

Wine Sales

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Introduction

Using the information about sample wine orders by restaurants and wine stores after a tasting, how can we predict wine sales by various wine characteristics? Using the `wine` dataset with 12,000 entries and variables mostly related to the chemical properties of each wine, we will build a count regression model to predict the number of cases of wine that will be sold. In practice, if a wine manufacturer can predict which wines will lead to greater sales, they can choose to offer those at more tastings in restaurants and wine stores.

Using the training data set we will build:

- two different poisson regression models
- two different negative binomial regression models
- two different multiple linear regression models

In this report we will:

- explore the data
- transform the data to meet conditions of count modeling
- compare models
- select an optimal model
- generate predictions for the evaluation data set

Data Exploration

As part of our initial data exploration below, we find the following issues that will be handled in the Data Preparation section:

- large amounts of negative values for 8 of the chemical measures (which must be in error)
- 26.25% of cases have a missing `STARS` value
- `Label Appeal` and `STARS` have imported as integers, but as could be interpreted as categorical variables due to lack of continuity
- many of the chemical variables could benefit from log transformations, after seeing the normality plots
- very few variables are correlated with the `TARGET` beyond `STARS` and `LabelAppeal`, consider dropping some

First Look

Taking a look at the structure of the dataset we have 12,795 cases and 14 potential predictor variables. All variables are numeric. We'll remove the `INDEX` variable as it isn't needed in model building.

```

## 'data.frame':   12795 obs. of  16 variables:
## $ i..INDEX      : int  1 2 4 5 6 7 8 11 12 13 ...
## $ TARGET        : int  3 3 5 3 4 0 0 4 3 6 ...
## $ FixedAcidity  : num  3.2 4.5 7.1 5.7 8 11.3 7.7 6.5 14.8 5.5 ...
## $ VolatileAcidity: num  1.16 0.16 2.64 0.385 0.33 0.32 0.29 -1.22 0.27 -0.22 ...
## $ CitricAcid    : num  -0.98 -0.81 -0.88 0.04 -1.26 0.59 -0.4 0.34 1.05 0.39 ...
## $ ResidualSugar : num  54.2 26.1 14.8 18.8 9.4 ...
## $ Chlorides     : num  -0.567 -0.425 0.037 -0.425 NA 0.556 0.06 0.04 -0.007 -0.277 ...
## $ FreeSulfurDioxide: num  NA 15 214 22 -167 -37 287 523 -213 62 ...
## $ TotalSulfurDioxide: num  268 -327 142 115 108 15 156 551 NA 180 ...
## $ Density       : num  0.993 1.028 0.995 0.996 0.995 ...
## $ pH            : num  3.33 3.38 3.12 2.24 3.12 3.2 3.49 3.2 4.93 3.09 ...
## $ Sulphates     : num  -0.59 0.7 0.48 1.83 1.77 1.29 1.21 NA 0.26 0.75 ...
## $ Alcohol       : num  9.9 NA 22 6.2 13.7 15.4 10.3 11.6 15 12.6 ...
## $ LabelAppeal   : int  0 -1 -1 -1 0 0 0 1 0 0 ...
## $ AcidIndex     : int  8 7 8 6 9 11 8 7 6 8 ...
## $ STARS         : int  2 3 3 1 2 NA NA 3 NA 4 ...

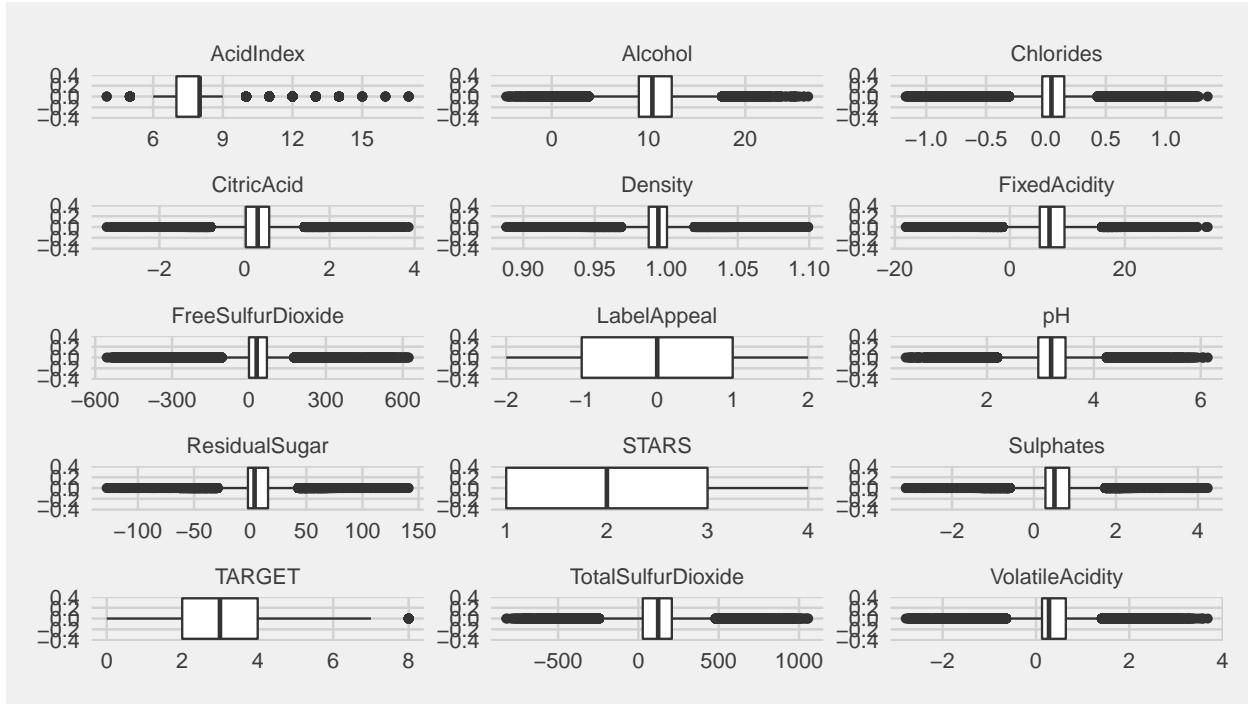
```

The table below shows the range of the TARGET (# cases purchased) ranges from 0 - 8. We also see a large amount of negative values across some of the chemical variables. We will need to deal with these values and/or cases later as it isn't possible for wine to have negative values in any of these chemical measures.

variables	min	mean	median	max	zero	minus
TARGET	0.00	3.03	3.00	8.00	2,734	0
FixedAcidity	-18.10	7.08	6.90	34.40	39	1,621
VolatileAcidity	-2.79	0.32	0.28	3.68	18	2,827
CitricAcid	-3.24	0.31	0.31	3.86	115	2,966
ResidualSugar	-127.80	5.42	3.90	141.15	6	3,136
Chlorides	-1.17	0.05	0.05	1.35	5	3,197
FreeSulfurDioxide	555.00	30.85	30.00	623.00	11	3,036
TotalSulfurDioxide	823.00	120.71	123.00	1,057.00	7	2,504
Density	0.89	0.99	0.99	1.10	0	0
pH	0.48	3.21	3.20	6.13	0	0
Sulphates	-3.13	0.53	0.50	4.24	22	2,361
Alcohol	-4.70	10.49	10.40	26.50	2	118
LabelAppeal	-2.00	-0.01	0.00	2.00	5,617	3,640
AcidIndex	4.00	7.77	8.00	17.00	0	0
STARS	1.00	2.04	2.00	4.00	0	0

Checking for Normality

Look at the distribution of all of the predictor variables with boxplots.



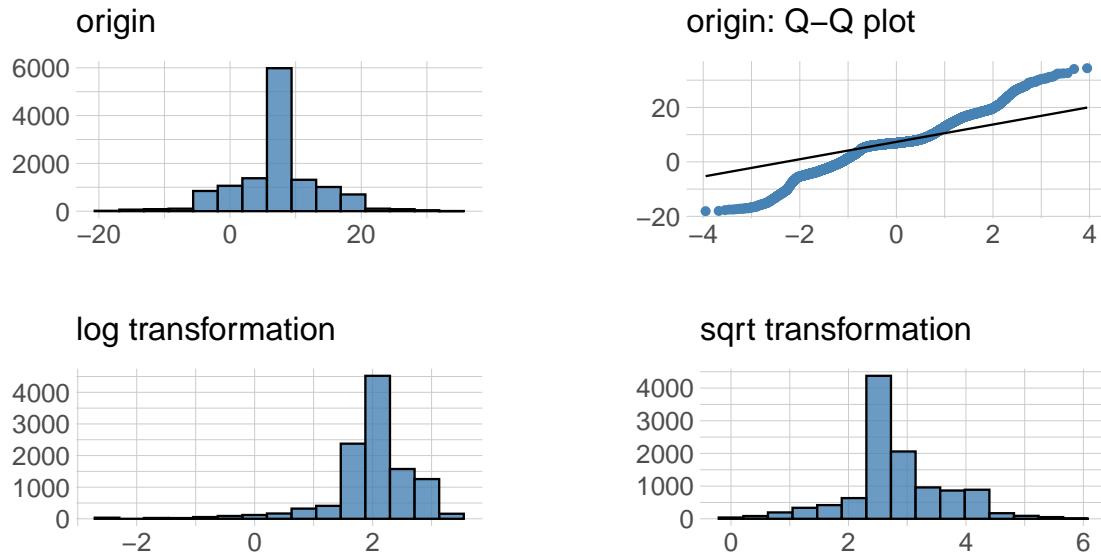
Using the Shapiro-Wilk normality test on each of the variables, we see all of the p-values are less than 0.05 which means none of our variables are normally distributed in their raw form.

vars	statistic	p_value	sample
Alcohol	0.974	0.000	5,000.000
pH	0.963	0.000	5,000.000
TotalSulfurDioxide	0.959	0.000	5,000.000
FixedAcidity	0.952	0.000	5,000.000
Sulphates	0.946	0.000	5,000.000
VolatileAcidity	0.949	0.000	5,000.000
ResidualSugar	0.942	0.000	5,000.000
CitricAcid	0.944	0.000	5,000.000
FreeSulfurDioxide	0.935	0.000	5,000.000
Density	0.937	0.000	5,000.000
Chlorides	0.928	0.000	5,000.000
TARGET	0.906	0.000	5,000.000
STARS	0.851	0.000	5,000.000
LabelAppeal	0.892	0.000	5,000.000
AcidIndex	0.844	0.000	5,000.000

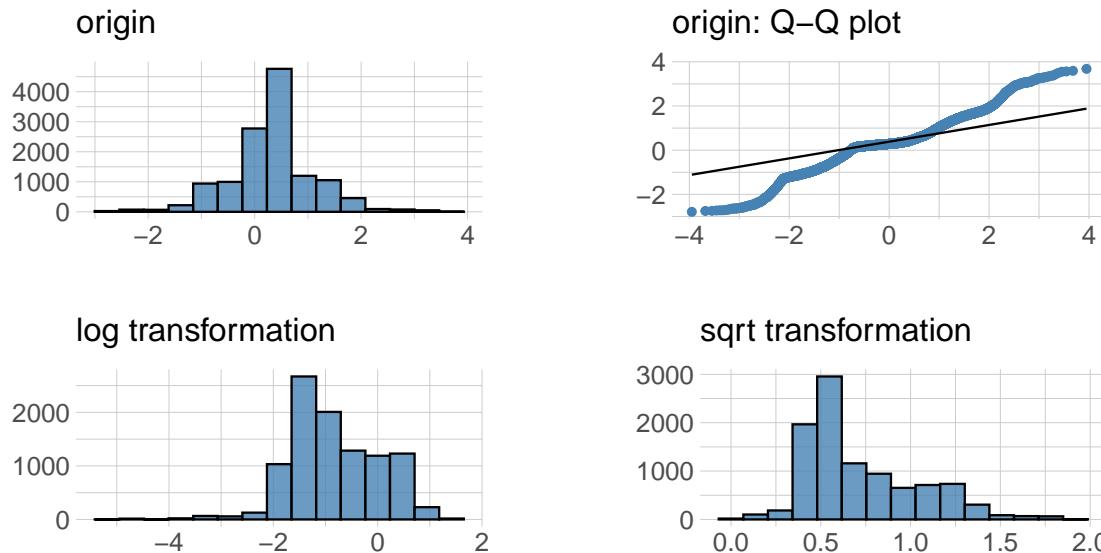
Below we visualize with a histogram and Q-Q plot for each variable for which we want to check for normality, excluding the TARGET variable and variables we will convert to factors later. It appears that all 11 of the

variables would benefit from a log transformation, which will likely become even more necessary once we correct for the un-interpretable negative values many of these variables have in the original dataset.

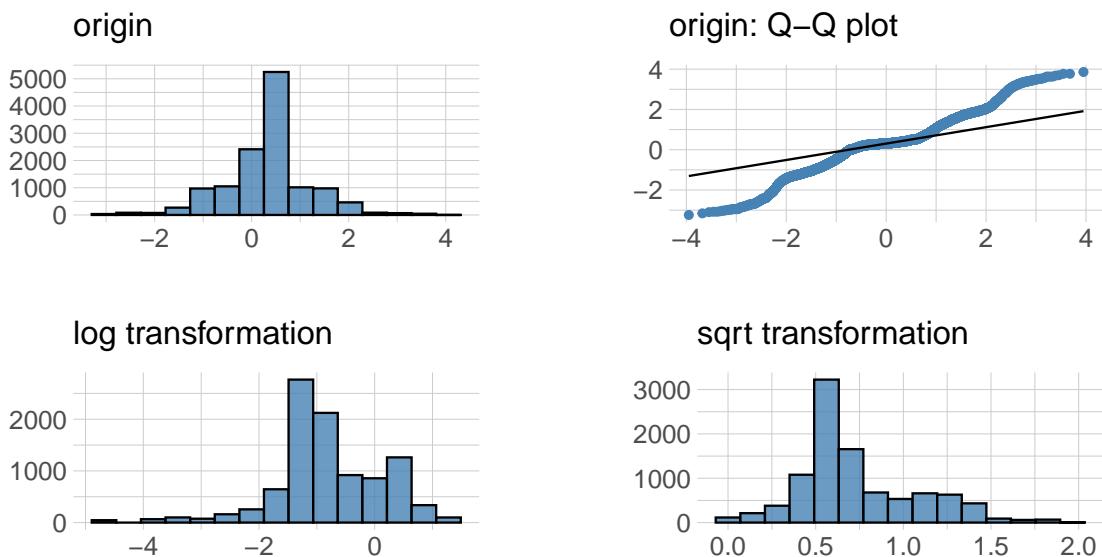
Normality Diagnosis Plot (FixedAcidity)



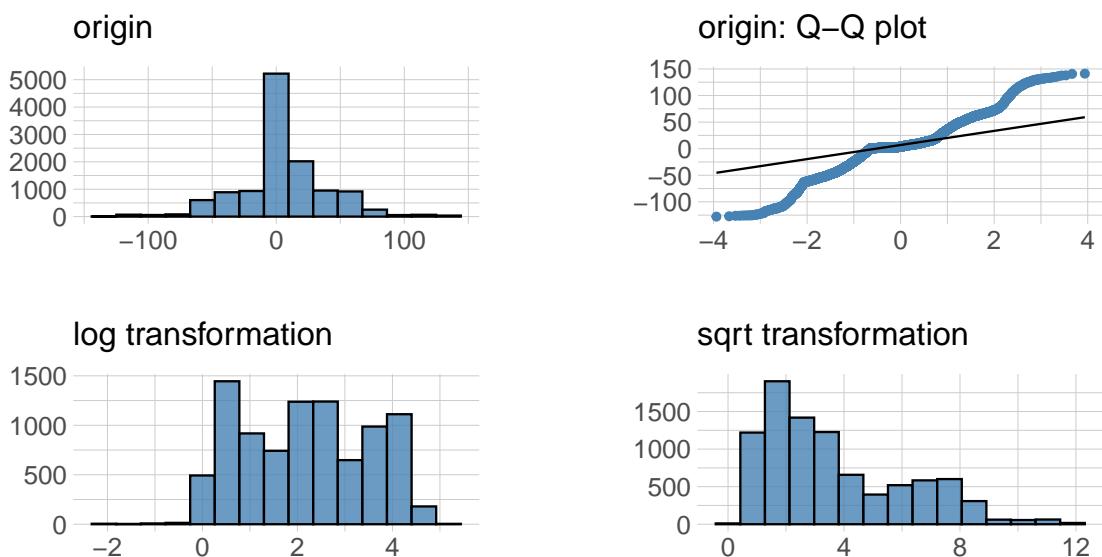
Normality Diagnosis Plot (VolatileAcidity)



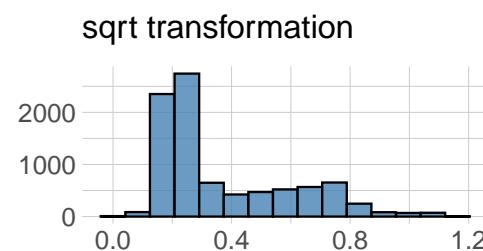
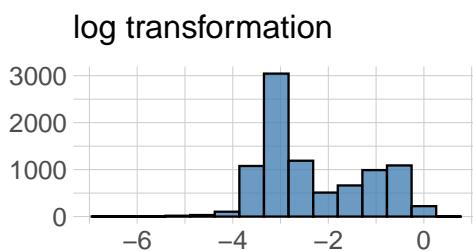
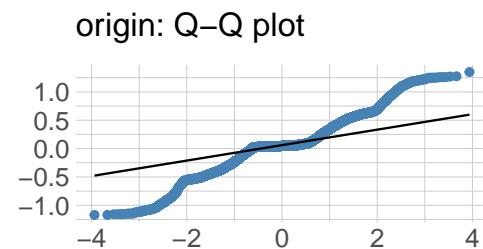
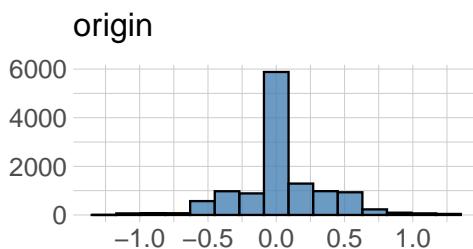
Normality Diagnosis Plot (CitricAcid)



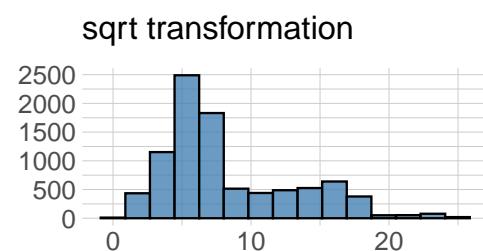
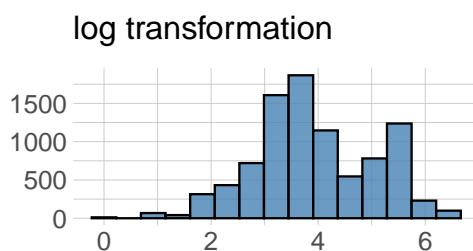
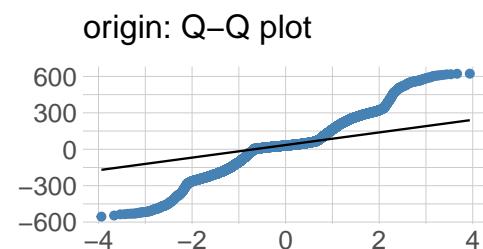
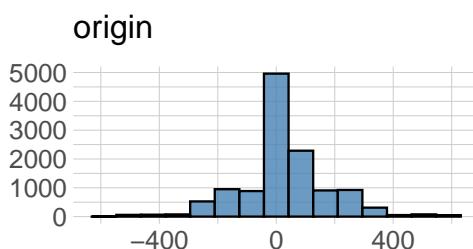
Normality Diagnosis Plot (ResidualSugar)



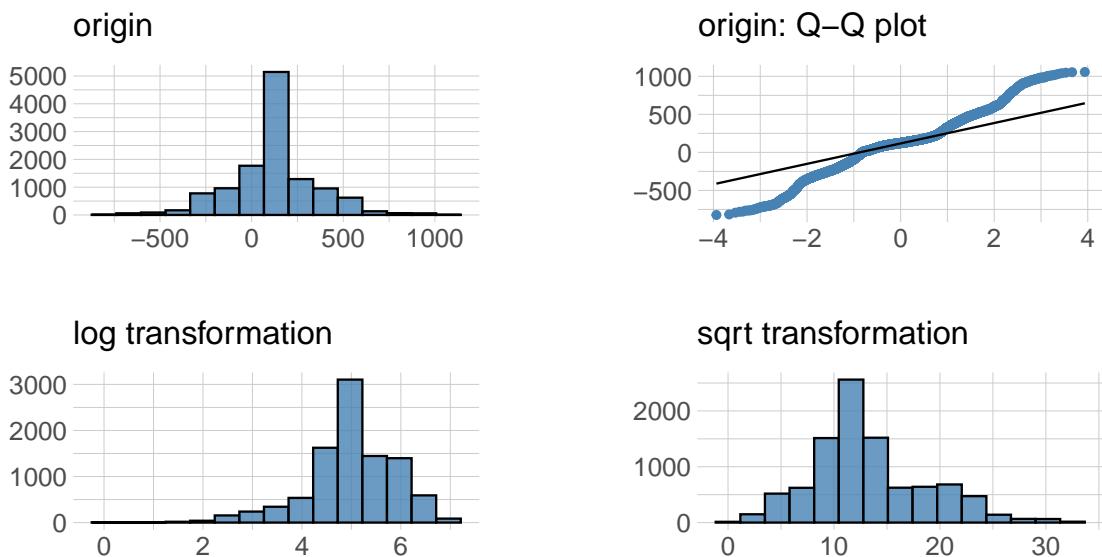
Normality Diagnosis Plot (Chlorides)



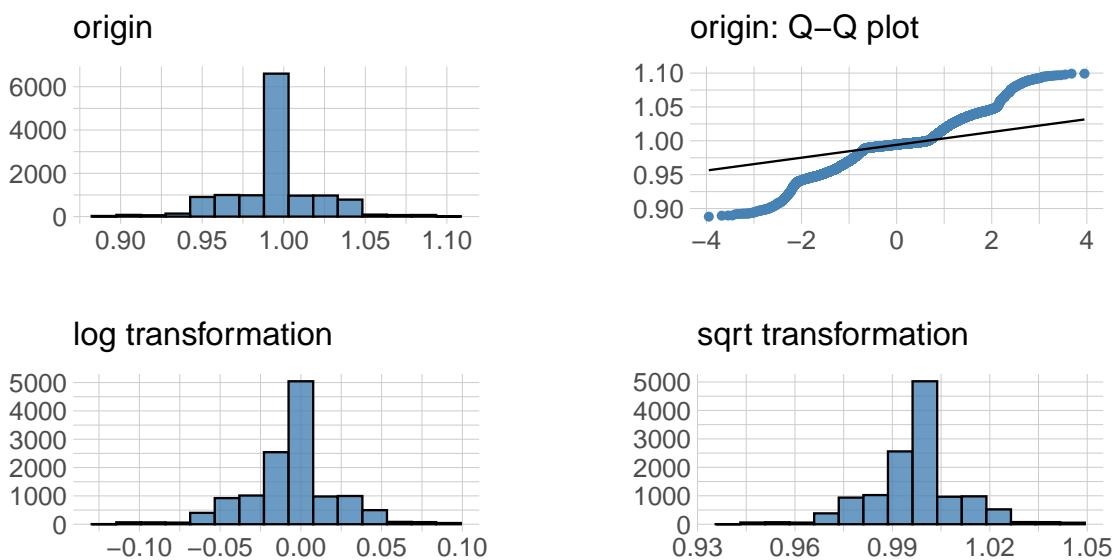
Normality Diagnosis Plot (FreeSulfurDioxide)



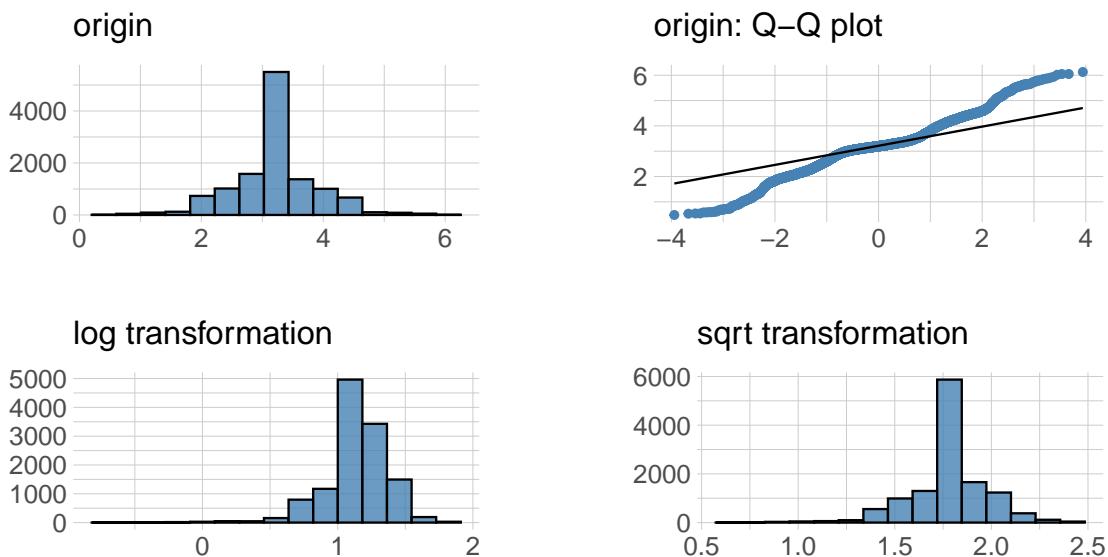
Normality Diagnosis Plot (TotalSulfurDioxide)



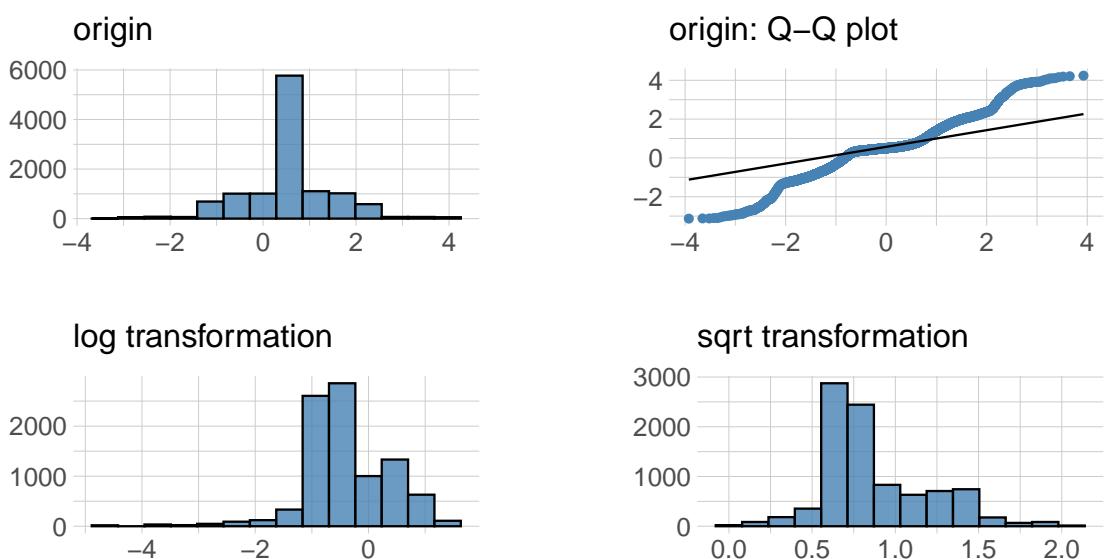
Normality Diagnosis Plot (Density)



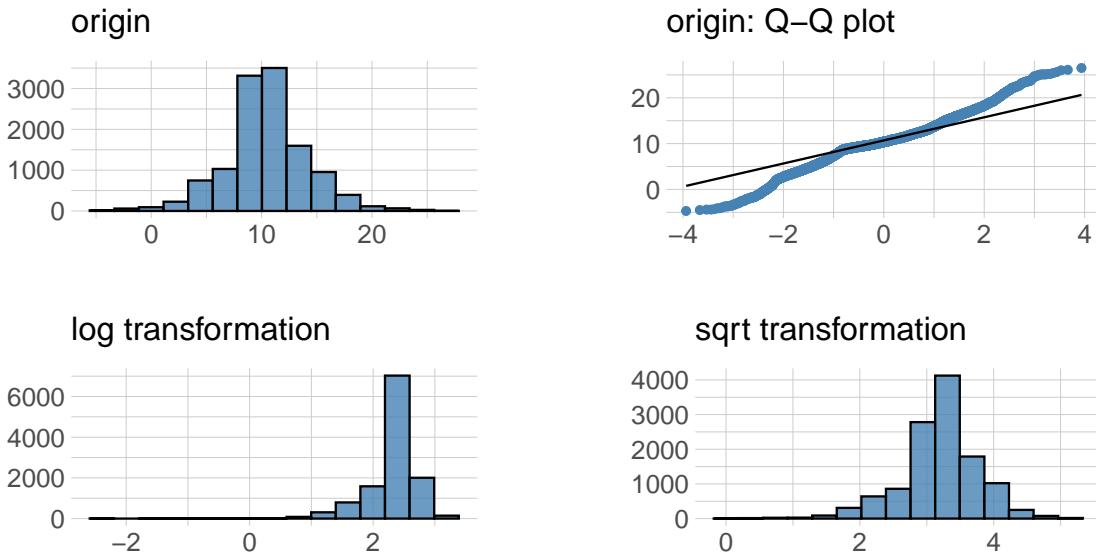
Normality Diagnosis Plot (pH)



Normality Diagnosis Plot (Sulphates)



Normality Diagnosis Plot (Alcohol)



Missingness

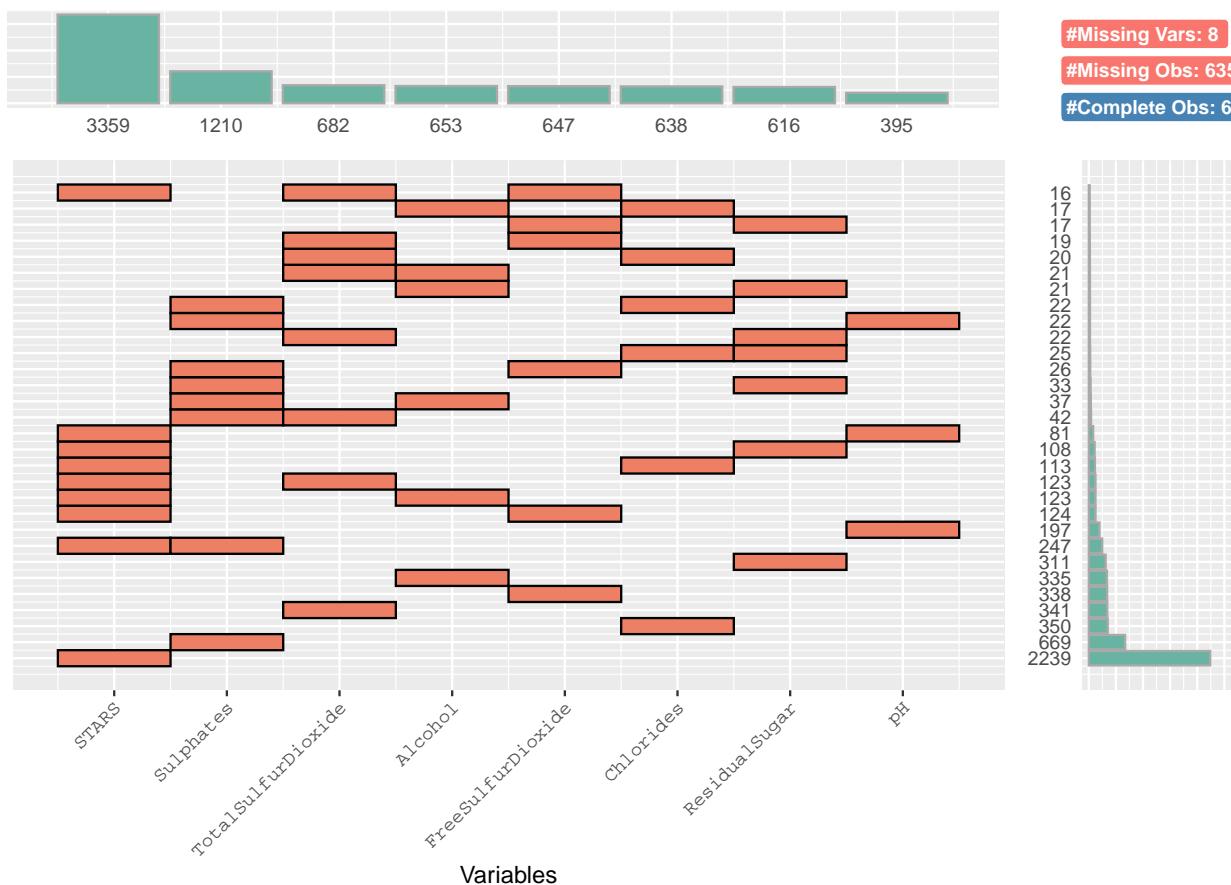
With regards to missingness, we have 6 variables with data for every case. This leaves 8 variables that have some degree of missing data, with the worst being the **STARS** variable with 26.25% of cases missing a value for **STARS** (the wine rating by experts). None of the remaining 7 variables have more than 10% missing, so we will not consider dropping or imputing missing values for them.

variables	types	missing_count	missing_percent
STARS	integer	3,359	26.25
Sulphates	numeric	1,210	9.46
TotalSulfurDioxide	numeric	682	5.33
Alcohol	numeric	653	5.10
FreeSulfurDioxide	numeric	647	5.06
Chlorides	numeric	638	4.99
ResidualSugar	numeric	616	4.81
pH	numeric	395	3.09

Looking for patterns in missingness can be telling. Below the 8 variables with at least some missingness are plotted for the top 30 most frequent combinations of missing values.

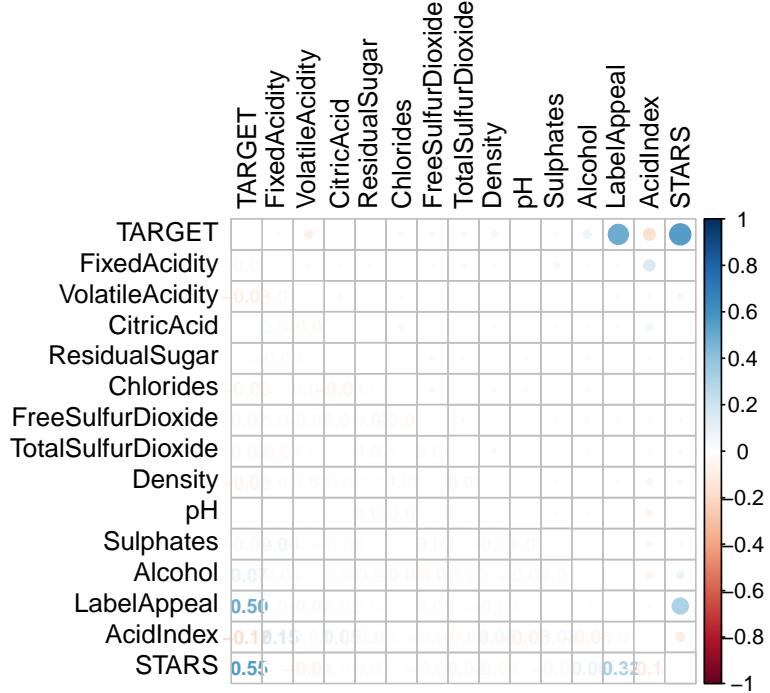
We don't see any major relationships of missingness that affect a large number of cases in the dataset.

Missing with intersection of variables



Correlation

We see a very sparse correlation plot below. `LabelAppeal` and `STARS` jump out as having the largest positive correlation with `TARGET`, with a faint negative correlation between `AcidIndex` and the `TARGET`. We also see a correlation between `LabelAppeal` and `STARS`.



Check for Outliers

The table below shows the count and percent of outliers within each variable arranged with the highest outlier count starting at the top. The outliers_ratio shows the percent of outliers identified within all cases, which is greater than 5% for the first 12 variables. We will recheck that table after transformations in the Data Preparation section.

variables	outliers_cnt	outliers_ratio	outliers_mean	with_mean	without_mean
Density	3,823	29.879	0.994	0.994	0.994
FreeSulfurDioxide	3,712	29.011	24.169	30.846	33.783
ResidualSugar	3,298	25.776	3.499	5.419	6.132
Chlorides	3,021	23.611	0.048	0.055	0.057
CitricAcid	2,688	21.008	0.288	0.308	0.314
Sulphates	2,606	20.367	0.463	0.527	0.546
VolatileAcidity	2,599	20.313	0.208	0.324	0.354
FixedAcidity	2,455	19.187	6.761	7.076	7.150
pH	1,864	14.568	3.203	3.208	3.208
TotalSulfurDioxide	1,590	12.427	127.610	120.714	119.672
AcidIndex	1,151	8.996	10.552	7.773	7.498
Alcohol	928	7.253	9.470	10.489	10.574
TARGET	17	0.133	8.000	3.029	3.022
LabelAppeal	0	0.000		-0.009	-0.009

variables	outliers_cnt	outliers_ratio	outliers_mean	with_mean	without_mean
STARS	0	0.000	2.042	2.042	

Data Preparation

To address the issues in the data we discovered in the data exploration section, we will:

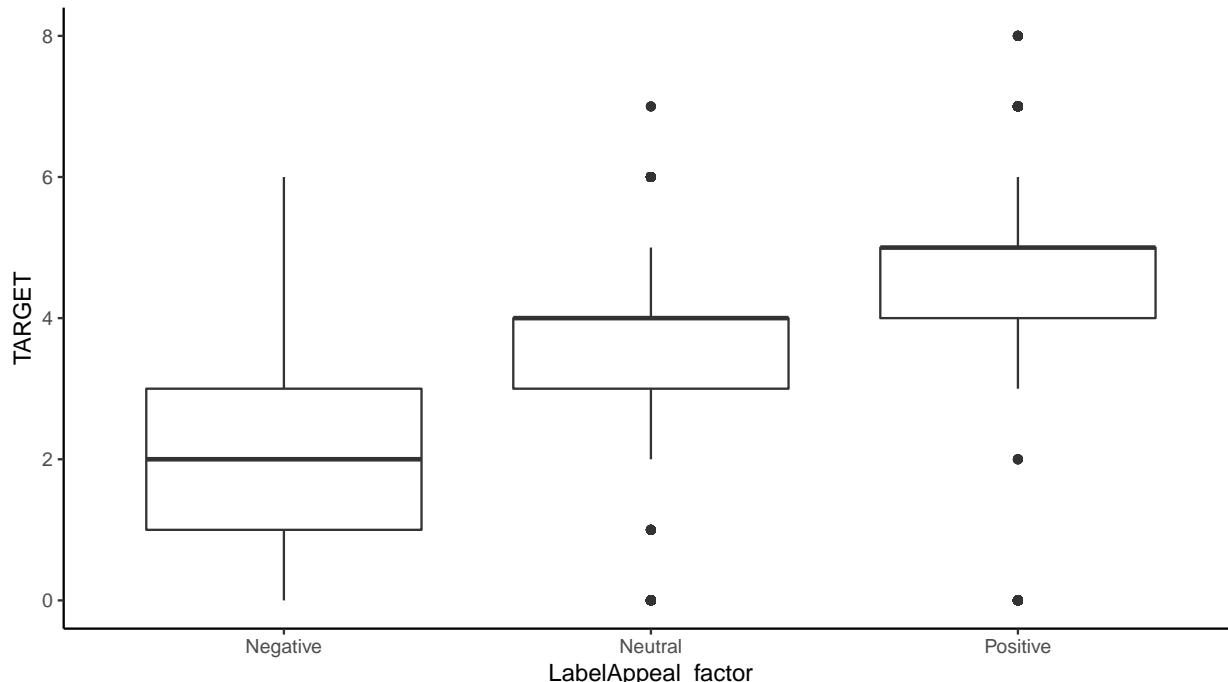
- **CHANGE DATA TYPE** to factors for STARS, interpreting as categorical variables due to lack of continuity
- **Bucket LabelAppeal Ratings** into Negative, Neutral, and Positive scores
- **TAKE ABSOLUTE VALUE of all negative values** for 8 of the chemical measures (which must be in error)
- **IMPUTE missing values** for variables (except STARS) using the median
- **Created missing STARS variable** for 26.25% of cases that have a missing STARS value
- **Drop variables** that have no correlation to TARGET even after above transformations
- ****LOG transformation*** for all of the numeric chemical variables that were not normally distributed

Change Data Type of STARS

We set the STARS variable as a factor as it's a rating and not a continuous scale.

Bucket LabelAppeal Ratings

Switch LabelAppeal to a factor after coding the ratings into buckets of Negative, Neutral, and Positive. This will be easier to interpret as well. The boxplots after this change show how increased LabelAppeal seems to be positively associated with the TARGET.



Fix Negative Values

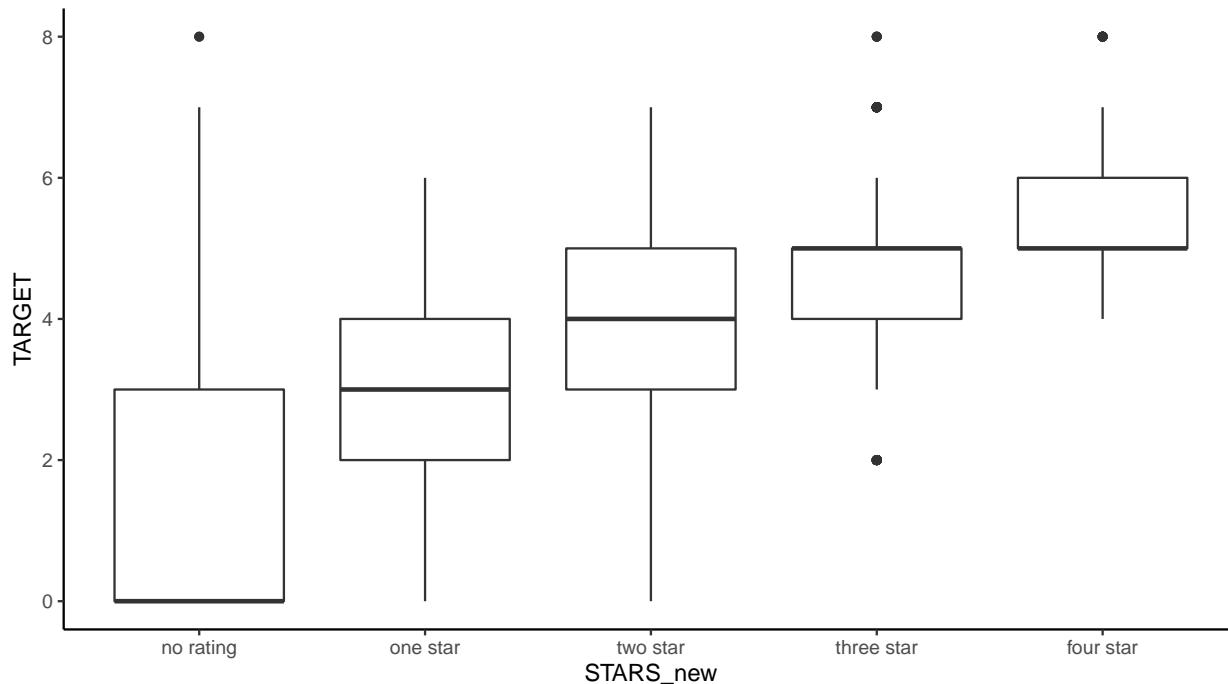
With 21,766 negative values across many of the chemical variables, for which it doesn't make sense to have a negative value, we convert these to positive values so we retain some value (as opposed to omitting these measures). Variables include: `FixedAcidity`, `VolatileAcidity`, `CitricAcid`, `ResidualSugar`, `Chlorides`, `FreeSulfurDioxide`, `TotalSulfurDioxide`, `Sulphates`, `Alcohol`.

Impute Missing Values

For the 7 variables that had <10% missing values, we will impute the missing values with the median for that variable. Variables include: `ResidualSugar`, `Chlorides`, `FreeSulfurDioxide`, `TotalSulfurDioxide`, `pH`, `Sulphates`, `Alcohol`.

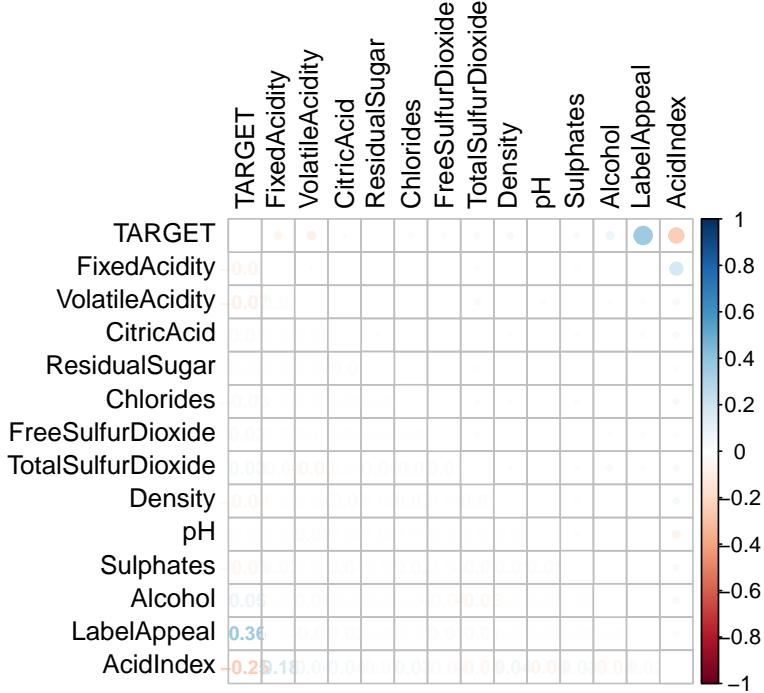
Flag STARS Missing Values

With 26.25% of cases missing a STARS rating, we need to consider if we should drop the variable from modeling, impute the missing values, or flag these cases. There are some guidelines in data science that if there are beyond 30% missing values, the variable may be best dropped. Theoretically, the STARS variable should represent something close to our TARGET variable as we'd expect a relationship between high expert reviews and high case sales. Since this seems like too valuable of a variable to drop, and considering that depending on how the STARS data was obtained, a missing value could indicate a lesser quality or less popular wine (such that it hasn't been rated by experts), we choose to create a new variable where a '1' indicates a missing STARS value. We leave the NAs in the original STARS variable. We set the `STARS_new` variable as a factor.



Drop Variables

The correlation plot below show that, even after some of the above transformations, the majority of the numeric variables are not correlated with the TARGET. We choose to drop `FixedAcidity`, `VolatileAcidity`, `CitricAcid` as theoretically they should be represented in the `AcidIndex`.



Preform Log Transformations

The normality plots earlier identified the following variables could benefit from log transformations, which is even more true after having taken the absolute value of many of these variables (as a result of un-interpretable negative chemical values). We also add 0.00000001 to the new value in order to avoid any values of zero for which there is no defined log value while not affect the variables distribution greatly.

Re-Run Normality, Outlier, & Correlation Plots

After all of the above changes, we check the dataset below. We've dropped the pre-logging variables for simplicity.

variables	min	mean	median	max	zero	minus
TARGET	0.00	3.03	3.00	8.00	2,734	0
LabelAppeal	-2.00	-0.01	0.00	2.00	5,617	3,640
AcidIndex	4.00	7.77	8.00	17.00	0	0
log_ResidualSugar	18.42	2.43	2.56	4.95	0	138
log_Chlorides	-18.42	-2.12	-2.32	0.30	0	12,630
log_FreeSulfurDioxide	18.42	4.09	4.03	6.43	0	11
log_Density	-0.12	-0.01	-0.01	0.09	0	9,492
log_PH	-0.73	1.14	1.16	1.81	0	53
log_Sulphates	-18.42	-0.48	-0.53	1.44	0	9,569
log_Alcohol	-18.42	2.27	2.34	3.28	0	76

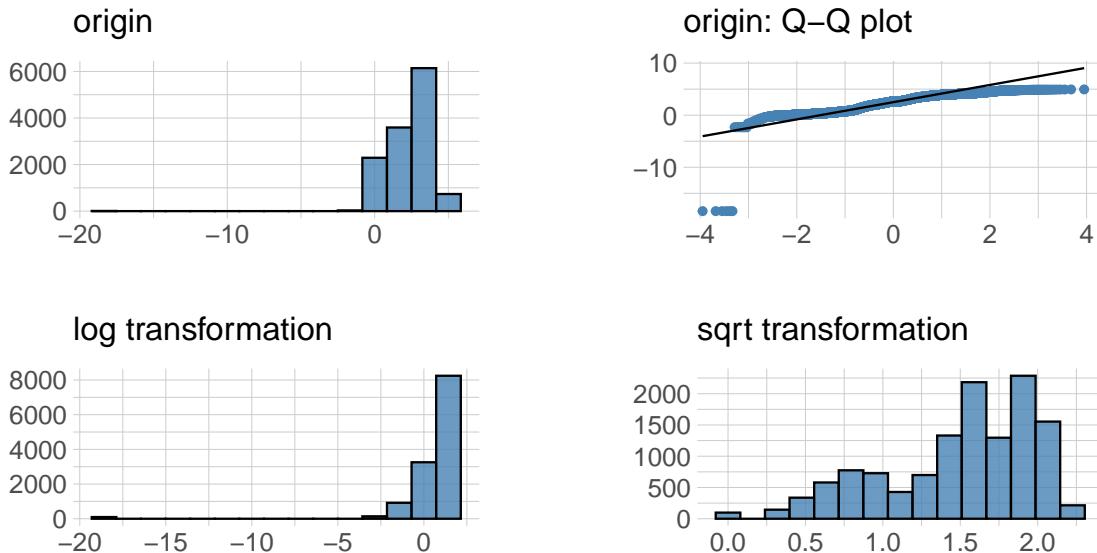
Next we check the outlier table to see if we still have greater than 5% of data points identified as outliers in a large proportion of the chemical variables. It appears we have normalized some of the outliers with the above transformations, but `log_Density`, `log_PH`, `log_Alcohol`, and `AcidIndex` still have more than 5% of values identified as outliers.

is there anything else we can/should do for these variables with high proportion of outliers?
-rachel

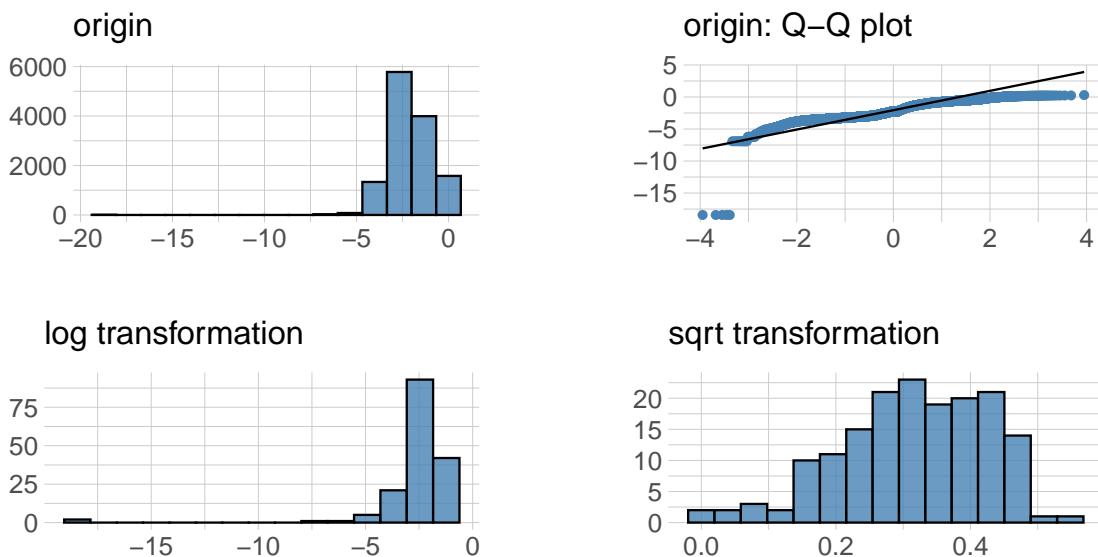
variables	outliers_cnt	outliers_ratio	outliers_mean	with_mean	without_mean
<code>log_Density</code>	3,817	29.832	-0.007	-0.006	-0.006
<code>log_PH</code>	2,121	16.577	0.963	1.141	1.176
<code>log_Alcohol</code>	1,485	11.606	1.459	2.271	2.378
<code>AcidIndex</code>	1,151	8.996	10.552	7.773	7.498
<code>log_Sulphates</code>	551	4.306	-2.746	-0.484	-0.382
<code>log_FreeSulfurDioxide</code>	55	0.430	-3.412	4.089	4.121
<code>log_Chlorides</code>	27	0.211	-8.757	-2.117	-2.103
<code>TARGET</code>	17	0.133	8.000	3.029	3.022
<code>log_ResidualSugar</code>	16	0.125	-8.347	2.430	2.444
<code>LabelAppeal</code>	0	0.000		-0.009	-0.009

Looking at the normality plots for the 7 variables for which we converted negative values into positive values and then performed a log transformation, they are more normal than they were previously, but some are still seriously skewed.

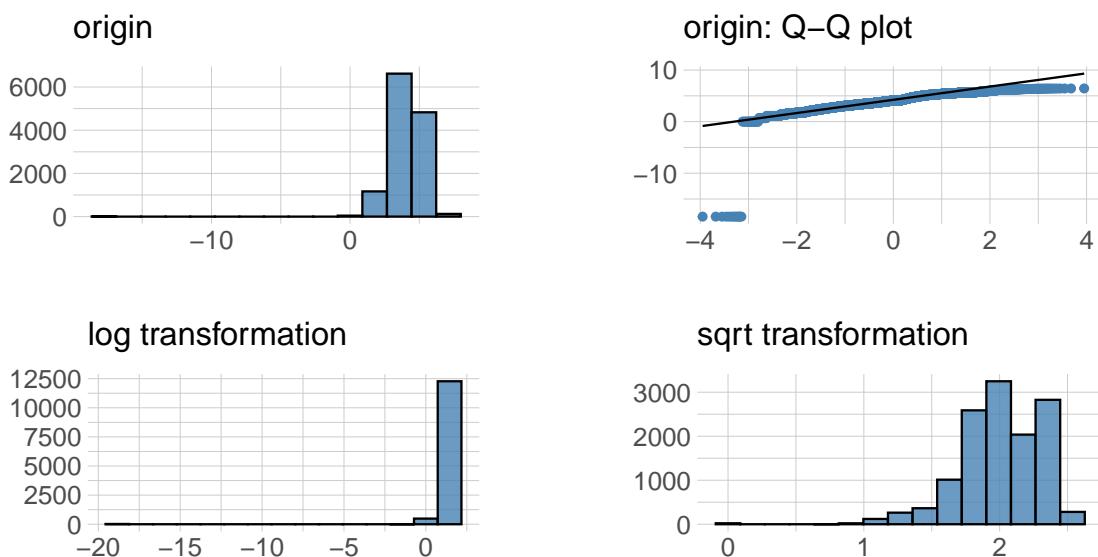
Normality Diagnosis Plot (`log_ResidualSugar`)



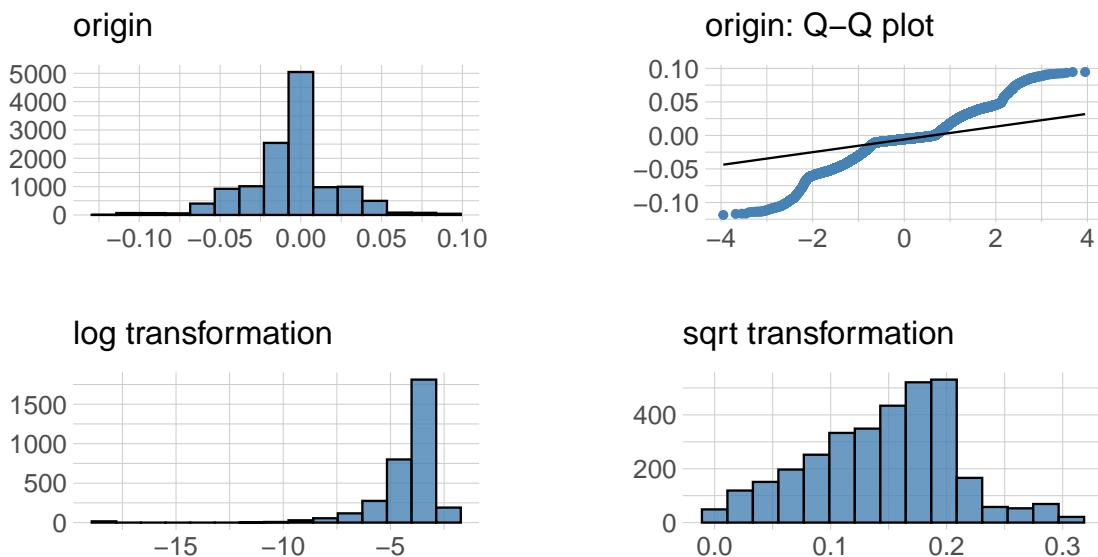
Normality Diagnosis Plot (log_Chlorides)



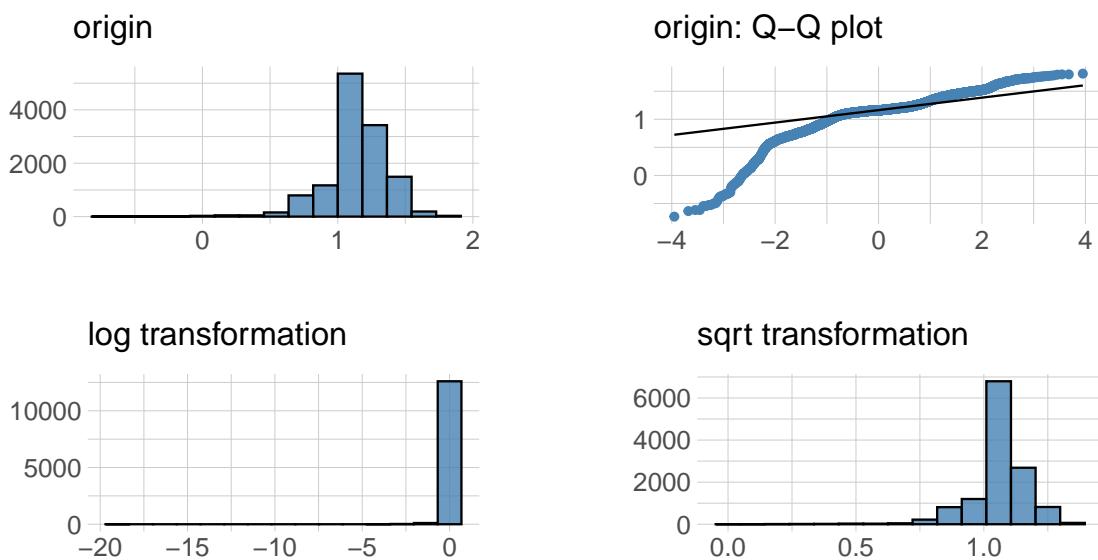
Normality Diagnosis Plot (log_FreeSulfurDioxide)



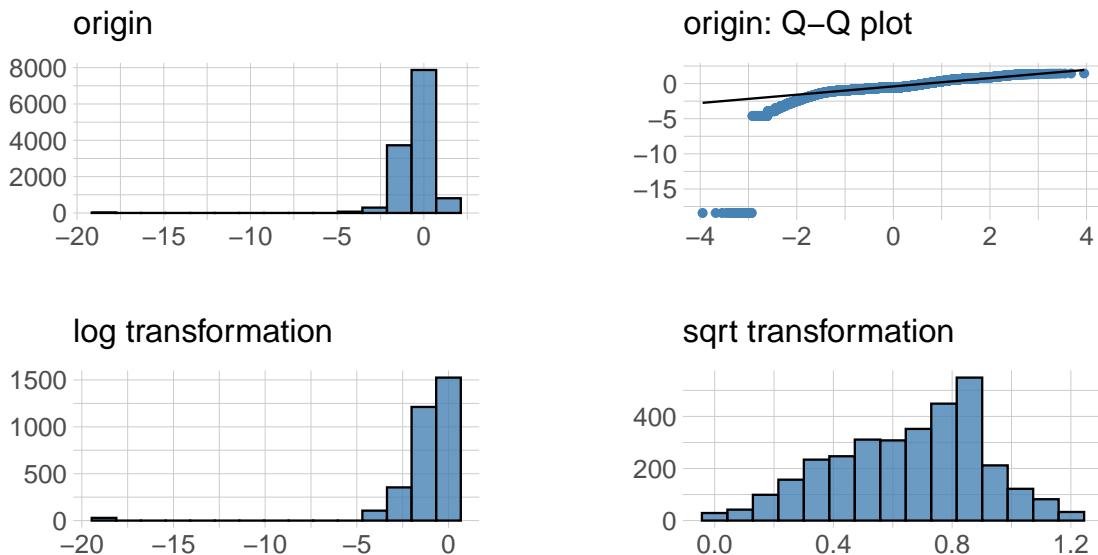
Normality Diagnosis Plot (log_Density)



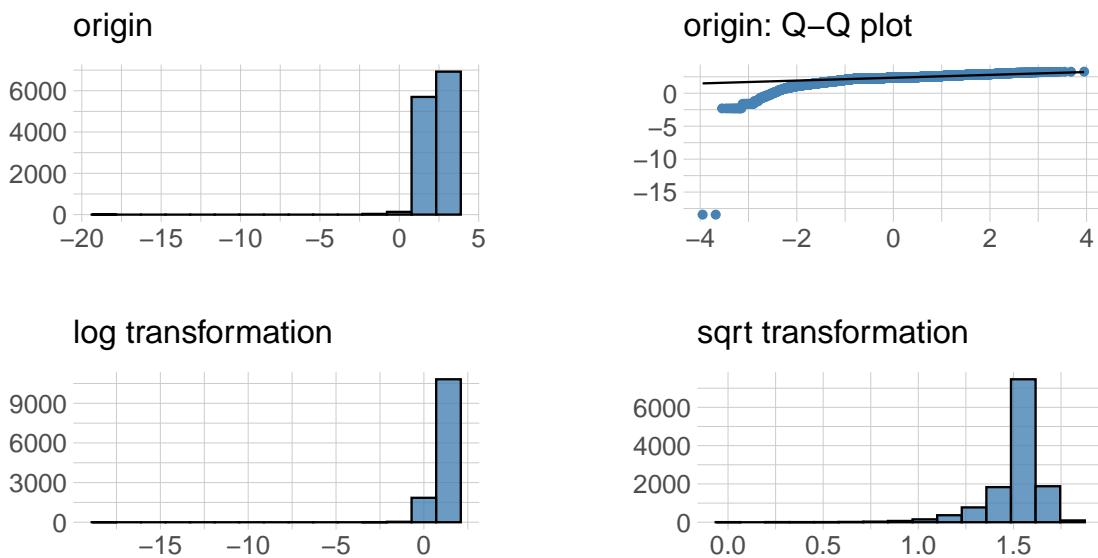
Normality Diagnosis Plot (log_PH)



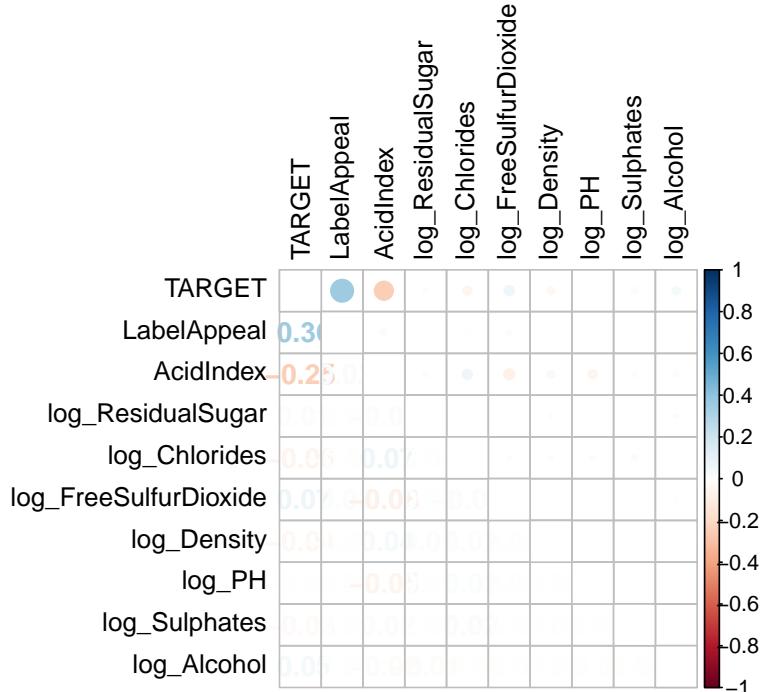
Normality Diagnosis Plot (log_Sulphates)



Normality Diagnosis Plot (log_Alcohol)



Creating a new correlation plot with our transformed numeric variables it appears there is very little correlation between our `TARGET` variable and any of these chemical measures with the exception of `AcidIndex`. At this point the `LabelAppeal`, `AcidIndex`, and earlier we saw the `STARS` variable have the strongest correlations with the `TARGET`.



Build Models

Our prompt asks us to build at least two of three different models: *poisson*, *negative binomial*, and *multiple linear regression*. As there appears to be no correlation from the logged chemical variables, we won't include those in any of the following models.

The Poissons

Poisson distributions are used for count data and relies on the distribution generally have a mean = variance. Poisson is particularly useful when the counts are small, if they are larger we may be able to get use out of a linear regression (which we'll try later).

*resources to add to end later: <https://www.dataquest.io/blog/tutorial-poisson-regression-in-r/> https://cran.r-project.org/web/packages/GlmSimulatoR/vignettes/count_data_and_overdispersion.html

First we model based on the AcidIndex, STAR_new, and LabelAppeal_factor variables. It appears all have significant p-values. We see a residual deviance of 13,776 which is greater than the 12,787 degrees of freedom - this suggests over-dispersion exists. Our estimates are correct, but the standard errors are wrong and the model isn't accounting for them. Finally, comparing the null deviance (a model with only the intercept) we see that we have a greatly lower residual deviance for the 8 degrees of freedom we lost in adding our predictive variables. This means the model we built fits better than the null.

```
##
## Call:
## glm(formula = TARGET ~ AcidIndex + STARS_new - 1 + LabelAppeal_factor,
##      family = "poisson", data = raw)
##
## Deviance Residuals:
##       Min        1Q     Median        3Q       Max
## -3.0499  -0.6778   0.0020   0.4831   3.7943
##
## Coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)
```

```

## AcidIndex          -0.080665  0.004488 -17.97 <2e-16 ***
## STARS_newno rating   0.638253  0.039938 15.98 <2e-16 ***
## STARS_newone star    1.408526  0.036982 38.09 <2e-16 ***
## STARS_newtwo star    1.736149  0.036041 48.17 <2e-16 ***
## STARS_newthree star   1.860790  0.036407 51.11 <2e-16 ***
## STARS_newfour star    1.986422  0.039312 50.53 <2e-16 ***
## LabelAppeal_factorNeutral 0.213817  0.013850 15.44 <2e-16 ***
## LabelAppeal_factorPositive 0.365598  0.014892 24.55 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for poisson family taken to be 1)
##
## Null deviance: 56842  on 12795  degrees of freedom
## Residual deviance: 13776  on 12787  degrees of freedom
## AIC: 45734
##
## Number of Fisher Scoring iterations: 6

```

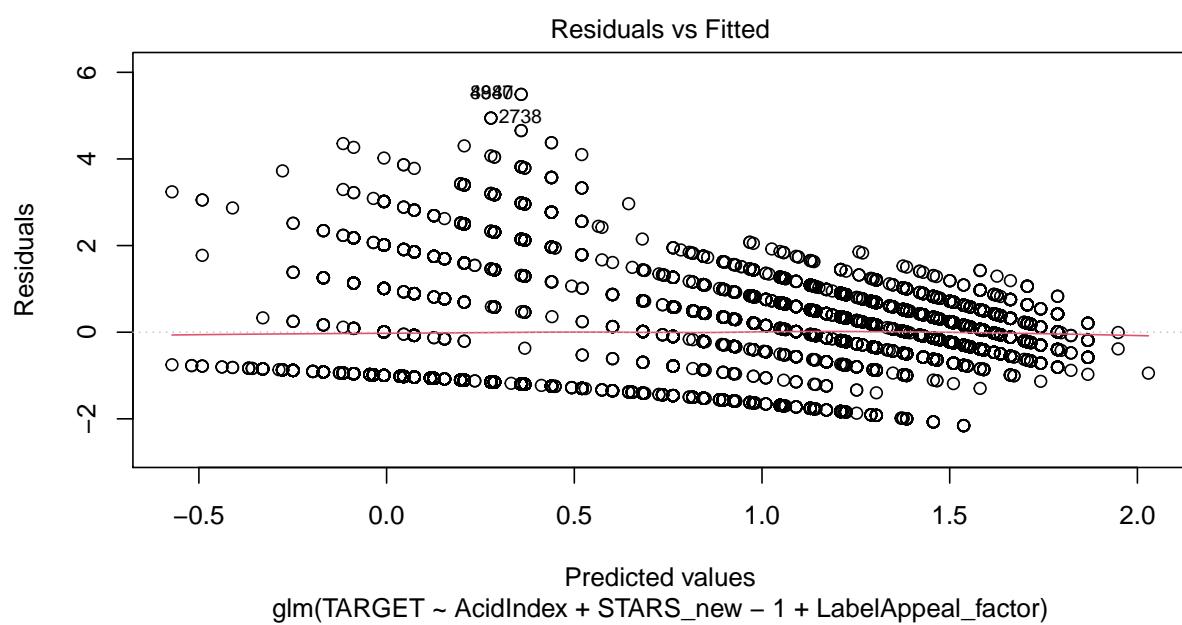
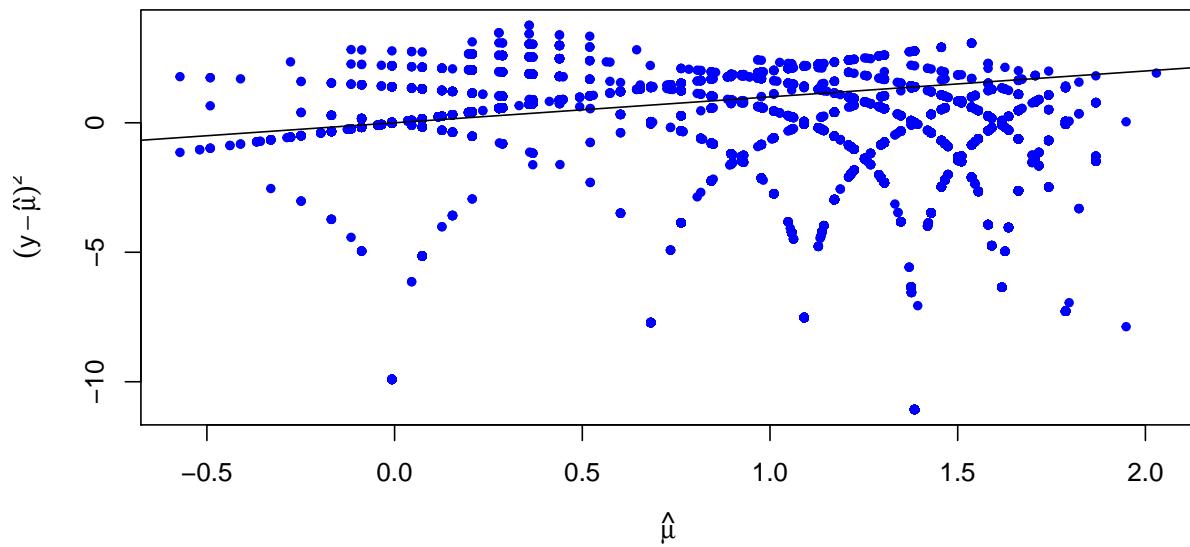
We calculate the dispersion parameter that's based on Pearson's Chi-squared statistic and the degrees of freedom with a function from the AER library.. A value over 1 indicates over-dispersion, which in this case we do not find as we have a value of 0.897. Generally a value greater than 1.10 is considering dispersed, so we extend this rational to say a value of nearl 0.9 is close enough to 1.0 to not be concerned about dispersion issues.

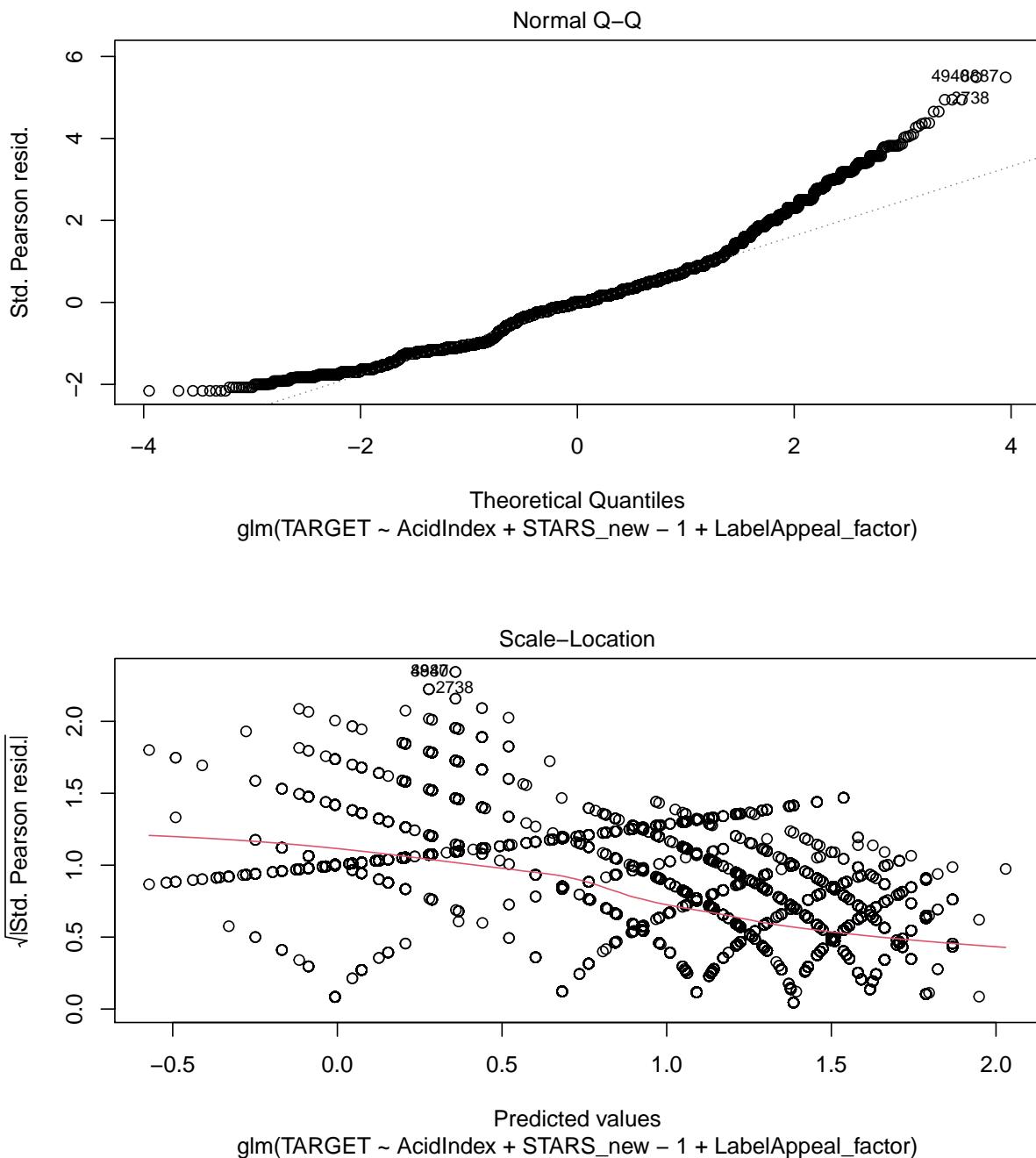
```

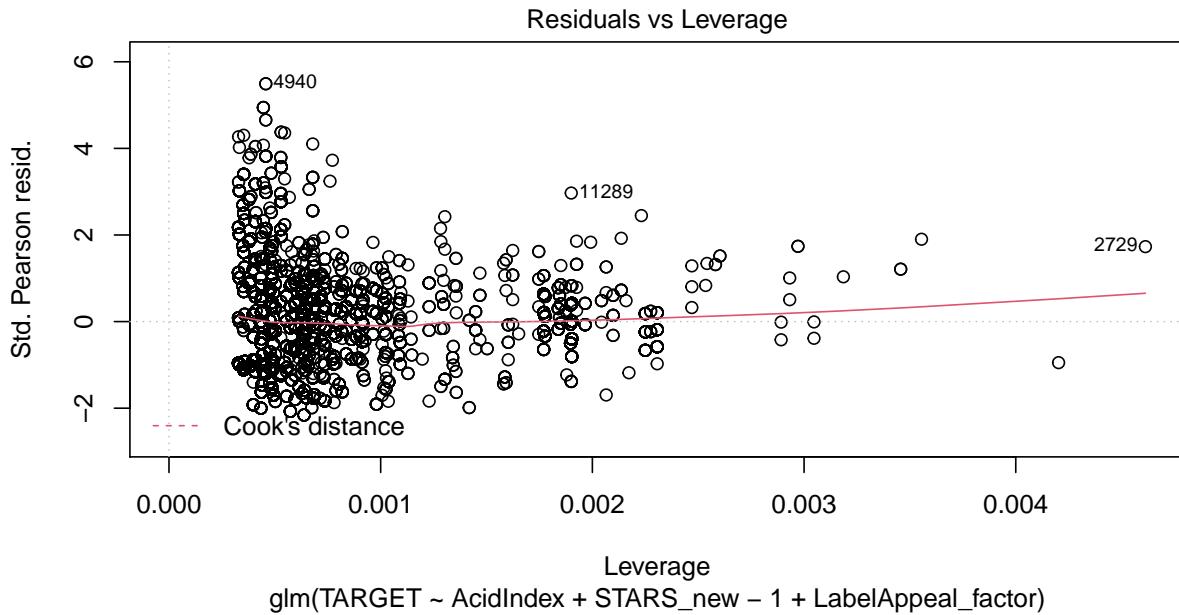
##
## Overdispersion test
##
## data: m_pois_1
## z = -7.8039, p-value = 1
## alternative hypothesis: true dispersion is greater than 1
## sample estimates:
## dispersion
## 0.8971707

```

Plotting the estimated variance against the mean for the above model. ##### not sure how to interpret this, I think we want ideally we want the data balance around the line - rachel







For our second poisson model we include all variables, except for the original STARS rating. A dispersion check yields a 0.895 value, which is not cause for concern.

The model below shows that `log_ResidualSugar`, `log_Density`, `log_PH`, and `log_Sulphates` do not have significant p-values. Despite low values in the correlation plots earlier, it does appear that `log_Chlorides`, `log_FreeSulfurDioxide`, and `log_Alcohol` are significant at this stage.

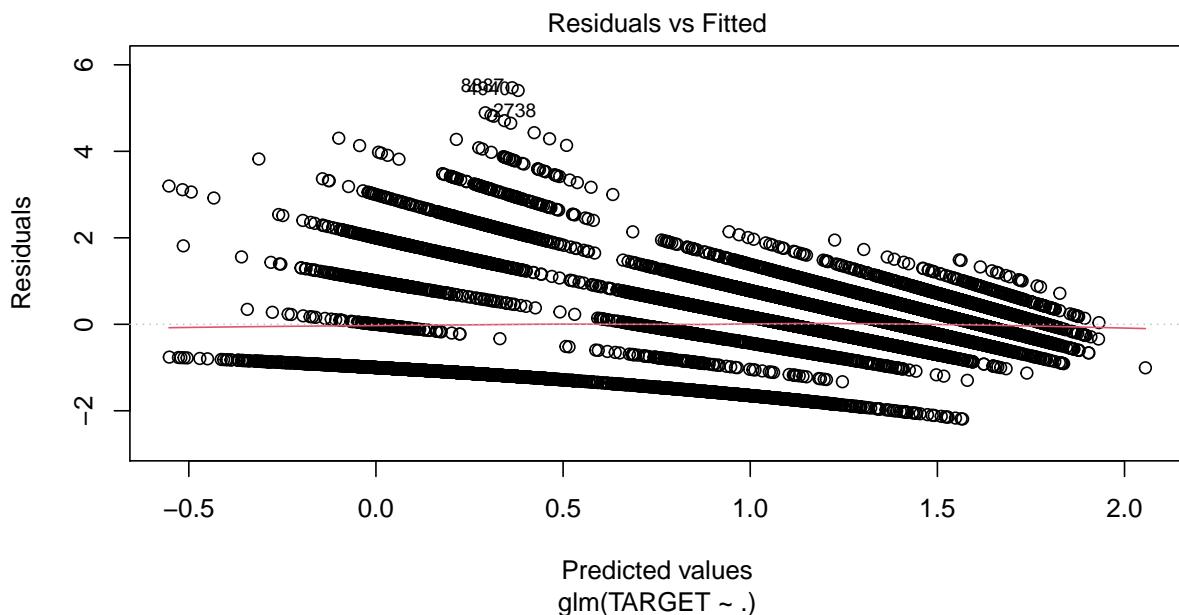
```
##
## Call:
## glm(formula = TARGET ~ ., family = "poisson", data = raw[, c(1,
##           3, 5:13)])
##
## Deviance Residuals:
##    Min      1Q  Median      3Q     Max
## -3.0965 -0.6761 -0.0152  0.4679  3.7851
##
## Coefficients:
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                 0.514311   0.059110   8.701 < 2e-16 ***
## AcidIndex                  -0.079059   0.004517 -17.504 < 2e-16 ***
## LabelAppeal_factorNeutral  0.213800   0.013852  15.435 < 2e-16 ***
## LabelAppeal_factorPositive  0.365335   0.014895  24.527 < 2e-16 ***
## STARS_newone star          0.768043   0.019534  39.319 < 2e-16 ***
## STARS_newtwo star          1.094779   0.018205  60.135 < 2e-16 ***
## STARS_newthree star        1.217634   0.019165  63.535 < 2e-16 ***
## STARS_newfour star         1.342582   0.024227  55.417 < 2e-16 ***
## log_ResidualSugar          0.003777   0.003634   1.039  0.29874
## log_Chlorides              -0.011329   0.004231  -2.678  0.00741 **
## log_FreeSulfurDioxide       0.012898   0.004253   3.033  0.00242 **
## log_Density                -0.235670   0.189971  -1.241  0.21477
## log_PH                     -0.024020   0.021648  -1.110  0.26719
## log_Sulphates              -0.007440   0.004682  -1.589  0.11210
```

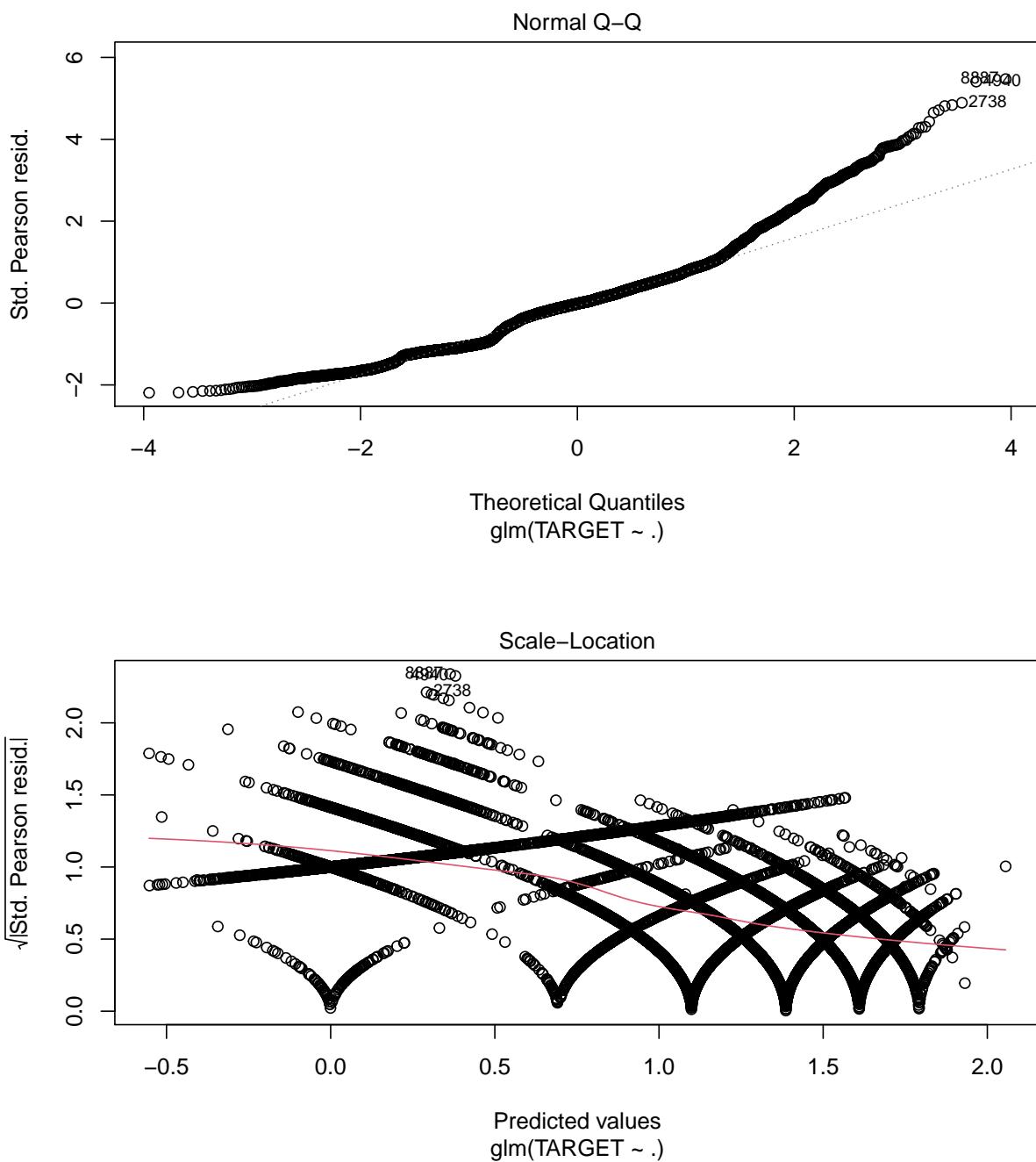
```

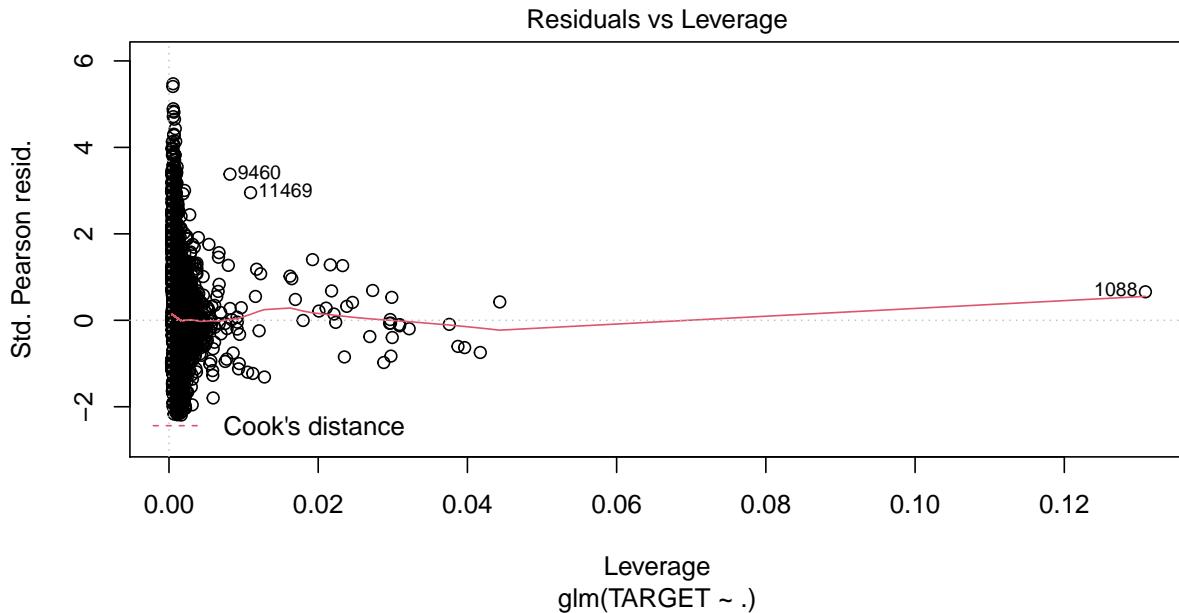
## log_Alcohol          0.022065   0.010165   2.171  0.02995 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for poisson family taken to be 1)
##
## Null deviance: 22861  on 12794  degrees of freedom
## Residual deviance: 13748  on 12780  degrees of freedom
## AIC: 45720
##
## Number of Fisher Scoring iterations: 6

##
## Overdispersion test
##
## data: m_pois_2
## z = -8.0054, p-value = 1
## alternative hypothesis: true dispersion is greater than 1
## sample estimates:
## dispersion
##  0.8949892

```







For our final poisson model we use backwards selection on the above model to see if we can simplify the model. A dispersion value of 0.951 is not a concern.

```

## Start:  AIC=45719.56
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_ResidualSugar +
##      log_Chlorides + log_FreeSulfurDioxide + log_Density + log_PH +
##      log_Sulphates + log_Alcohol
##
##                                     Df Deviance   AIC
## - log_ResidualSugar           1   13749 45719
## - log_PH                      1   13749 45719
## - log_Density                 1   13749 45719
## <none>                         13748 45720
## - log_Sulphates               1   13750 45720
## - log_Alcohol                  1   13752 45722
## - log_Chlorides                1   13755 45725
## - log_FreeSulfurDioxide       1   13757 45727
## - AcidIndex                    1   14067 46037
## - LabelAppeal_factor          2   14362 46330
## - STARS_new                    4   19809 51773
##
## Step:  AIC=45718.64
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##      log_FreeSulfurDioxide + log_Density + log_PH + log_Sulphates +
##      log_Alcohol
##
##                                     Df Deviance   AIC
## - log_PH                       1   13750 45718
## - log_Density                   1   13750 45718
## <none>                         13749 45719
## - log_Sulphates                1   13751 45719

```

```

## - log_Alcohol           1   13753 45721
## - log_Chlorides         1   13756 45724
## - log_FreeSulfurDioxide 1   13758 45726
## - AcidIndex              1   14068 46036
## - LabelAppeal_factor     2   14363 46329
## - STARS_new               4   19812 51774
##
## Step: AIC=45717.84
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##          log_FreeSulfurDioxide + log_Density + log_Sulphates + log_Alcohol
##
##                               Df Deviance    AIC
## - log_Density             1   13751 45717
## <none>                   13750 45718
## - log_Sulphates           1   13752 45718
## - log_Alcohol              1   13755 45721
## - log_Chlorides            1   13757 45723
## - log_FreeSulfurDioxide   1   13759 45725
## - AcidIndex                1   14068 46034
## - LabelAppeal_factor       2   14364 46328
## - STARS_new                 4   19819 51779
##
## Step: AIC=45717.38
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##          log_FreeSulfurDioxide + log_Sulphates + log_Alcohol
##
##                               Df Deviance    AIC
## <none>                   13751 45717
## - log_Sulphates           1   13754 45718
## - log_Alcohol              1   13756 45720
## - log_Chlorides            1   13759 45723
## - log_FreeSulfurDioxide   1   13761 45725
## - AcidIndex                1   14072 46036
## - LabelAppeal_factor       2   14366 46328
## - STARS_new                 4   19825 51783
##
## Call:
## glm(formula = TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new +
##      log_Chlorides + log_FreeSulfurDioxide + log_Sulphates + log_Alcohol,
##      family = "poisson", data = raw[, c(1, 3, 5:13)])
##
## Deviance Residuals:
##      Min        1Q     Median        3Q       Max
## -3.0765  -0.6804  -0.0135   0.4666   3.7754
##
## Coefficients:
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                  0.496384   0.051467   9.645 < 2e-16 ***
## AcidIndex                   -0.078969   0.004503 -17.537 < 2e-16 ***
## LabelAppeal_factorNeutral   0.213763   0.013851  15.434 < 2e-16 ***
## LabelAppeal_factorPositive  0.365148   0.014894  24.516 < 2e-16 ***
## STARS_newone star            0.768357   0.019533  39.337 < 2e-16 ***
## STARS_newtwo star            1.095365   0.018202  60.177 < 2e-16 ***

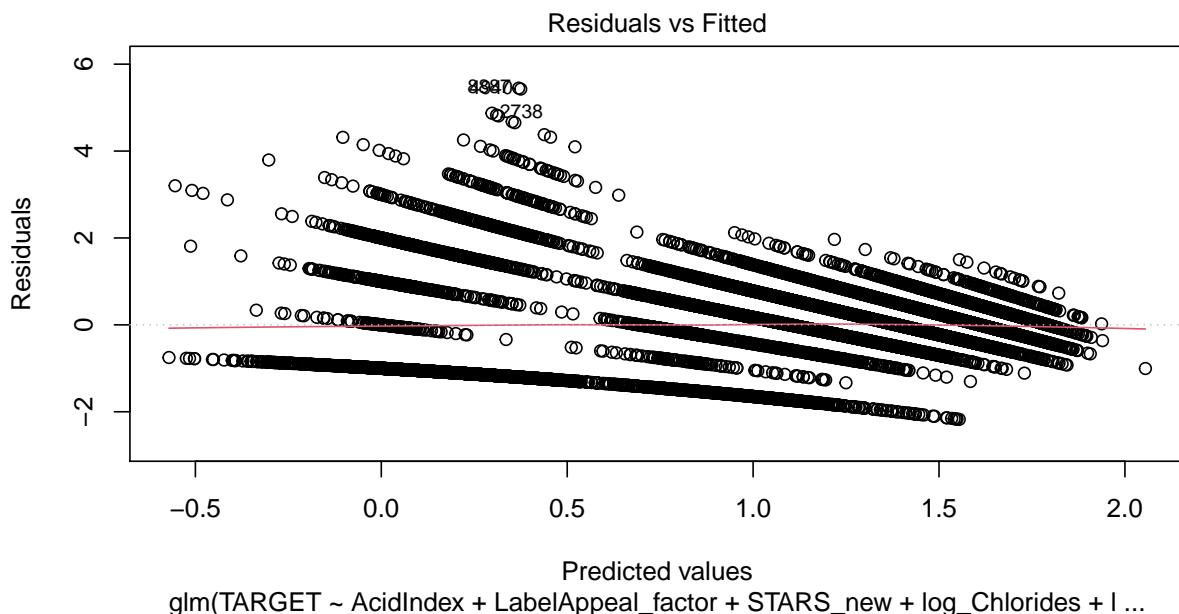
```

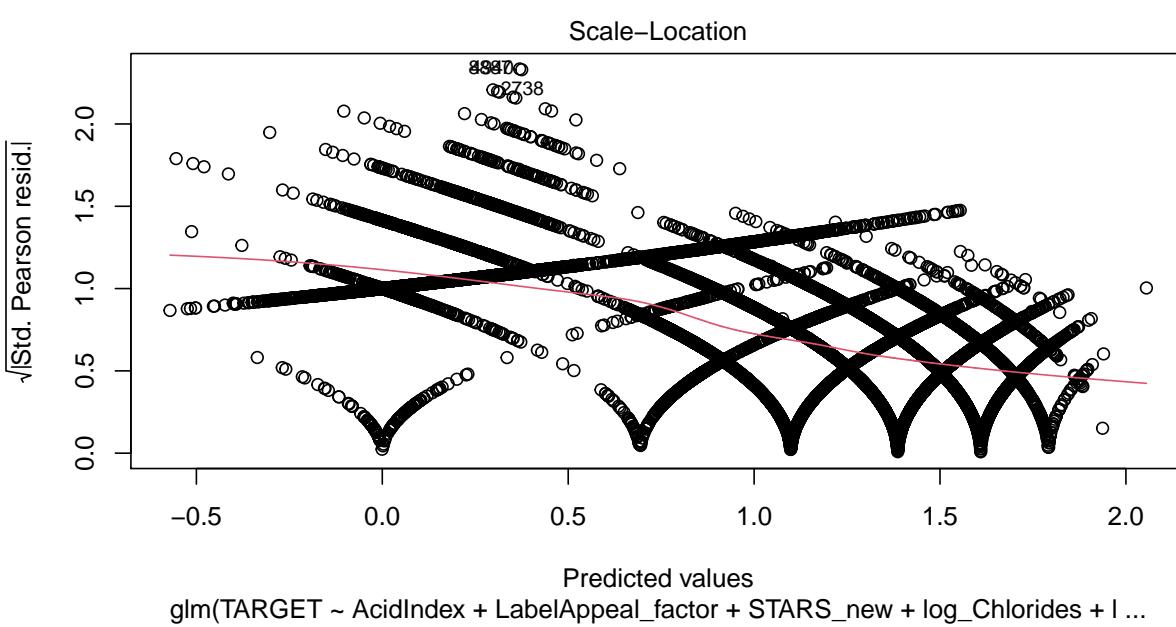
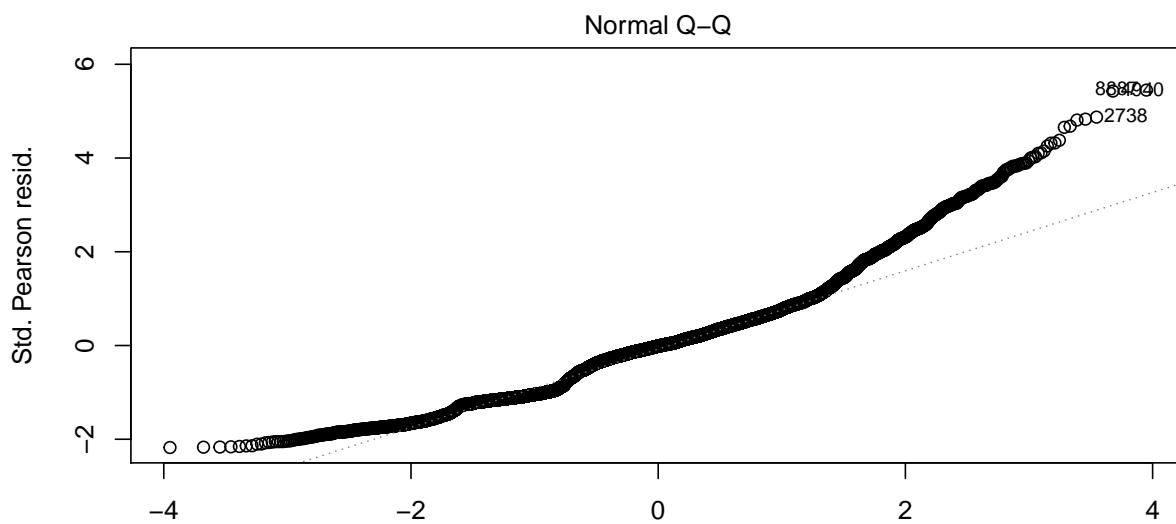
```

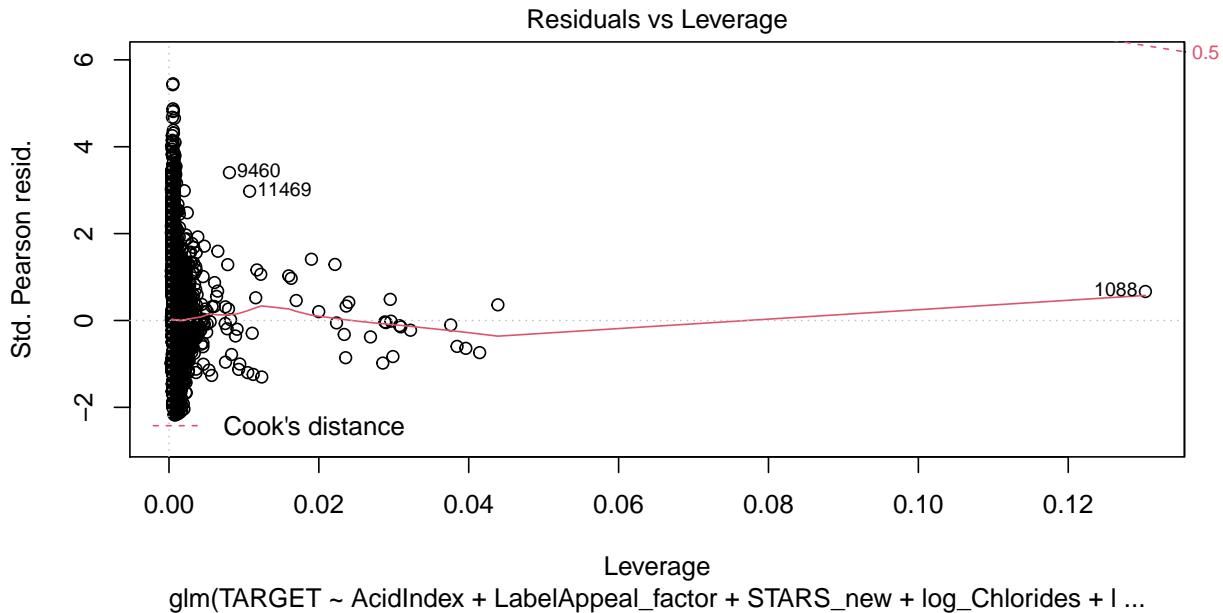
## STARS_newthree star      1.218487  0.019160  63.596 < 2e-16 ***
## STARS_newfour star      1.343172  0.024225  55.445 < 2e-16 ***
## log_Chlorides          -0.011444  0.004229 -2.706  0.00681 **
## log_FreeSulfurDioxide   0.012958  0.004254  3.046  0.00232 **
## log_Sulphates           -0.007439  0.004677 -1.590  0.11173
## log_Alcohol              0.021927  0.010162  2.158  0.03094 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for poisson family taken to be 1)
##
## Null deviance: 22861  on 12794  degrees of freedom
## Residual deviance: 13751  on 12783  degrees of freedom
## AIC: 45717
##
## Number of Fisher Scoring iterations: 6

##
## Overdispersion test
##
## data: m_pois_3
## z = -7.9918, p-value = 1
## alternative hypothesis: true dispersion is greater than 1
## sample estimates:
## dispersion
## 0.8951306

```







The AIC value is used when one wants to balance goodness of fit and a penalty for model complexity. This measure is generally considered better than others when prediction is the aim of the project, which is true in our case.

Poisson Model #1 had an AIC of 45734.

Poisson Model #2 had an AIC of 45720. Poisson Model #3 had an AIC of 45717.

These are all very similar, but Poisson Model #3 that used backwards elimination on the fullest model has the best AIC score.

The Negative Binomials

Generally the Negative Binomial is used in favor of the Poisson when the response variable is a count but the mean does not equal the variance. Further if there is overdispersion a Negative Binomial should be used instead of a Poisson.

Our first Negative Binomial mode uses the same 3 variables as the first Poisson model, Acid Index, STARS_new, and LabelAppeal_factor.

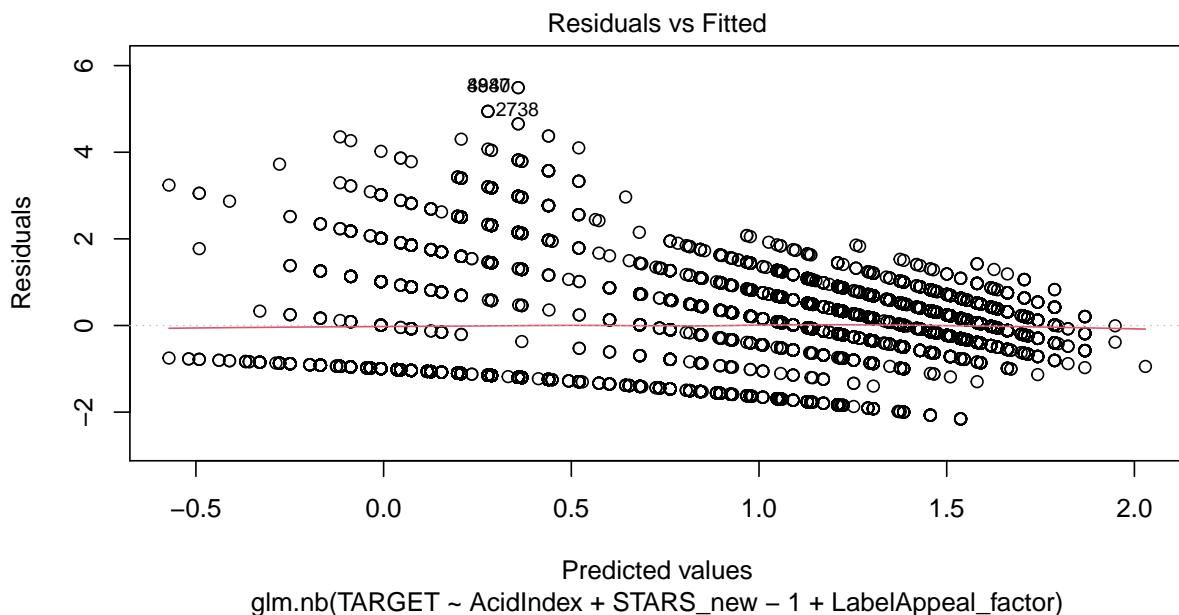
The AIC of 45736 is extremely close to the parallel Poisson model which had an AIC of 45734.

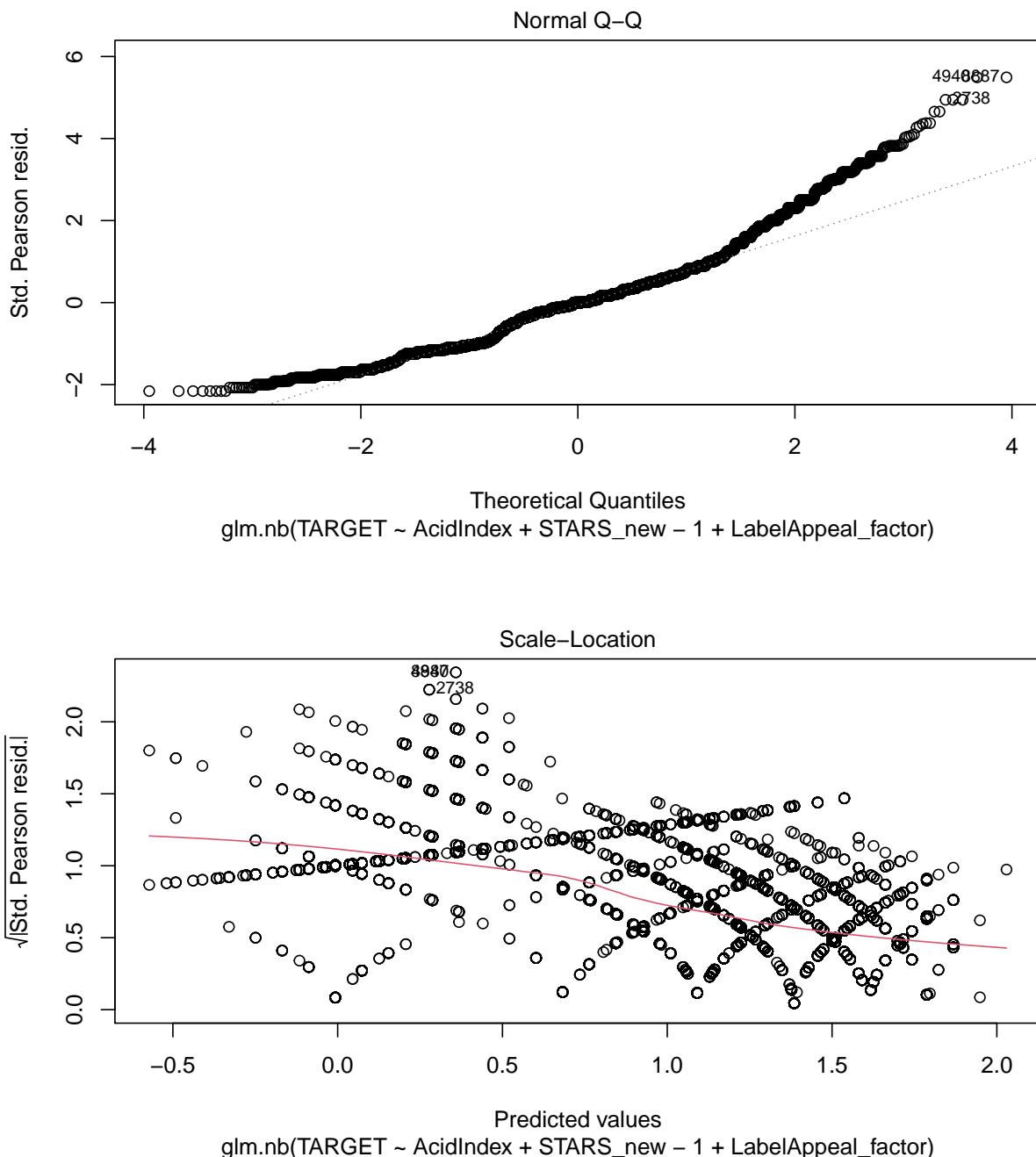
```
##
## Call:
## glm.nb(formula = TARGET ~ AcidIndex + STARS_new - 1 + LabelAppeal_factor,
##        data = raw, init.theta = 39984.50963, link = log)
##
## Deviance Residuals:
##      Min        1Q     Median        3Q       Max
## -3.0498   -0.6777    0.0020    0.4831    3.7942
##
## Coefficients:
##              Estimate Std. Error z value Pr(>|z|)
## AcidIndex -0.080668   0.004488  -17.97   <2e-16 ***
##
```

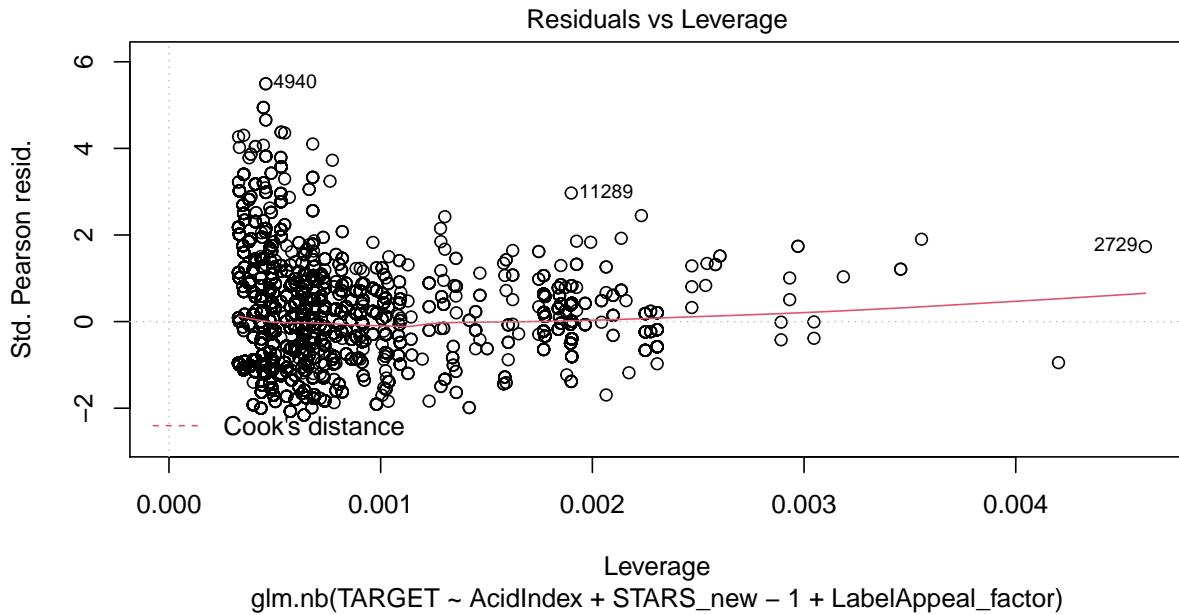
```

## STARS_newno rating          0.638275  0.039939  15.98 <2e-16 ***
## STARS_newone star          1.408546  0.036984  38.09 <2e-16 ***
## STARS_newtwo star          1.736170  0.036042  48.17 <2e-16 ***
## STARS_newthree star        1.860811  0.036408  51.11 <2e-16 ***
## STARS_newfour star         1.986444  0.039314  50.53 <2e-16 ***
## LabelAppeal_factorNeutral  0.213816  0.013851  15.44 <2e-16 ***
## LabelAppeal_factorPositive 0.365595  0.014892  24.55 <2e-16 ***
##
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for Negative Binomial(39984.51) family taken to be 1)
##
## Null deviance: 56840 on 12795 degrees of freedom
## Residual deviance: 13775 on 12787 degrees of freedom
## AIC: 45736
##
## Number of Fisher Scoring iterations: 1
##
##
## Theta: 39985
## Std. Err.: 33617
## Warning while fitting theta: iteration limit reached
##
## 2 x log-likelihood: -45718.13

```







Running a negative binomial model on all variables except the original STARS variable before it was recoded into `STARS_new`.

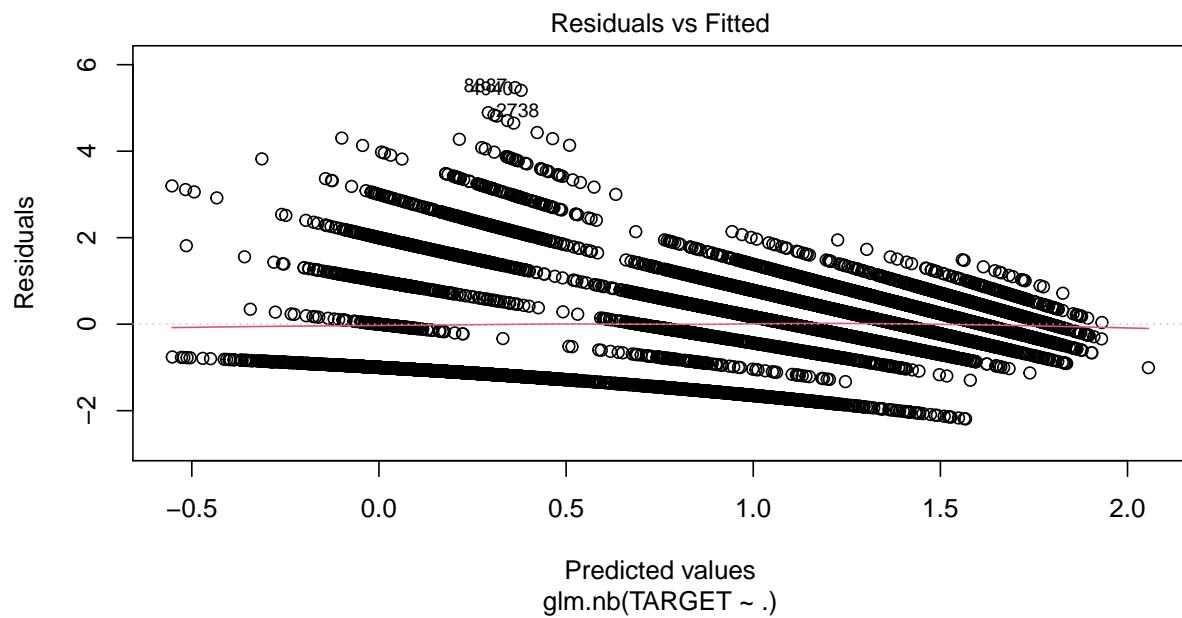
This is the lowest AIC we've seen so far, at 45722.

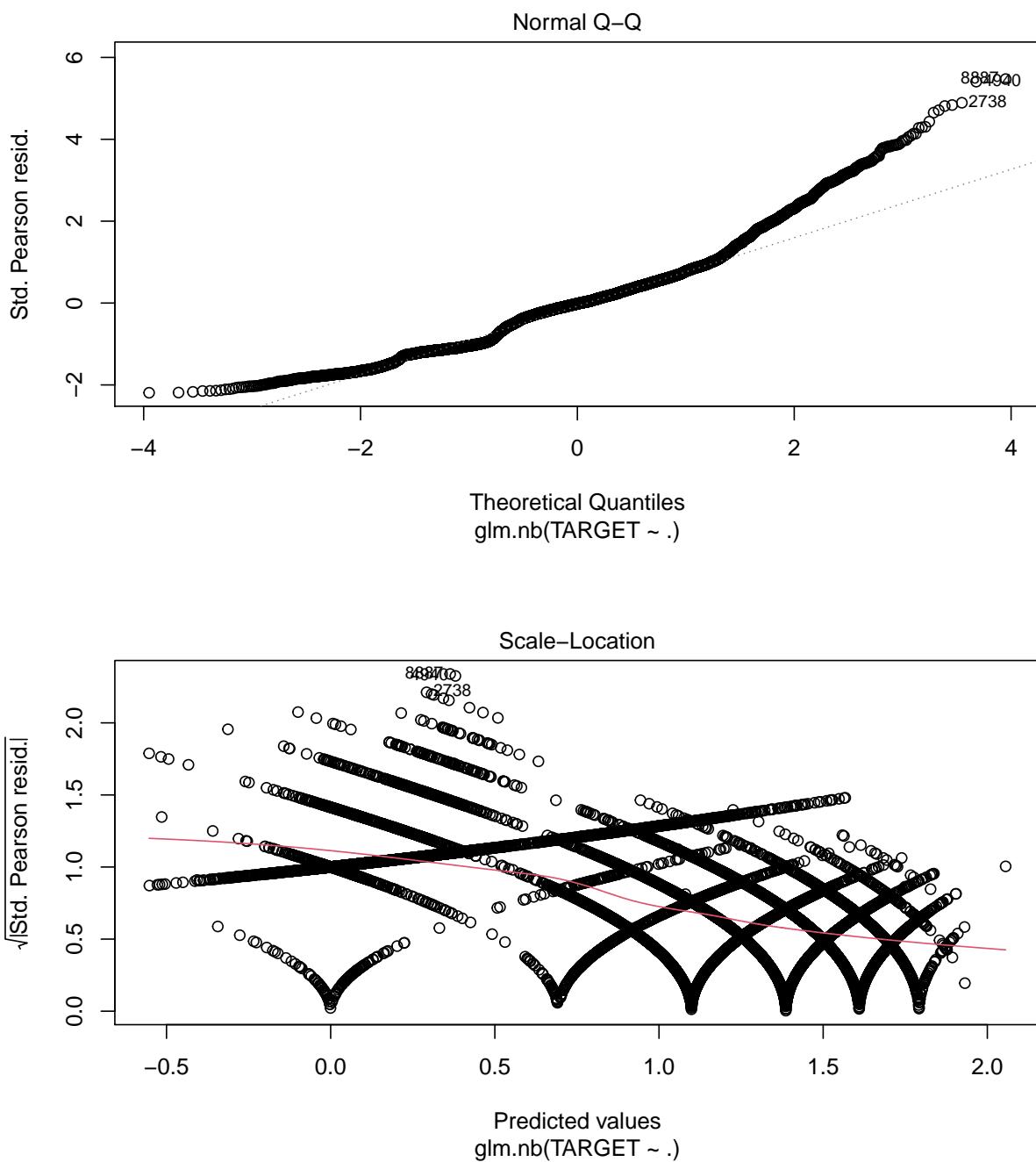
```
##
## Call:
## glm.nb(formula = TARGET ~ ., data = raw[, c(1, 3, 5:13)], init.theta = 40113.61096,
##         link = log)
##
## Deviance Residuals:
##      Min        1Q     Median        3Q       Max
## -3.0964   -0.6761   -0.0152    0.4679    3.7850
##
## Coefficients:
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                0.514334  0.059112  8.701 < 2e-16 ***
## AcidIndex                 -0.079062  0.004517 -17.504 < 2e-16 ***
## LabelAppeal_factorNeutral  0.213799  0.013852 15.434 < 2e-16 ***
## LabelAppeal_factorPositive 0.365332  0.014896 24.525 < 2e-16 ***
## STARS_newone star          0.768041  0.019534 39.318 < 2e-16 ***
## STARS_newtwo star          1.094778  0.018206 60.134 < 2e-16 ***
## STARS_newthree star        1.217634  0.019165 63.533 < 2e-16 ***
## STARS_newfour star         1.342583  0.024228 55.415 < 2e-16 ***
## log_ResidualSugar          0.003777  0.003634  1.039 0.29874
## log_Chlorides              -0.011329  0.004231 -2.678 0.00741 **
## log_FreeSulfurDioxide      0.012899  0.004253  3.033 0.00242 **
## log_Density                -0.235675  0.189980 -1.241 0.21478
## log_PH                     -0.024022  0.021649 -1.110 0.26716
## log_Sulphates              -0.007440  0.004683 -1.589 0.11209
## log_Alcohol                0.022065  0.010165  2.171 0.02996 *
## ---
```

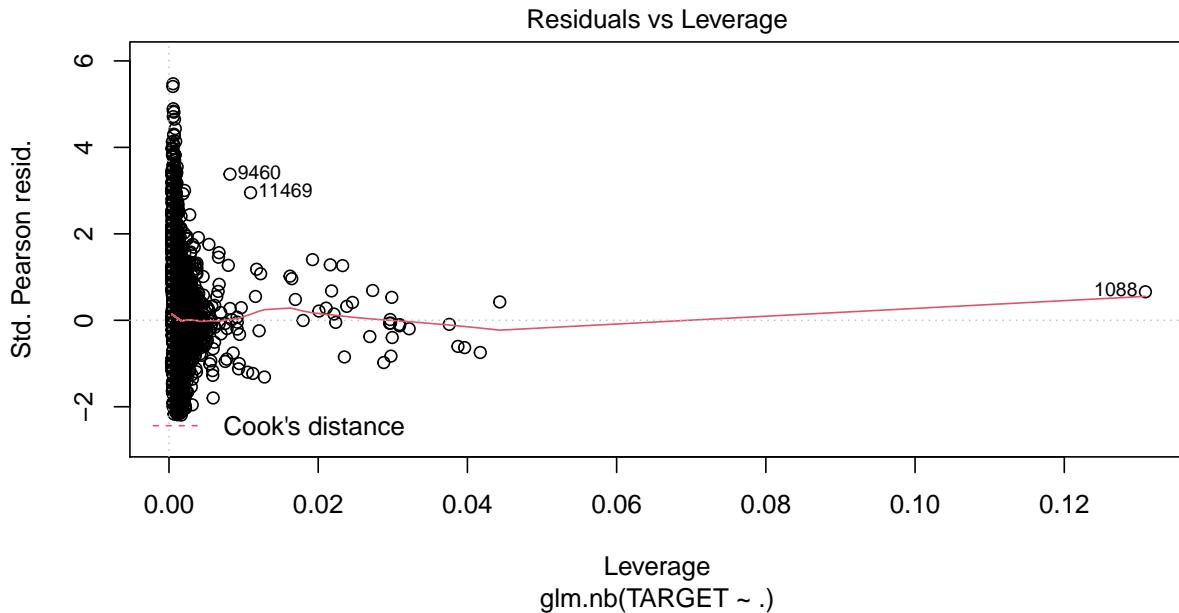
```

## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for Negative Binomial(40113.61) family taken to be 1)
##
##      Null deviance: 22860  on 12794  degrees of freedom
## Residual deviance: 13747  on 12780  degrees of freedom
## AIC: 45722
##
## Number of Fisher Scoring iterations: 1
##
##
##          Theta:  40114
##          Std. Err.: 33736
## Warning while fitting theta: iteration limit reached
##
## 2 x log-likelihood: -45689.98

```







For the third Negative Binomial we perform backwards selection on the above binomial model. This results in the lowest AIC yet at 45720.

```

## Start:  AIC=45719.98
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_ResidualSugar +
##          log_Chlorides + log_FreeSulfurDioxide + log_Density + log_PH +
##          log_Sulphates + log_Alcohol
##
##                               Df Deviance   AIC
## - log_ResidualSugar      1   13748 45719
## - log_PH                  1   13748 45719
## - log_Density              1   13748 45720
## <none>                   13747 45720
## - log_Sulphates           1   13750 45720
## - log_Alcohol              1   13752 45723
## - log_Chlorides            1   13754 45725
## - log_FreeSulfurDioxide    1   13756 45727
## - AcidIndex                 1   14067 46038
## - LabelAppeal_factor        2   14362 46331
## - STARS_new                 4   19808 51773
##
## Step:  AIC=45719.06
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##          log_FreeSulfurDioxide + log_Density + log_PH + log_Sulphates +
##          log_Alcohol
##
##                               Df Deviance   AIC
## - log_PH                  1   13749 45718
## - log_Density              1   13750 45719
## <none>                   13748 45719
## - log_Sulphates            1   13751 45720

```

```

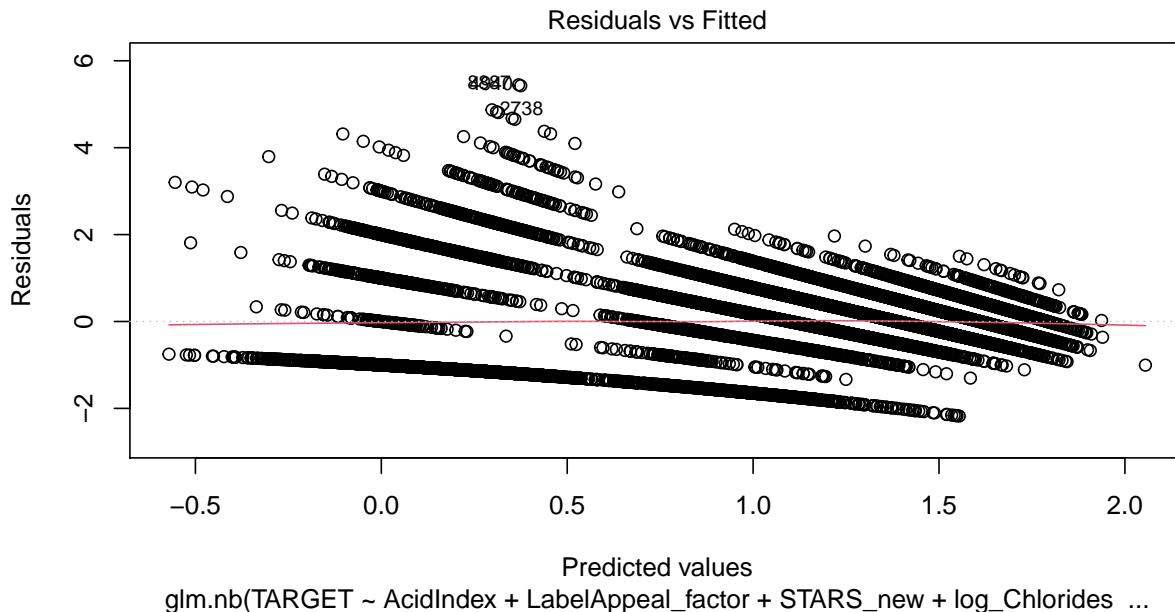
## - log_Alcohol           1   13753 45722
## - log_Chlorides         1   13755 45724
## - log_FreeSulfurDioxide 1   13758 45727
## - AcidIndex              1   14068 46037
## - LabelAppeal_factor     2   14362 46329
## - STARS_new               4   19811 51774
##
## Step: AIC=45718.26
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##          log_FreeSulfurDioxide + log_Density + log_Sulphates + log_Alcohol
##
##                                     Df Deviance    AIC
## - log_Density                1   13751 45718
## <none>                         13749 45718
## - log_Sulphates              1   13752 45719
## - log_Alcohol                 1   13754 45721
## - log_Chlorides               1   13756 45723
## - log_FreeSulfurDioxide      1   13759 45726
## - AcidIndex                   1   14068 46035
## - LabelAppeal_factor          2   14363 46328
## - STARS_new                   4   19818 51779
##
## Step: AIC=45717.8
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##          log_FreeSulfurDioxide + log_Sulphates + log_Alcohol
##
##                                     Df Deviance    AIC
## <none>                         13751 45718
## - log_Sulphates              1   13753 45718
## - log_Alcohol                 1   13756 45721
## - log_Chlorides               1   13758 45723
## - log_FreeSulfurDioxide      1   13760 45725
## - AcidIndex                   1   14072 46037
## - LabelAppeal_factor          2   14365 46328
## - STARS_new                   4   19824 51783
##
## Call:
## glm.nb(formula = TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new +
##          log_Chlorides + log_FreeSulfurDioxide + log_Sulphates + log_Alcohol,
##          data = raw[, c(1, 3, 5:13)], init.theta = 40104.73206, link = log)
##
## Deviance Residuals:
##      Min        1Q     Median        3Q       Max
## -3.0764  -0.6804  -0.0135   0.4666   3.7752
##
## Coefficients:
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)             0.496404   0.051469   9.645 < 2e-16 ***
## AcidIndex            -0.078971   0.004503 -17.537 < 2e-16 ***
## LabelAppeal_factorNeutral 0.213762   0.013851  15.433 < 2e-16 ***
## LabelAppeal_factorPositive 0.365145   0.014895  24.515 < 2e-16 ***
## STARS_newone star      0.768356   0.019533  39.336 < 2e-16 ***
## STARS_newtwo star      1.095364   0.018203  60.176 < 2e-16 ***

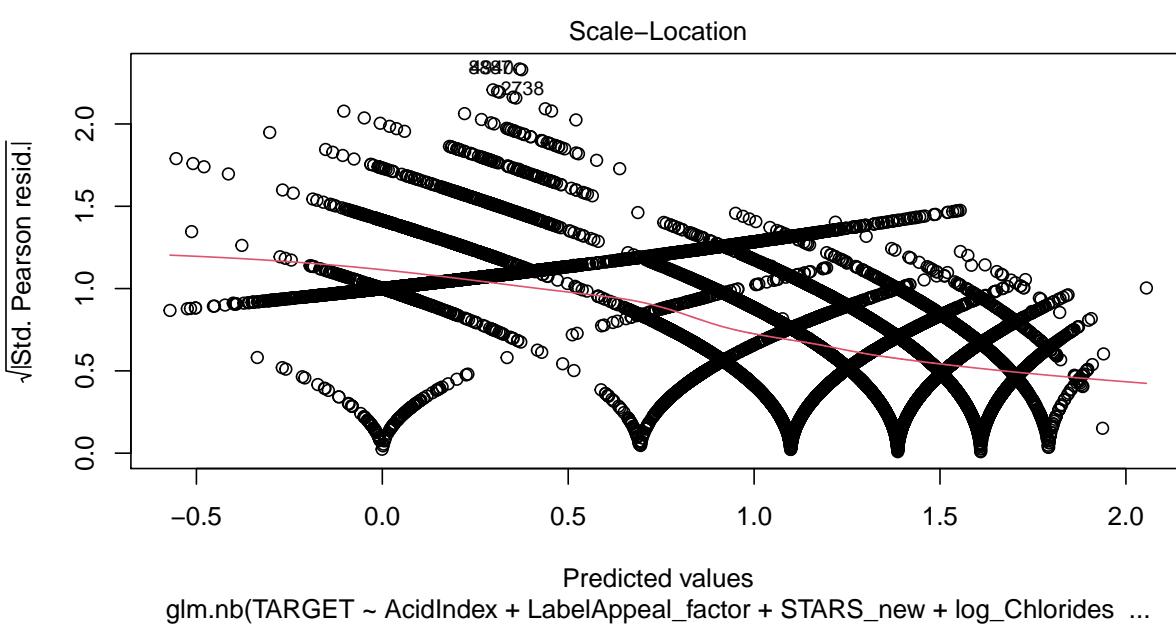
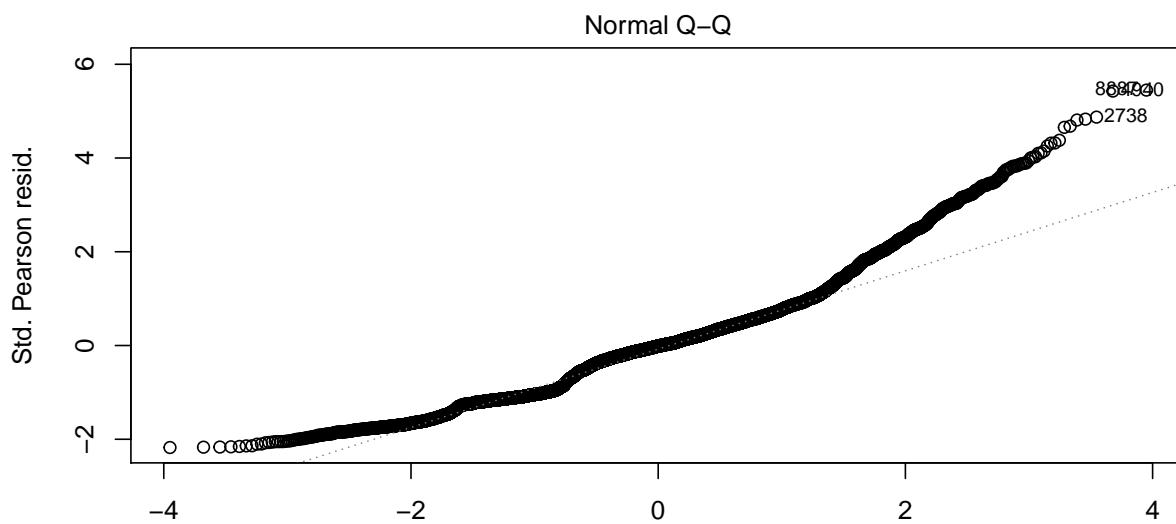
```

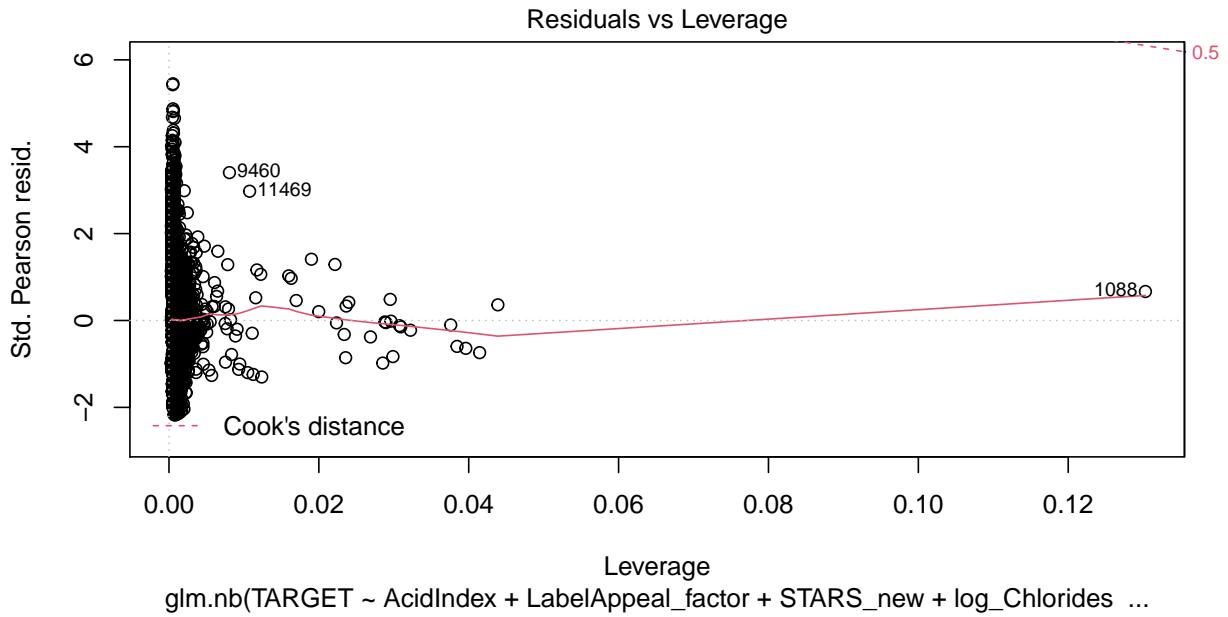
```

## STARS_newthree star      1.218487  0.019160  63.594 < 2e-16 ***
## STARS_newfour star      1.343173  0.024226  55.443 < 2e-16 ***
## log_Chlorides          -0.011445  0.004230  -2.706 0.00681 **
## log_FreeSulfurDioxide   0.012958  0.004254  3.046 0.00232 **
## log_Sulphates           -0.007439  0.004677  -1.590 0.11173
## log_Alcohol              0.021927  0.010162  2.158 0.03096 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for Negative Binomial(40104.73) family taken to be 1)
##
## Null deviance: 22860  on 12794  degrees of freedom
## Residual deviance: 13751  on 12783  degrees of freedom
## AIC: 45720
##
## Number of Fisher Scoring iterations: 1
##
##
## Theta: 40105
## Std. Err.: 33720
## Warning while fitting theta: iteration limit reached
##
## 2 x log-likelihood: -45693.8

```







The Multiple Linears

Theoretically, a linear regression is not a good choice for count data and further not a good choice when we have had some troubles with this dataset with respect to normality.

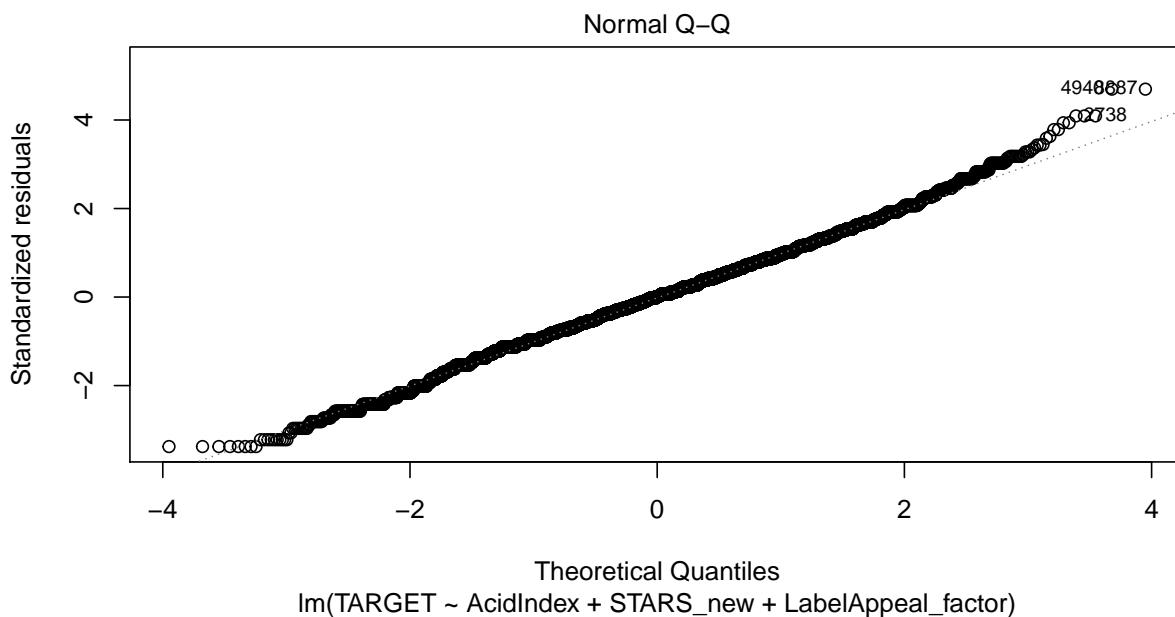
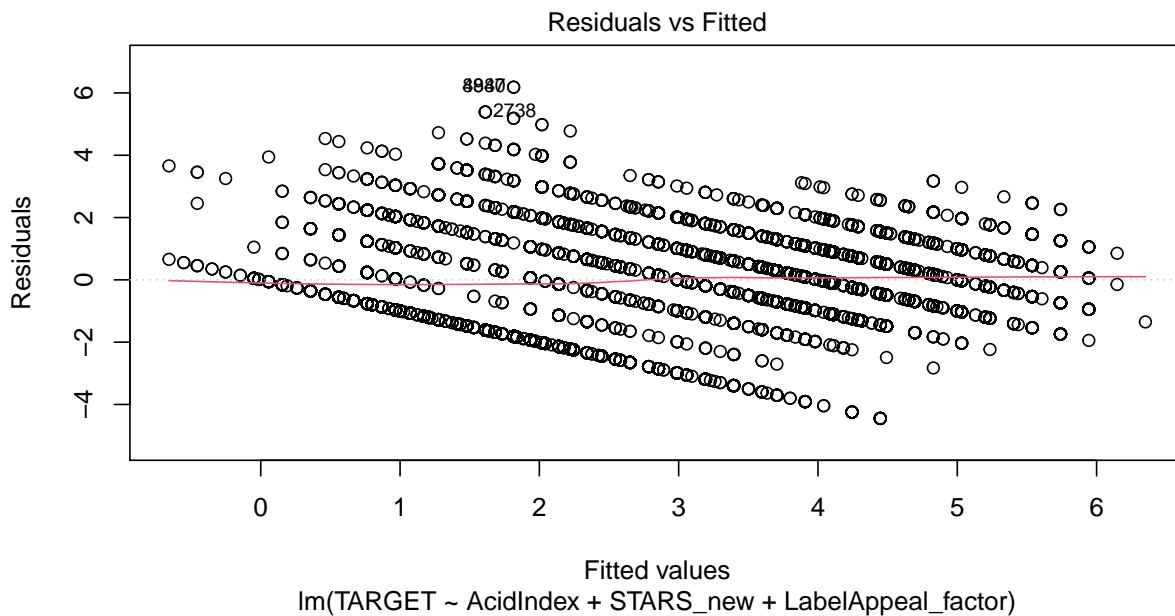
First, we try a model with the 3 variables we started with in the Poisson and Negative Binomial sections, AcidIndex, STARS_new, and LabelAppeal_factor. The Adjusted R-squared of 0.533 means that the model can explain 53.3% of the variance in the data.

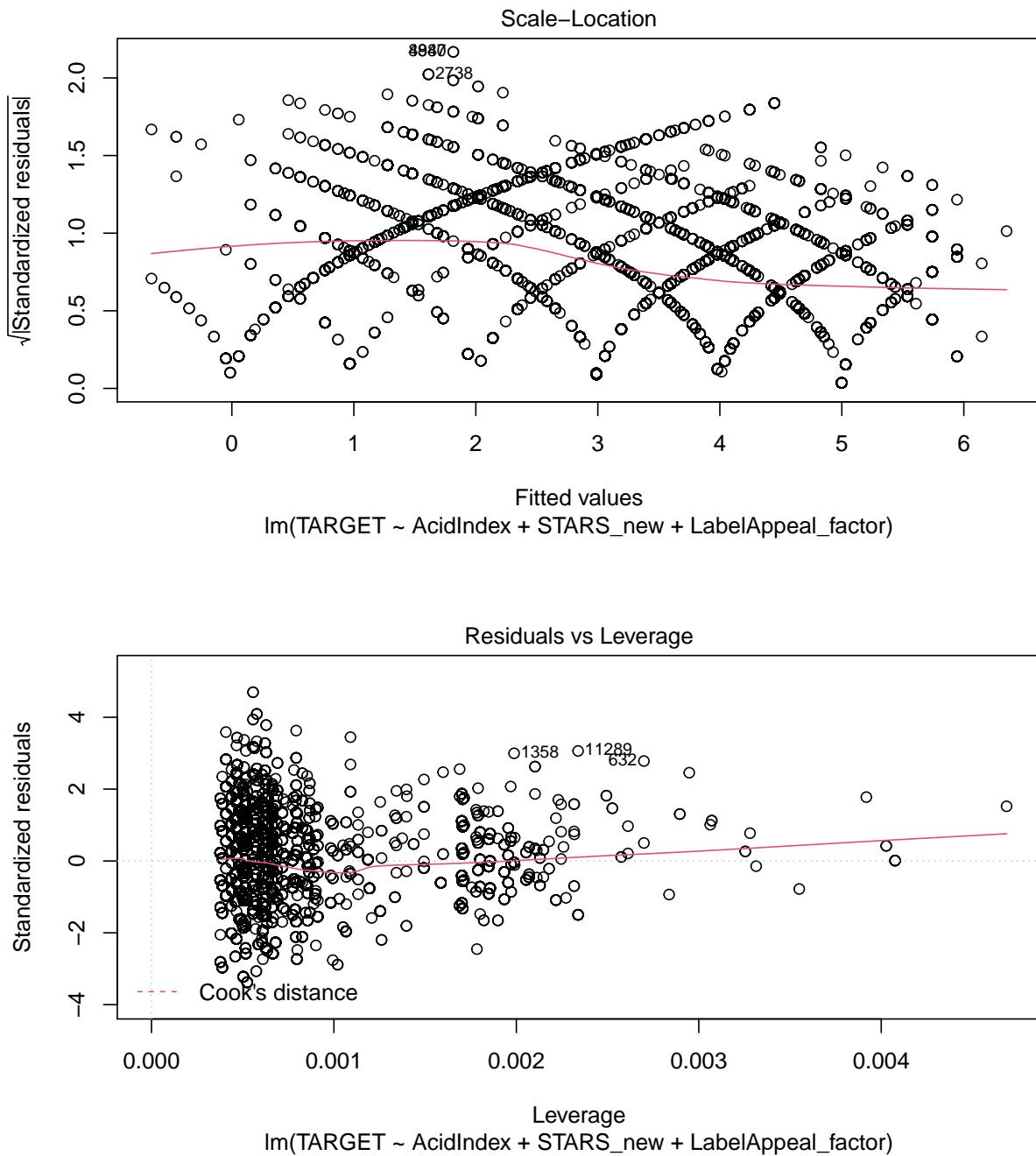
```
##  
## Call:  
## lm(formula = TARGET ~ AcidIndex + STARS_new + LabelAppeal_factor,  
##      data = raw)  
##  
## Residuals:  
##      Min       1Q   Median       3Q      Max  
## -4.4474 -0.9080  0.0106  0.8610  6.1847  
##  
## Coefficients:  
##                               Estimate Std. Error t value Pr(>|t|)  
## (Intercept)                2.389258  0.077577 30.80 <2e-16 ***  
## AcidIndex                 -0.203199  0.008961 -22.68 <2e-16 ***  
## STARS_newone star          1.375290  0.033162 41.47 <2e-16 ***  
## STARS_newtwo star          2.428917  0.032141 75.57 <2e-16 ***  
## STARS_newthree star        3.012819  0.037207 80.97 <2e-16 ***  
## STARS_newfour star         3.722427  0.059498 62.56 <2e-16 ***  
## LabelAppeal_factorNeutral  0.512209  0.028410 18.03 <2e-16 ***  
## LabelAppeal_factorPositive 1.051598  0.032602 32.26 <2e-16 ***  
## ---  
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1  
##
```

```

## Residual standard error: 1.317 on 12787 degrees of freedom
## Multiple R-squared:  0.5329, Adjusted R-squared:  0.5326
## F-statistic:  2084 on 7 and 12787 DF,  p-value: < 2.2e-16

```





Second, we run a full model using all variables (except the original STARS) and then perform backwards selection. We obtain a very similar Adjusted R-Squared that means the model can explain 53.4% of the variance in the data. For the sake of simplicity we would consider the first Multiple Linear Regression model ‘best’ as it would be easier to explain the relationship between the predictive variables and the target.

```
## Start: AIC=7021.51
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_ResidualSugar +
##       log_Chlorides + log_FreeSulfurDioxide + log_Density + log_PH +
##       log_Sulphates + log_Alcohol
```

```

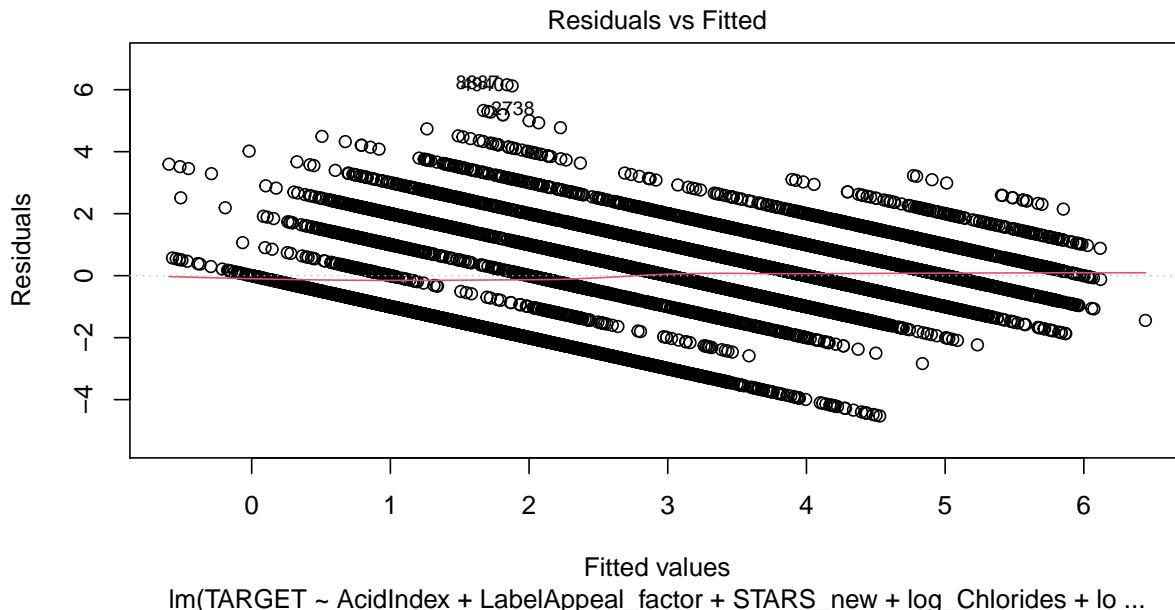
##                                     Df Sum of Sq   RSS      AIC
## - log_ResidualSugar           1     1.5 22099 7020.4
## - log_PH                      1     2.5 22100 7020.9
## <none>                         22098 7021.5
## - log_Density                 1     5.3 22103 7022.5
## - log_Sulphates               1     6.3 22104 7023.1
## - log_Alcohol                  1    16.0 22114 7028.8
## - log_Chlorides                1    21.4 22119 7031.9
## - log_FreeSulfurDioxide       1    26.1 22124 7034.6
## - AcidIndex                    1   836.7 22935 7495.0
## - LabelAppeal_factor          2  1800.4 23898 8019.7
## - STARS_new                    4 16466.1 38564 14138.2
##
## Step:  AIC=7020.35
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##        log_FreeSulfurDioxide + log_Density + log_PH + log_Sulphates +
##        log_Alcohol
##
##                                     Df Sum of Sq   RSS      AIC
## - log_PH                      1     2.5 22102 7019.8
## <none>                         22099 7020.4
## - log_Density                 1     5.2 22104 7021.4
## - log_Sulphates               1     6.3 22106 7022.0
## - log_Alcohol                  1    15.9 22115 7027.5
## - log_Chlorides                1    21.4 22121 7030.7
## - log_FreeSulfurDioxide       1    26.1 22125 7033.5
## - AcidIndex                    1   838.2 22937 7494.7
## - LabelAppeal_factor          2  1800.1 23899 8018.3
## - STARS_new                    4 16470.5 38570 14138.2
##
## Step:  AIC=7019.78
## TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new + log_Chlorides +
##        log_FreeSulfurDioxide + log_Density + log_Sulphates + log_Alcohol
##
##                                     Df Sum of Sq   RSS      AIC
## <none>                         22102 7019.8
## - log_Density                 1     5.2 22107 7020.8
## - log_Sulphates               1     6.4 22108 7021.5
## - log_Alcohol                  1    16.0 22118 7027.0
## - log_Chlorides                1    21.7 22123 7030.3
## - log_FreeSulfurDioxide       1    26.2 22128 7033.0
## - AcidIndex                    1   835.7 22937 7492.7
## - LabelAppeal_factor          2  1799.0 23901 8017.0
## - STARS_new                    4 16485.9 38588 14142.1
##
## Call:
## lm(formula = TARGET ~ AcidIndex + LabelAppeal_factor + STARS_new +
##      log_Chlorides + log_FreeSulfurDioxide + log_Density + log_Sulphates +
##      log_Alcohol, data = raw[, c(1, 3, 5:13)])
##
## Residuals:
##      Min       1Q   Median       3Q      Max

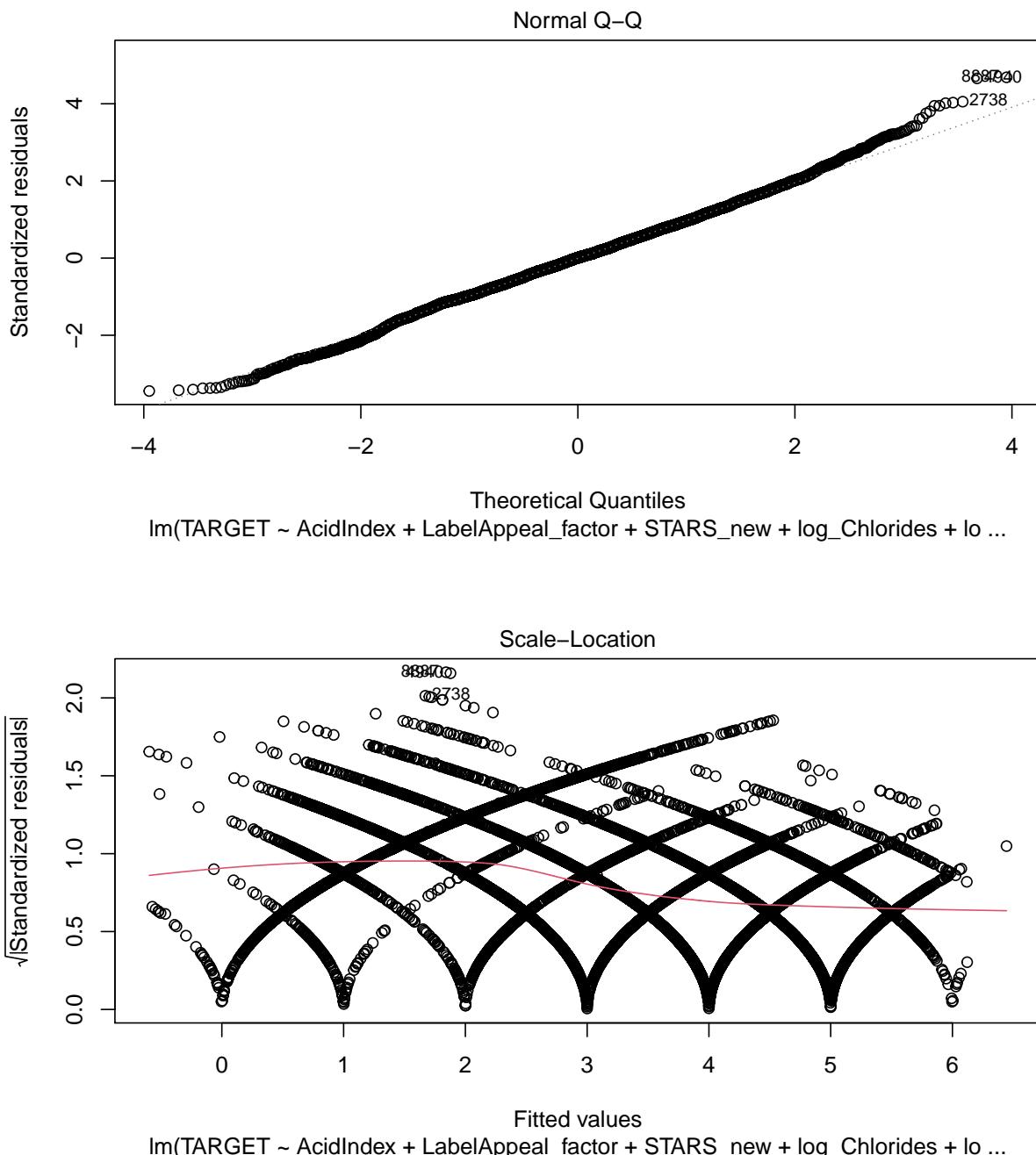
```

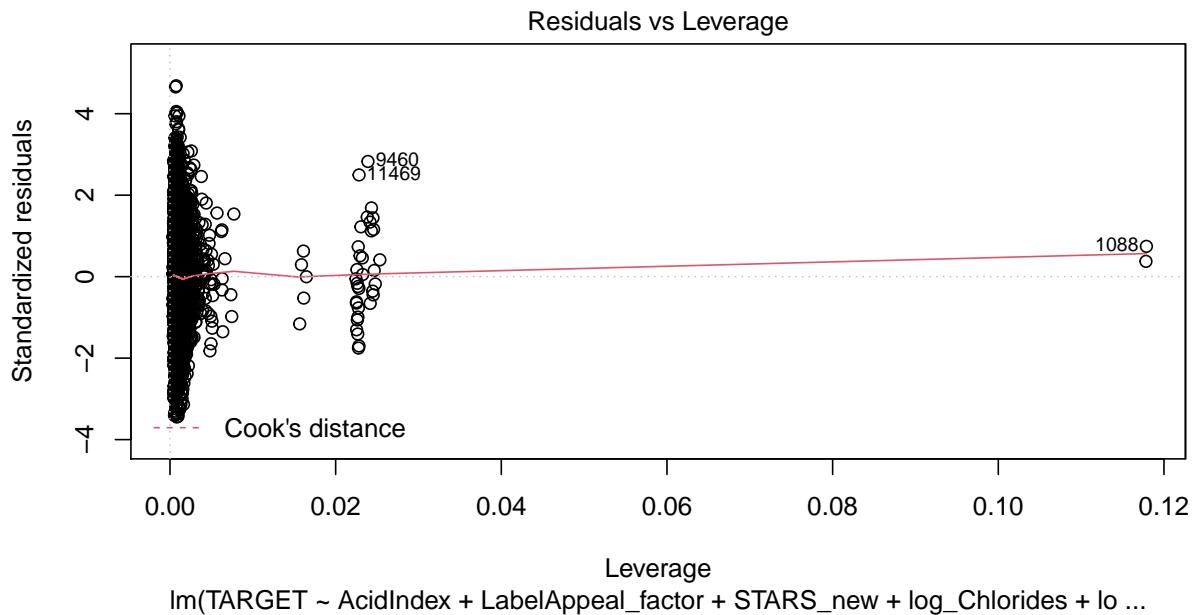
```

## -4.5283 -0.8796  0.0101  0.8574  6.1586
##
## Coefficients:
##                               Estimate Std. Error t value Pr(>|t|)
## (Intercept)                1.970757  0.104194 18.914 < 2e-16 ***
## AcidIndex                  -0.197691  0.008992 -21.985 < 2e-16 ***
## LabelAppeal_factorNeutral   0.510948  0.028370 18.010 < 2e-16 ***
## LabelAppeal_factorPositive  1.050114  0.032557 32.255 < 2e-16 ***
## STARS_newone star          1.369133  0.033128 41.328 < 2e-16 ***
## STARS_newtwo star          2.420862  0.032119 75.371 < 2e-16 ***
## STARS_newthree star        3.000080  0.037203 80.641 < 2e-16 ***
## STARS_newfour star         3.706050  0.059468 62.320 < 2e-16 ***
## log_Chlorides               -0.035355  0.009981 -3.542 0.000398 ***
## log_FreeSulfurDioxide      0.035059  0.009001  3.895 9.87e-05 ***
## log_Density                 -0.757568  0.435275 -1.740 0.081807 .
## log_Sulphates              -0.020845  0.010865 -1.919 0.055063 .
## log_Alcohol                 0.066226  0.021764  3.043 0.002348 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ',' 1
##
## Residual standard error: 1.315 on 12782 degrees of freedom
## Multiple R-squared:  0.5345, Adjusted R-squared:  0.534
## F-statistic:  1223 on 12 and 12782 DF,  p-value: < 2.2e-16

```







Model Selection

While we cannot directly compare the Adjusted R-squared values of the Multiple Linear Regression models to the AIC values in the Poisson and Negative Binomial models, we know that linear regression models are based on assumptions of normality that are not present in our data - so we don't consider these as options for our final model.

We saw the Negative Binomial and Poisson models perform very similarly with regard to the AIC values.