

3.3: Influential Observations and Outliers

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1 Why Care About Influential Observations/Outliers?

When we specify a model form of

$$Y = \beta_0 + \beta_1 X_1 + \dots + \beta_{p-1} X_{p-1} + \varepsilon$$

we assume that all observations in the data are generated from the same source (i.e. the theoretical line).

If we have observations that are **not** from the same source as the rest, OLS regression will try to **force** the model to fit the data, perhaps compromising the estimated coefficients and or inference.

Two things to watch for (not mutually exclusive):

- **Outliers** - observations with values of Y that are not well-explained by the model.
- **Influential Points** - observations that unduly influence the estimated coefficients b_k or predicted values \hat{Y} .

2 Ways to detect outliers or influential points

- (Primary) Scatterplots of X_k vs Y
- Other Diagnostics for Influential Observations
 - Hat matrix diagonals
 - DFBETAS
 - DFFITS
 - Cooks Distance
- Other Diagnostics for Outliers
 - Residuals
 - Studentized Residuals
 - Studentized Deleted Residuals

2.1 Hat Matrix Diagonals

Recall the linear algebra representation of the OLS regression model:

$$Y = X\beta + \varepsilon \quad b = (X'X)^{-1}X'Y$$

$$\hat{Y} = Xb = X(X'X)^{-1}X'Y = HY$$

In other words, the predicted values of Y are simply linear combinations of the actual values of Y where each observation “weight” is determined by the X matrix.

Let $h_{i,l}$ be the element in row i and column l of H

- sometimes called “leverage” (influence of obs. i on its fitted value)

Since $\hat{Y} = HY$, then $\hat{Y}_i = \sum_{l=1}^n h_{i,l}Y_l$

(Individual) What would a “larger” diagonal element $h_{i,i}$ mean?

It means that the value of Y_i is more influential in its own prediction (\hat{Y}_i). We care about this because if the influence of a particular point is large enough, then the model is likely fitting that particular point at the sacrifice of the rest of the data.

We usually consider a point to be influential if:

- rule of thumb: $h_{i,i} > \frac{2p}{n}$ or $h_{i,i} > \frac{3p}{n}$
- can plot $h_{i,i}$ against observation number, with reference lines at $2p/n$ (SAS default) and/or $3p/n$

Another graphical diagnostic with $h_{i,i}$:

- leverage plots/partial regression/added variable plots); for X_1 :
 1. Regress X_1 on X_2, \dots, X_{p-1} and obtain residuals $e_{X_1|X_2, \dots, X_{p-1}}$
 2. Regress Y on X_2, \dots, X_{p-1} and obtain residuals $e_{Y|X_2, \dots, X_{p-1}}$
 3. Plot $e_{Y|X_2, \dots, X_{p-1}}$ vs. $e_{X_1|X_2, \dots, X_{p-1}}$, and add regression line
 - slope will be b_1 from multiple regression model
 - Helps to visualize the marginal effect of adding X_1 in the model after already including all other X variables.
 - Influential points fall significantly farther away from the line than other points.
- (possible) modification here: point-size in leverage plot proportional to corresponding $h_{i,i}$
NOT shown in the SAS output provided in HO 3.3.1.
 - then this is called a proportional leverage plot
 - influential observations will be the points with big “bubbles” that appear to “pull” the regression line in their direction

2.2 DFBETAS

Provide a measure of how **different** (“DF”) an estimate of β_k would be if we removed one observation from the data.

$$\begin{aligned}b_k &= \text{estimate of } \beta_k \text{ using full data} \\b_{k(i)} &= \text{estimate of } \beta_k \text{ when observation } i \text{ is ignored} \\MSE_{(i)} &= \text{Mean SS for error when observation } i \text{ is ignored} \\C_{kk} &= k^{th} \text{ diagonal element of } (X'X)^{-1} \\DFBETAS_{k(i)} &= \frac{b_k - b_{k(i)}}{\sqrt{MSE_{(i)}C_{kk}}}\end{aligned}$$

Interpreting DFBETAS:

- DFBETAS_{k(i)} positive: obs. i “pulls” b_k up
- DFBETAS_{k(i)} negative: obs. i “pulls” b_k down

How “large” to declare observation i “influential” on b_k ?

- *Rough* rule of thumb:

$$|DFBETAS_{k(i)}| > 1 \quad \text{for } n \leq 30$$

$$|DFBETAS_{k(i)}| > 2/\sqrt{n} \quad \text{for } n > 30 \text{ (SAS)}$$

- Graphical diagnostics probably better for DFBETAS:
 - Histograms or boxplots for each k
 - Proportional leverage plot with “bubble” size prop. to DFBETAS_{k(i)}
 - Plot DFBETAS_{k(i)} against obs. number for each k (Provided by SAS, unlike the others)

2.3 DFFITS

Similar to DFBETAS: how different would \hat{Y}_i be if observation i were not used to fit the model

$$DFFITS_i = \frac{\hat{Y}_i - \hat{Y}_{i(i)}}{\sqrt{MSE_{(i)}h_{i,i}}}$$

How large DFFITS to declare obs. i as influential on \hat{Y}_i ?

- *Rough* rule of thumb:

$$|DFFITS_i| > 1 \quad \text{for } n \leq 30$$

$$|DFFITS_i| > 2\sqrt{\frac{p}{n}} \quad \text{for } n > 30 \text{ (SAS)}$$

- Good graphical diagnostics for DFFITS:
 - Plot DFFITS vs. Observation Number

- Plot Residuals vs. Predicted Values, with point sizes proportional to corresponding $DFBETAS_i$

($DFBETAS_{ij}$ vs. $DFBETAS_i$) vs. $h_{i,i}$

- somewhat related, so “conclusions” will quite often agree
- BUT: if two or more points exert “influence” together then the drop-one diagnostics ($DFBETAS$ and $DFBETAS_i$) may not detect them
 - these are leverage points - need to look at $h_{i,i}$

2.4 Cooks Distance

Kind of an overall measure of effect of obs. i on all of the \hat{Y}_l values:

$$D_i = \frac{\sum_{j=1}^n \left(\hat{Y}_j - \hat{Y}_{j(i)} \right)^2}{p \cdot \text{MSE}}$$

Diagnostics:

- Numerical:
 - simple: compare D_i with $4/n$ (SAS)
 - more useful: compare D_i with the $F_{p,n-p}$ distribution (See 3.3.1 pg 8 for example of how to do this “by hand”)
 - * percentile 10-20: little influence
 - * percentile 50+: major influence
- Graphical: plot D_i (or percentile from $F_{p,n-p}$) vs. observation number i

2.5 Residuals

$$e_i = Y_i - \hat{Y}_i$$

Sometimes a large $|e_i|$ indicates an outlier

- not well-explained by fitted model
- but how “large” it needs to be depends on the residuals:
 - Recall $\varepsilon \sim N(0, \sigma^2)$, so $e_i \sim N(0, \sigma^2(1 - h_{ii}))$
 - because $\hat{Y} = HY$ results in $e = Y - HY = (I - H)Y$
 - Could compare e_i with the normal critical values, but need to estimate variance (including σ^2) \Rightarrow normal approx. not appropriate; need Student’s t

2.6 Studentized Residuals

$$r_i = \frac{e_i}{\sqrt{MSE \cdot (1 - h_{ii})}} \quad (MSE = \hat{\sigma}^2)$$

If ε_i iid $N(0, \sigma^2)$, then the r_i follow the t_{n-p} distribution; diagnostics:

- Numerical: compare $|r_i|$ with upper $\alpha/2$ critical value of t_{n-p}
- Graphical: plot \hat{Y}_i vs. r_i , with ref. lines at upper $\alpha/2$ critical value of t_{n-p}

2.7 Studentized Deleted Residuals

If obs. i really is an outlier, then including it in the data will inflate MSE

- So consider dropping it and re-calculating the studentized residual:

$$e_i^* = \frac{e_i}{\sqrt{MSE_{(i)}(1 - h_{ii})}} \quad (\text{Text uses } t_i \text{ instead of } e_i^*)$$

2.8 Other Diagnostics (similar to studentized residuals)

- plot \hat{Y}_i vs. e_i^*
- compare to $|e_i^*|$ to some critical value of t_{n-p} (for each of $i = 1, \dots, n$)

BUT: α = probability of type I error (calling obs. i outlier when it's not)

- actually want α to be probability of *at least one* type I error in all n tests
- a family-wise error rate
- many ways to adjust the critical value; here, we'll use Bonferroni correction:

compare $|e_i^*|$ to upper $\alpha/(2n)$ critical value of t_{n-p}

3 Remedial Measures for Influential Observations or Outliers

1. Look for:

- typos in data (more common than would like to think)
- fundamental differences in observations
 - drop obs. if from a different "population"
- very skewed distributions of predictors
 - remember that in general, there is no assumption regarding the distribution of X 's
 - sometimes transforming X will reduce influence of obs. with extreme values
- **Caution:** Important to not remove outlier points simply because they are outliers.
 - <https://rss.onlinelibrary.wiley.com/doi/full/10.1111/j.1740-9713.2017.01016.x>

2. Look at potential changes to model:

- will a transformation “bring in” the observations?
 - should a curvilinear or other predictor be added?
 - look at leverage plot for the possible predictor
 - any trend suggests adding it to model
3. Could obtain estimates differently (instead of OLS, robust regression - more in Module 4):
- LAD (least absolute deviation) regression
 - IRLS (iteratively reweighted least squares) regression