sample, but not to a statistically detectable degree, based on the large p value.

Section 11

Validation including Hurdle Models

Validation: Test Sample Predictions

Predict the visit counts for each subject in our test sample.

```
test_5 <- predict(mod_5, newdata = med_test,  
                  type.predict = "response")  
test_6 <- predict(mod_6, newdata = med_test,  
                  type.predict = "response")
```

Create a Tibble with Predictions

Combine the various predictions into a tibble with the original data.

```
test_res6 <- bind_cols(med_test,  
  pre_m1 = test_1, pre_m2 = test_2,  
  pre_m3 = test_3, pre_m4 = test_4,  
  pre_m5 = test_5, pre_m6 = test_6)  
  
names(test_res6)
```

```
[1] "subject"  "visits"    "hospital"  "health"  
[5] "chronic"  "sex"       "school"    "insurance"  
[9] "pre_m1"   "pre_m2"    "pre_m3"    "pre_m4"  
[13] "pre_m5"   "pre_m6"
```

Summarize fit in test sample for each model

```
m1_sum <- mets(test_res6, truth = visits, estimate = pre_m1)
  mutate(model = "mod_1")
m2_sum <- mets(test_res6, truth = visits, estimate = pre_m2)
  mutate(model = "mod_2")
m3_sum <- mets(test_res6, truth = visits, estimate = pre_m3)
  mutate(model = "mod_3")
m4_sum <- mets(test_res6, truth = visits, estimate = pre_m4)
  mutate(model = "mod_4")
m5_sum <- mets(test_res6, truth = visits, estimate = pre_m5)
  mutate(model = "mod_5")
m6_sum <- mets(test_res6, truth = visits, estimate = pre_m6)
  mutate(model = "mod_6")

test_sum6 <- bind_rows(m1_sum, m2_sum, m3_sum, m4_sum,
                      m5_sum, m6_sum)
```

Validation Results in Test Sample: All Models

```
test_sum6 <- bind_rows(m1_sum, m2_sum, m3_sum, m4_sum,  
                      m5_sum, m6_sum) |>  
  pivot_wider(names_from = model,  
              values_from = .estimate)  
  
test_sum6 |>  
  select(-.estimator) |> kable(dig = 4)
```

.metric	mod_1	mod_2	mod_3	mod_4	mod_5	mod_6
rsq	0.1032	0.1082	0.0993	0.0970	0.0992	0.0937
rmse	7.2122	7.2051	5.9069	5.9674	5.9072	6.0009
mae	4.4550	4.4496	3.9943	4.0095	3.9946	4.0265

- Now which model would you choose based on test sample performance?

Section 12

After Spring Break

After Spring Break

- Submission (Monday 2023-03-20) and then feedback on Project A
- Will get started on Project B
- Regression on Multi-Categorical Outcomes
- *also some discussion of hierarchical data*