

Lab 3: Reducing Crime (FINAL: Stage 3)

N. Akkineni, K. Hanna, A. Thorp

December 10, 2018

Contents

| | |
|--|-----------|
| Introduction | 2 |
| Exploratory Data Analysis | 2 |
| Data Summary | 2 |
| Data Clean Up | 3 |
| Concerns about the data | 4 |
| Univariate Analysis | 5 |
| Key Variable | 5 |
| Explanatory Variables | 6 |
| Relationships | 7 |
| Correlation Matrix | 7 |
| Model Analysis | 9 |
| Model 1 - Minimum Specification | 9 |
| Intuition of the effects of potential data issues in county 115 on the model | 9 |
| Testing the validity of the 6 CLM assumptions | 9 |
| Model 2 - Optimal Specification | 14 |
| Intuition of the Effects of County 71 Existing in Both Central and West | 15 |
| Intuition of the effects of potential data issues in county 115 on the model | 16 |
| Testing the Validity of the 6 CLM assumptions | 16 |
| Model 3 - Sub-optimal Specification | 20 |
| Intuition of the effects of potential data issues in county 115 on the model | 21 |
| Testing the Validity of the 6 CLM assumptions | 21 |
| Omitted Variables | 28 |
| Conclusion | 30 |

Introduction

Our team has been hired to provide research for a local political campaign, which would like to understand the determinants of crime rates in order to provide policy suggestions that are applicable to local government. We examine the provided dataset to determine if a model with causal interpretation is feasible. After examining the data, we detail three regression models and find that estimators related to variables used to operationalize the concept of certainty of punishment are directionally consistent and statistically significant across modeling specifications. From this we draw a limited policy recommendation to adopt a model of community policing to improve trust and information flow to law enforcement. However, our policy recommendations are limited because omitted variable bias confounds our estimators. Should local officials desire more robust conclusions, we recommend involving data scientists in the data collection process to improve our ability to draw causal inference from our modeling process and thus be able to make robust policy recommendations.

```
#load package dependencies
library(knitr)
library(kableExtra)
suppressMessages(library(car))
suppressMessages(library(stargazer))
suppressMessages(library(lmtest))
suppressMessages(library(corrplot))
library(sandwich)

#load data and codebook explaining the meaning of variables
crime <- read.csv('crime_v2.csv',header = TRUE, sep = ",")
codebook <- read.csv('codebook.csv')

crime$county = as.factor(crime$county)
crime$west = as.logical(crime$west)
crime$central = as.logical(crime$central)
crime$urban = as.logical(crime$urban)
```

Exploratory Data Analysis

Data Summary

We were provided with a dataset that includes variables for 90 counties in North Carolina. This data appears to have been collated from: 1)crime statistics from the North Carolina Department of Corrections' prison and probation files; 2)demographic statistics taken from the decennial census; 3)police data derived from FBI police agency data; and 4)wage data from the North Carolina Employment Security commission.

Some of the values in this dataset were calculated from other datasets and we found some characteristics in the dataset which may bring its veracity in to question and we have addressed those below and in our analyses.

Table 1: Crime Data Codebook

| Variable | Label |
|----------|-----------------------------|
| county | county identifier |
| year | 1987 |
| crmrte | crimes committed per person |
| prbarr | 'probability' of arrest |
| prbconv | 'probability' of conviction |

Table 1: Crime Data Codebook (*continued*)

| Variable | Label |
|----------|--|
| prbpris | 'probability' of prison sentence |
| avgsen | avg. sentence, days |
| polpc | police per capita |
| density | people per sq. mile |
| taxpc | tax revenue per capita |
| west | =1 if in western N.C. |
| central | =1 if in central N.C. |
| urban | =1 if in SMSA |
| pctmin80 | perc. Minority, 1980 |
| wcon | weekly wage, construction |
| wtuc | wkly wge, trns, util, commun |
| wtrd | wkly wge whlesle, retail, trade |
| wfir | wkly wge, fin, ins, real est |
| wser | wkly wge, service industry |
| wmfg | wkly wge, manufacturing |
| wfed | wkly wge fed employees |
| wsta | wkly wge state employees |
| wloc | wkly wge local gov emps |
| mix | offense mix: face-to-face/other |
| pctymle | percent young male |
| east | Created: observations not in west or central |
| avgwage | Created: mean of all wages |

Data Clean Up

Create avgwage and east Variables

We create two new variables based on data provided to aid in our analysis. 'avgwage' is the mean of all the weekly wages included in the dataset, and 'east' is all the counties that are not in central or west. Note, we do not use east in our core regression specifications, but rather to better understand 'west'.

```
# Create a variable for counties not in west or central.
crime$east <- !(crime$west | crime$central)

# Average of all weekly wage variables.
crime$avgwage = (crime$wcon + crime$wtuc + crime$wtrd + crime$wfir +
                 crime$wser + crime$wmfg + crime$wfed + crime$wsta +
                 crime$wloc)/9
```

Removing Null Rows

The dataset contained an apostrophe 6 rows after the data which caused the csv reader to create 6 invalid rows. We removed these rows as they contain no data.

```
# Delete the 6 empty observations at the end, including the row with the apostrophe.
crime <- crime[!is.na(crime$county) & !is.na(crime$crmrte), ]
```

Removing Duplicate County

We found two identical observations for county 193. There is no logical reason to have two identical observations in this cross-sectional dataset, so we feel removing one of these two observations can only improve the quality of our analysis.

```
# county 193 is duplicated, remove one
crime = crime[!duplicated(crime), ]
```

Convert prbconv to numeric

```
# Convert prbconv to numeric
crime$prbconv = as.numeric(as.character(crime$prbconv))
```

Concerns about the data

prbarr (Probability of Arrest)

We found that county 115 contained a value of 1.09 in prbarr (probability of arrest) which, if it was a true probability, would not be possible. We believe this to either be a labeling error, as it is a ratio used to approximate a probability, or erroneous, as we'll explain later, there are several concerns about the observations for county 115.

prbconv (Probability of Conviction)

We found 10 observations with values greater than 1, which, again, is not a possible value for true probability. The documentation in the codebook specifies that “(t)he probability of conviction is proxied by the ratio of convictions to arrests”, which leaves some ambiguity, however, by construction as such a ratio, it is plausible to have values greater than 1 as a single arrest can result in multiple convictions, this may reflect natural differences in time period as arrests in one year do not mean all cases are decided in the same year, and persons can be convicted in absentia. Similar to the prbarr, we believe this to be a labeling error, as it is a ratio used to approximate a probability, rather than a true probability.

Omitted Counties Creating Bias

The dataset contained 90 counties, and there are 100 counties in North Carolina. The observation id labeled ‘county’ in our data set appears to contain FIPS codes. If this assumption is correct, the following are the missing counties: Camden County, Carteret County, Clay County, Gates County, Graham County, Iredell County, Jones County, Mitchell County, Tyrrell County and Yancey County

These missing counties will introduce a slight clustering bias into our analyses at a minimum, and possibly a more significant bias if they were omitted based on specific criteria whether deliberate or not.

Mislabeled Region County 71

County 71 is both part of the West region and Central region. It's possible to straddle the border however, we'd expect more instances if it was done in this manner, thus we expect one of these to be erroneous and should belong in only one region. This is the only case where this occurs.

Suspicious values for county 115

There are several causes for concern about the data for county 115. First the percentage of police per person is 0.009, the highest value in the dataset and twice that of the second highest value for that variable. It also has the lowest crime rate in the dataset, a variable we show later is actually positively correlated with police per person. The probability of arrest is greater than 1 as we mentioned above, the only variable in the dataset greater than 1. Lastly, the values for probability of conviction, probability of prison and crime mix

are listed to the tenths digit at 1.5, 0.5 and 0.1 respectively. Typical values for these variables contain 6, 7 and 8 decimal places, making 3 values all rounding to the tenths digit highly improbable.

A small number of these issues is cause for concern. This many issues suggests the observations for county 115 may be erroneous. We test the impact of this observation below.

Extreme Outlier Single Data point - County 185 Service Industry Wage

The value for the mean weekly wage for the service industry is 2177, nearly 8 times greater than the mean, and 5.5 times greater than the second highest value for that variable. After researching the county in question through other data sources and seeing that its per capita income is lower than state average and that its population is not especially small (mitigating concerns about small-n leading to a handful of individuals exerting large influence on the mean), we believe this value may be erroneous.

Univariate Analysis

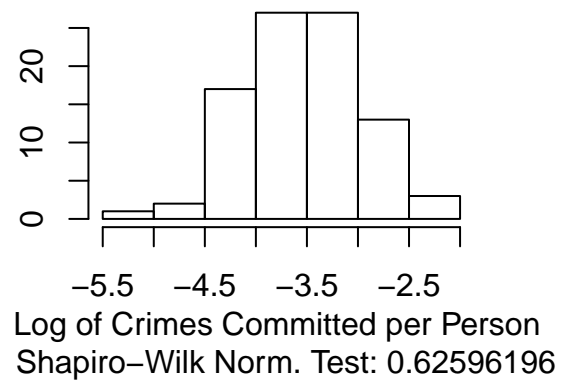
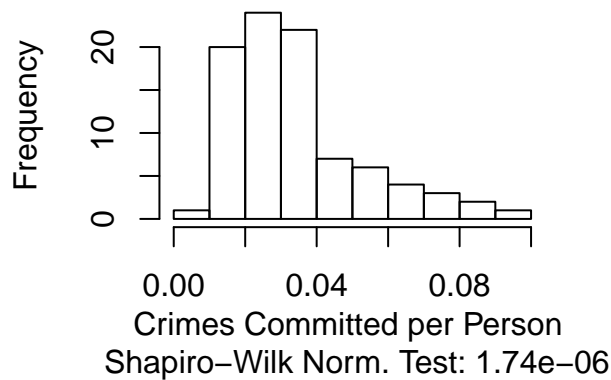
Key Variable

Crimes Committed Per Person

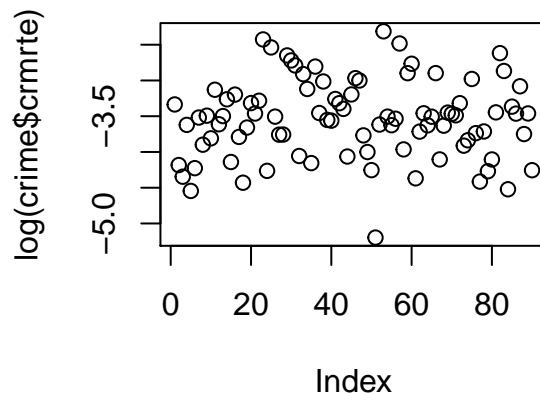
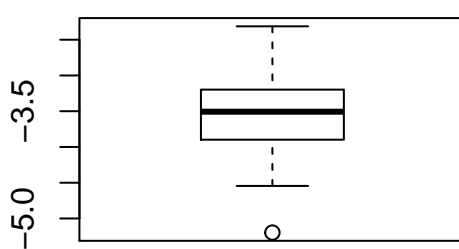
Campaign Significance: The political campaign which hired us is interested in policy prescriptions derived from causal analysis of crime rates. This is the key variable our models will attempt to explain.

```
quick_uni_analysis = function(variable, description, roundto = 8) {
  hist(variable, xlab = paste(tools::toTitleCase(description),
    paste('\n Shapiro-Wilk Norm. Test:',
      round(as.numeric(shapiro.test(variable)[2]), roundto)
    )), main = "")
  hist(log(variable),
    xlab = tools::toTitleCase(paste('Log of', description,
      paste('\n Shapiro-Wilk Norm. Test:', ... =
        round(as.numeric(shapiro.test(log(variable))[2]), roundto)
      ))), main = "", ylab = '')
}

par(mfrow=c(1,2))
quick_uni_analysis(crime$crmrte, 'crimes committed per person')
boxplot(log(crime$crmrte), main = 'log Crime Rate')
plot(log(crime$crmrte))
```



log Crime Rate



Crimes committed per capita has a fairly strong positive skew, applying a natural log transformation creates a more symmetrical distribution and results in a Shapiro-Wilk test p-value that we cannot reject. The transformed variable is preferable for modelling.

```
crime$log_crmrte <- log(crime$crmrte)
crmte.outliers = boxplot(crime$log_crmrte, plot = FALSE)$out
```

The log transformed crime rate has a single outlier, it is not significant enough to cause concern.

Explanatory Variables

People per Square Mile

Both tax revenue per capita and the average wages are positively correlated with people per square mile. This is relevant since those are positively correlated with crime rate, the opposite of what we would expect. However, since they are correlated with people per square mile, which is, as expected, strongly positively correlated with crime rate, this will likely account for some of the correlation in tax revenue per capita and average wages, along with some omitted variables discussed later in the analysis.

Table 2: Explanatory Variable Summary

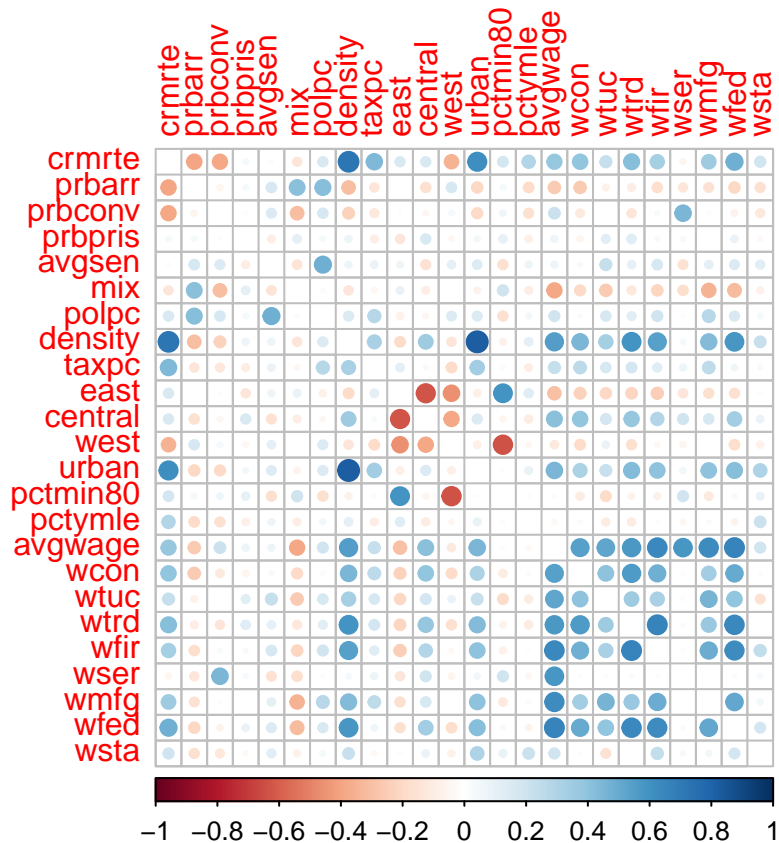
| | Variable | Label | Cor.crmrte | Summary |
|----|----------|--|------------|--|
| 4 | prbarr | 'probability' of arrest | -0.3952830 | Positively correlated, with a possitive skew |
| 5 | prbconv | 'probability' of conviction | -0.3859656 | Positively correlated, with a possitive skew |
| 6 | prbpris | 'probability' of prison sentence | 0.0479954 | Slight negative correlation, with a negative skew |
| 7 | avgsen | avg. sentence, days | 0.0197965 | Slight correlation. |
| 8 | polpc | police per capita | 0.1672816 | Positive correlation |
| 9 | density | people per sq. mile | 0.7283706 | High positive correlation, with a strong positive skew |
| 10 | taxpc | tax revenue per capita | 0.4487151 | Positive correlation, with positive skew, positively correlated to density |
| 11 | west | =1 if in western N.C. | -0.3455515 | Negative correlation |
| 12 | central | =1 if in central N.C. | 0.1658803 | Positive correlation |
| 13 | urban | =1 if in SMSA | 0.6150631 | Positive correlation |
| 14 | pctmin80 | perc. Minority, 1980 | 0.1816506 | Positive correlation |
| 24 | mix | offense mix: face-to-face/other | -0.1320004 | Negative correlation, with a positive skew |
| 25 | pctymle | percent young male | 0.2903397 | Positively correlated, with a possitive skew |
| 26 | east | Created: observations not in west or central | 0.1650083 | Positive correlation |
| 27 | avgwage | Created: mean of all wages | 0.3804003 | Positive correlation, with positive skew, positively correlated to density |

Relationships

Correlation Matrix

```
# Used for displaying subsets of variables.
columns_logical_order = c("county", "year", "crmte", "prbarr", "prbconv",
                           "prbpris", "avgsen", "mix", "polpc", "density",
                           "taxpc", "east", "central", "west", "urban",
                           "pctmin80", "pctymle", "avgwage", "wcon", "wtuc", "wtrd",
                           "wfir", "wser", "wmfg", "wfed", "wsta", "wloc")

corrmatrix <- cor(crime[,columns_logical_order[3:26]])
corrplot(corrmatrix, cl.pos = "b", diag = FALSE)
```



Using the correlation matrix above we can see there are some strong correlations between crime rate (crmrte) and population density (density), crime rate and urban, other (likely east) counties and percentage minority from 1980 (pctmin80) and west and percentage minority, interestingly opposite correlations in those last two. We also see strong correlation with population density and the average wage (avgwage) and several wages, specifically trade, financial, insurance real estate and federal employees.

Significance of wage variables

```
crmrte_wage_model <- lm(log(crmrte)~wcon + wtuc + wtrd + wfir + wser + wmfg
                        +wfed + wsta + wloc, data=crime)
(crmrte_wage_model$coefficients)
```

```
##      (Intercept)          wcon          wtuc          wtrd          wfir
## -6.0765119907  0.0024350006 -0.0003371284  0.0025645560 -0.0021917914
##           wser          wmfg          wfed          wsta          wloc
## -0.0003059448  0.0006737030  0.0038141894  0.0018627518 -0.0011344846
```

```
(f <- summary(crmrte_wage_model)$fstatistic)
```

```
##      value      numdf      dendf
##  4.693485    9.000000   80.000000
```

As all coefficients are close to 0 -> we can say none of the wage variables are independently significant. But, the F-stat p-value 5.2040089×10^{-5} shows that all the wage variables are jointly significant. wcon and wfed are somewhat important.

Model Analysis

Based on the correlation table above, we are apply transformations to the following variables and storing them in our data frame.

```
crime$log_polpc <- log(crime$polpc)
crime$log_pctymle <- log(crime$pctymle)
crime$log_density <- log(crime$density)
crime$log_taxpc <- log(crime$taxpc)
crime$log_mix <- log(crime$mix)
```

Model 1 - Minimum Specification

Based on the table above, we anticipate that variables operationalizing certainty of punishment (prbarr, prbconv, polpc) may have explanatory power for log(crime rate). We also expect that density may have a strong predictive power. As such, we include these variables in our baseline specification.

$$\log(\text{crmrte}) = \beta_0 + \beta_1 \text{prbarr} + \beta_2 \text{prbconv} + \beta_3 \log(\text{polpc}) + \beta_4 \log(\text{density}) + u$$

```
model1 = lm(log_crmrte ~ prbarr + prbconv +
            log_polpc + log_density, data = crime)
(model1$coefficients)
```

```
## (Intercept)      prbarr      prbconv  log_polpc log_density
##    1.0078551   -1.9244220   -0.6923862   0.5559296    0.1112556
```

Intuition of the effects of potential data issues in county 115 on the model

Checking if county 115 that has high prbarr and low crime and low polpc and very low density has any impact on our model.

```
model1.b = lm(log_crmrte ~ (prbarr) + (prbconv) +
              log_polpc + log_density, data = crime[crime$county != 115,])
(model1.b$coefficients)
```

```
## (Intercept)      prbarr      prbconv  log_polpc log_density
##    1.4845485   -1.4606859   -0.5934248   0.6575126    0.1238930
```

From the coefficients summary, we can observe that the county 115 has a very high impact on our proposed model. This county can impact our CLM assumptions, particularly for the variables operationalizing certainty of punishment.

Testing the validity of the 6 CLM assumptions

CLM 1: Linear model

The model is specified such that the dependent variable is a linear function of the explanatory variables.

We assume linearity in the dependent variable vs independent variables by default.

****We have not uncovered evidence that would lead us to question the validity of assumption.***

CLM 2: Random Sampling

Since we got 90% of records from the total counties in North Carolina, we expect this assumption is valid. But to point out, the counties we didn't have can have high density or high policing and low probability of arrest or probability of conviction. This could change our interpretation of the crime rate. Since, we see that crime rate is normally distributed in the given data set, we anticipate that this would be same if we consider the entire population. In other words, we assume that the 10 missing observations are missing completely at random. We have no information at hand that would lead us to think otherwise.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 3: Multicollinearity

Table 3: Correlation Matrix: Model 1

| | prbarr | prbconv | polpc | density | log_polpc | log_density |
|-------------|---------|---------|---------|---------|-----------|-------------|
| prbarr | 1.0000 | -0.0558 | 0.4260 | -0.3027 | 0.2162 | -0.3479 |
| prbconv | -0.0558 | 1.0000 | 0.1719 | -0.2267 | -0.0076 | -0.0861 |
| polpc | 0.4260 | 0.1719 | 1.0000 | 0.1591 | 0.9058 | -0.0563 |
| density | -0.3027 | -0.2267 | 0.1591 | 1.0000 | 0.3250 | 0.5785 |
| log_polpc | 0.2162 | -0.0076 | 0.9058 | 0.3250 | 1.0000 | 0.0230 |
| log_density | -0.3479 | -0.0861 | -0.0563 | 0.5785 | 0.0230 | 1.0000 |

In the matrix above, we find that probability of arrest and density are highly correlated: -0.3478909. We also test the probability of arrest and density alone are jointly affecting crime rate.

```
model1.c = lm(log_crmrte ~ prbarr + log_density, data = crime)
f <- summary(model1.c)$fstatistic
```

The p-value of the entire model 9.0164669×10^{-9} indicates that both these variables are jointly significant.

```
vif(model1)
```

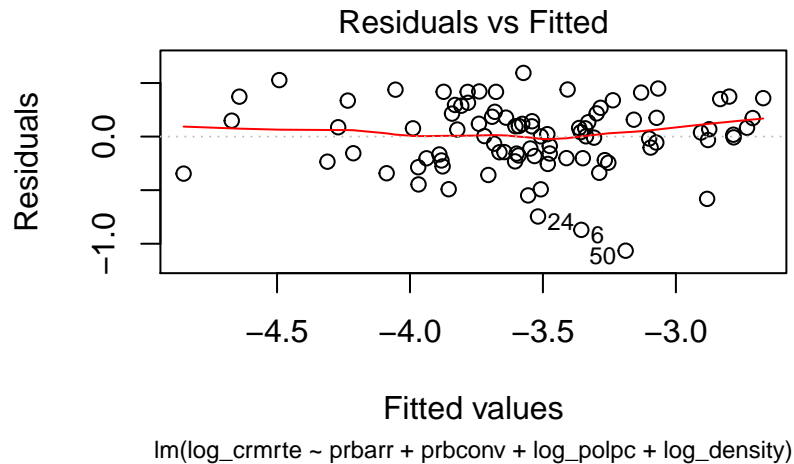
```
##      prbarr      prbconv  log_polpc log_density
##      1.217343      1.016318      1.061591      1.166073
```

Based on pairwise correlation in the independent variables prbarr, prbconv, log_polpc, and log_density, and the fact that no variance inflation factor nears 10, we do not detect evidence of multicollinearity negatively impacting our specification.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 4: Zero conditional mean

```
plot(model1, which=1, cex.sub=0.75)
```



From the residuals vs fitted plot, the residuals appear largely centered on 0.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 5: Homoscedasticity

It is not easy to determine Homoscedasticity from the residuals vs fitted values plot alone, so we run some additional tests.

```
bptest(model1)
```

```
##
## studentized Breusch-Pagan test
##
## data: model1
## BP = 7.186, df = 4, p-value = 0.1264
```

```
ncvTest(model1)
```

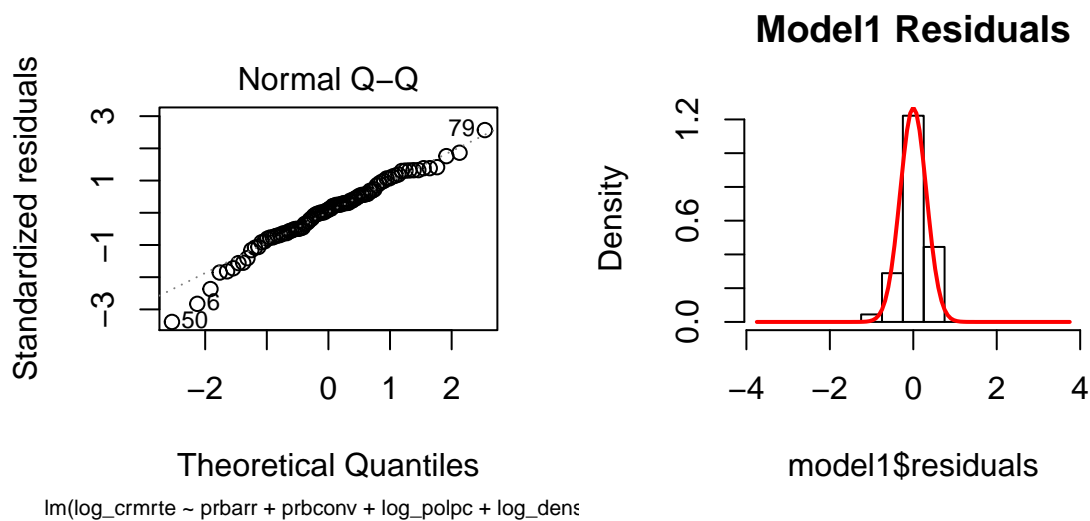
```
## Non-constant Variance Score Test
## Variance formula: ~ fitted.values
## Chisquare = 0.0004349806, Df = 1, p = 0.98336
```

For both tests, we fail to reject the null hypothesis of homoscedasticity.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 6: Normality of Residuals

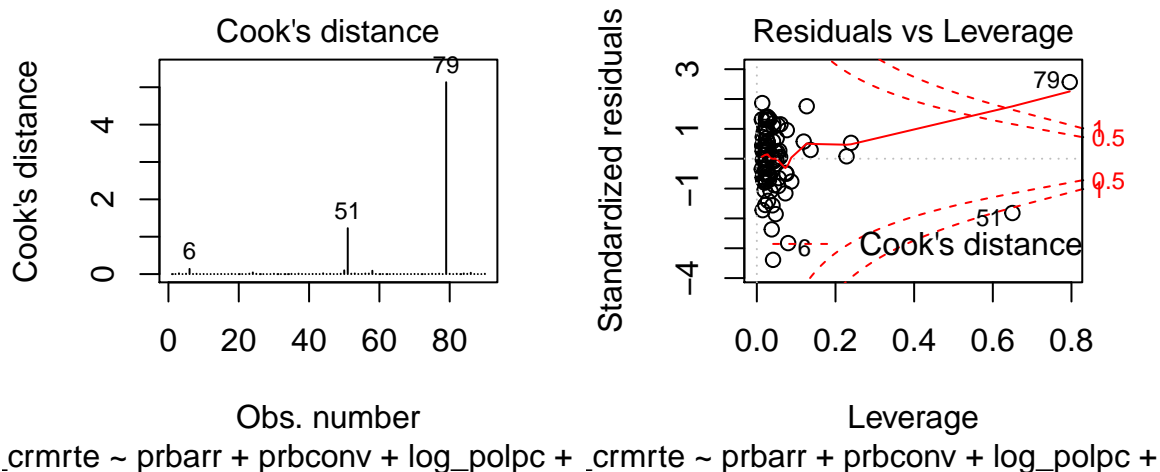
```
plot(model1, which=2, cex.sub=0.66)
hist(model1$residuals, main="Model1 Residuals", breaks = seq(-3.75, 3.75, 0.5), freq=FALSE)
curve(dnorm(x, mean=0, sd=sd(model1$residuals)), col="red", lwd=2, add=TRUE)
```



Other than a few outliers, the distribution is relatively normal for our given sample size. We do see some outliers in the Q-Q plot indicating that there is some skew because of the outlier values at the ends. Is the assumption valid? Highly likely but not 100% sure

Cook's Distance:

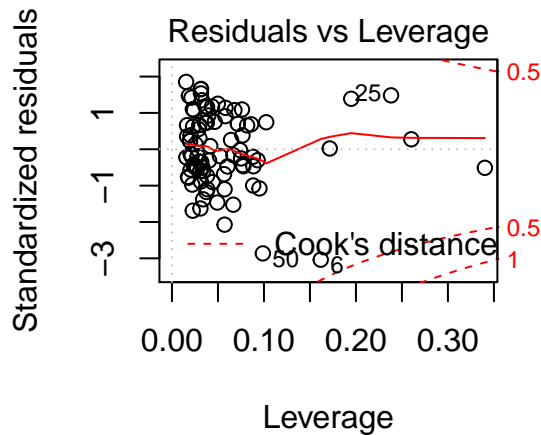
```
plot(model1, which=4)
plot(model1, which=5)
```



There are some influential values at value 51 and 79.

if we remove those values and plot the graph .

```
model1.d <- lm(log_crmrte ~ (prbarr) + (prbconv) +
               log_polpc + log_density, data = crime[c(-79,-51),])
plot(model1.d, which=5)
```



$\text{rmrte} \sim (\text{prbarr}) + (\text{prbconv}) + \log_polpc$

Index 51 and 79 - Density and polpc are quite low for 51 and 79, while the crime rate and probability of arrest are similar to other counties. Of note, these are both western counties.

Now, we could see Cook's is within the bounds.

| | Model.1.Coefficients | Interpretation |
|-------------|----------------------|---|
| (Intercept) | 1.0079 | |
| prbarr | -1.9244 | For ~ 1 unit increase in probability of arrest, crime rate decreases by ~ 1.92% |
| prbconv | -0.6924 | For ~ 1 unit increase in probability of conviction, crime rate decreases by ~ 0.69% |
| log_polpc | 0.5559 | For ~ 1% increase in polpc, crime rate increases by ~ 0.55% |
| log_density | 0.1113 | For ~ 1 unit increase (100 people per square mile) in density, crime rate increases by ~ 0.111% |

Most of the coefficients are highly statistically significant when we look at heteroskedastic-robust errors:

Coefficient-Significance (Heteroskedastic-Robust Errors)

```
coefTest(model1, vcov = vcovHC, level = 0.05)
```

```
##
## t test of coefficients:
##
##      Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.00786    1.26028  0.7997 0.426110
## prbarr      -1.92442    0.61493 -3.1295 0.002400 **
## prbconv     -0.69239    0.15783 -4.3870 3.28e-05 ***
## log_polpc    0.55593    0.18755  2.9642 0.003937 **
## log_density  0.11126    0.13045  0.8529 0.396129
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model 1 Conclusion

Probability of arrest has more impact on crime rate - it is easier to get arrested than convicted. From the arrests, we can see even 50% are not convicted.

The adjusted R^2 for this model is 0.6579144% which means a lot of the the variation in crime rate is explained by this model

The Akaike information criterion indicates that the relative quality of predicting crime rate based on our variables is 57.7000864.

Model 2 - Optimal Specification

In addition to the explanatory variables introduced in our #Model1, we have decided to include the following variables in the model: `west`, `pctmin80`, and an interaction of `west` and `polpc`. This is because as seen in the below table, western counties have a higher concentration of police, but a lower crime rate on average. This is opposite to what we have observed in our #Model1.

```
boxplot(crime$crmte[crime$east],crime$crmte[crime$central],
crime$crmte[crime$west], names=c("East","Central","West"),
main="Crime Rate and Location", xlab ="Location",ylab="Crime Rate")

crime$region <- ifelse(crime$west == 1, "West",
                      ifelse(crime$central == 1, "Central",
                              ifelse(crime$east == 1, "East", "other")))

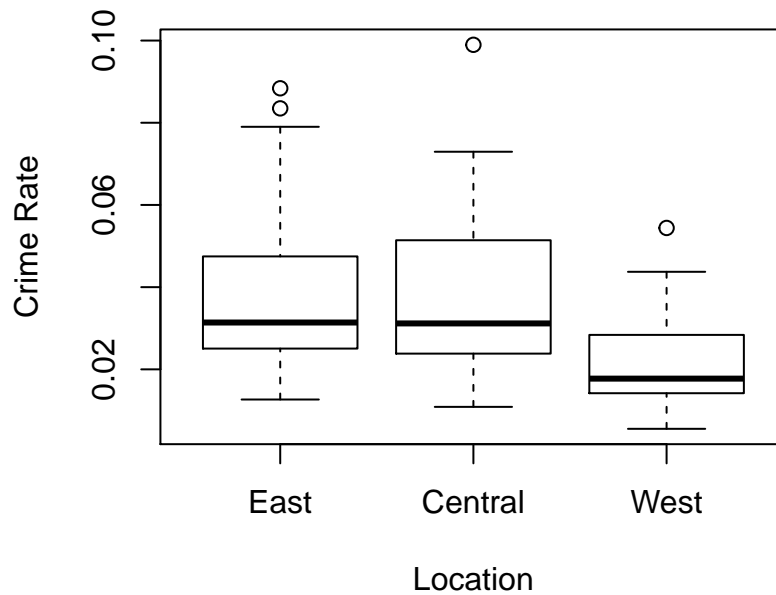
region = aggregate(density ~ region, data = crime, mean)
region$polpc = aggregate(polpc ~ region, data = crime, mean)[2]
region$crmte = aggregate(crmte ~ region, data = crime, mean)[2]
colnames(region) = c("Region", "Mean Density", "Mean Police per Cap", "Mean Crime Rate")

kable(region, "latex", longtable = TRUE, booktabs = TRUE, caption = "Regions") %>%
  kable_styling(full_width = TRUE, latex_options =
    c("HOLD_position", "striped", "repeat_header"),
    row_label_position = 1)
```

Table 4: Regions

| Region | Mean Density | Mean Police per Cap | Mean Crime Rate |
|---------|--------------|---------------------|-----------------|
| Central | 2.047960 | 0.001637046 | 0.03699627 |
| East | 1.085503 | 0.001609983 | 0.03739491 |
| West | 1.074319 | 0.001970259 | 0.02209975 |

Crime Rate and Location



There are three regions, two provided in the data set; West and Central, and those not in those two regions which we have determined to be East.

West shows a higher mean police per capita and a lower crime rate, a relationship which is opposite to that observed in other regions and the overall model.

$$\begin{aligned} \log(\text{crmrte}) = & \beta_0 + \beta_1(\text{prbarr}) + \beta_2(\text{prbconv}) + \beta_3\log(\text{polpc}) + \\ & \beta_4\log(\text{density}) + \beta_5(\text{pctmin80}) + \beta_6\text{west} + \\ & \beta_7\text{west} * \log(\text{polpc}) + u \end{aligned}$$

```
model2 = lm(log_crmrte ~ (prbarr) + (prbconv) + log_polpc +
            log_density + pctmin80 +
            west + west * log_polpc, data = crime)
(model2$coefficients)
```

```
##      (Intercept)          prbarr          prbconv
##      1.91895608      -1.82080087      -0.69040694
##      log_polpc      log_density          pctmin80
##      0.73628656      0.10439659      0.01001377
##      westTRUE log_polpc:westTRUE
##      -1.81032462      -0.26035345
```

Intuition of the Effects of County 71 Existing in Both Central and West

This new model removes county 71 as the dataset we were provided show it is in both Western and Central North Carolina, this will allow us to understand the impacts of this error on our model.

```
model2.a = lm(log_crmrte ~ (prbarr) + (prbconv) + log_polpc +
              log_density + pctmin80 +
```

```
west + west * log_polpc, data = crime[crime$county != 71,])
(model2.a$coefficients)
```

```
##      (Intercept)          prbarr          prbconv
##      1.968389066      -1.784011302      -0.677641311
##      log_polpc      log_density      pctmin80
##      0.744786409      0.099275321      0.009661545
##      westTRUE log_polpc:westTRUE
##      -2.090092375      -0.299829159
```

There is a small change in the coefficient of west, $-1.81 - (-2.09) = 0.3$ when county 71 is removed. This change of ~ 0.3 represents bias in west if county 71 is in fact in central NC.

Intuition of the effects of potential data issues in county 115 on the model

checking if county 115 that has high prbarr and low crime and low polpc and very low density has any impact on our model.

```
model2.b = lm(log_crmrte ~ (prbarr) + (prbconv) + log_polpc +
              log_density + pctmin80 +
              west + west * log_polpc, data = crime[crime$county != 115,])
(model2.b$coefficients)
```

```
##      (Intercept)          prbarr          prbconv
##      1.93987440      -1.89308556      -0.70741807
##      log_polpc      log_density      pctmin80
##      0.73576203      0.10010645      0.01018997
##      westTRUE log_polpc:westTRUE
##      -2.17568786      -0.31697141
```

From the coefficients summary, we can observe that the county 115 doesn't appear to have a very high impact on our proposed model. It is possible that adding a control for west and the interaction between west and polpc has mitigated this broader influence.

Testing the Validity of the 6 CLM assumptions

CLM 1: Linear model

Our views are identical to the previous model.

CLM 2: Random Sampling

Our views are identical to the previous model

CLM 3: Multicollinearity

Table 5: Correlation Matrix: Model 2

| | prbarr | prbconv | polpc | density | log_polpc | log_density | pctmin80 | west |
|-----------|---------|---------|--------|---------|-----------|-------------|----------|---------|
| prbarr | 1.0000 | -0.0558 | 0.4260 | -0.3027 | 0.2162 | -0.3479 | 0.0491 | 0.1737 |
| prbconv | -0.0558 | 1.0000 | 0.1719 | -0.2267 | -0.0076 | -0.0861 | 0.0625 | 0.0473 |
| polpc | 0.4260 | 0.1719 | 1.0000 | 0.1591 | 0.9058 | -0.0563 | -0.1691 | 0.1514 |
| density | -0.3027 | -0.2267 | 0.1591 | 1.0000 | 0.3250 | 0.5785 | -0.0746 | -0.1358 |
| log_polpc | 0.2162 | -0.0076 | 0.9058 | 0.3250 | 1.0000 | 0.0230 | -0.1456 | 0.1088 |

Table 5: Correlation Matrix: Model 2 (*continued*)

| | prbarr | prbconv | polpc | density | log_polpc | log_density | pctmin80 | west |
|-------------|---------|---------|---------|---------|-----------|-------------|----------|---------|
| log_density | -0.3479 | -0.0861 | -0.0563 | 0.5785 | 0.0230 | 1.0000 | -0.0967 | -0.2149 |
| pctmin80 | 0.0491 | 0.0625 | -0.1691 | -0.0746 | -0.1456 | -0.0967 | 1.0000 | -0.6336 |
| west | 0.1737 | 0.0473 | 0.1514 | -0.1358 | 0.1088 | -0.2149 | -0.6336 | 1.0000 |

```
vif(model2)
```

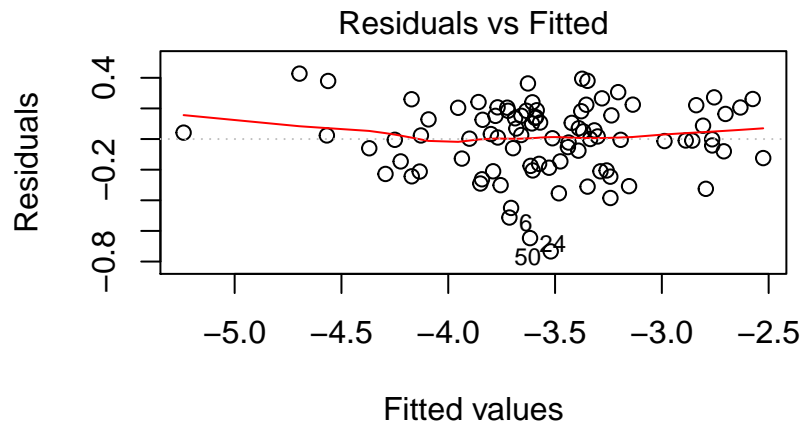
```
##          prbarr          prbconv      log_polpc      log_density      pctmin80
##      1.538158      1.086812      1.893781      1.364137      1.946049
##          west log_polpc:west
##    350.110767    337.569876
```

Based on the low pairwise correlation between the independent variables and variance inflation factors all well below 10, we do not detect evidence of multicollinearity negatively impacting our specification.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 4: Zero conditional mean

```
plot(model2, which=1, cex.sub=0.75)
```



$\text{lm}(\log_crrmte \sim (\text{prbarr}) + (\text{prbconv}) + \log_polpc + \log_density + \text{pctmin80} +$

From the residuals vs fitted plot, the residuals are largely centered on 0 except few values. **We have not uncovered evidence that would lead us to question the validity of assumption.**

CLM 5: Homoscedasticity

It is not easy to determine Homoscedasticity from the residuals vs fitted values plot alone, so we run some additional tests.

```
bptest(model2)
```

```
##
## studentized Breusch-Pagan test
##
```

```
## data: model2
## BP = 11.268, df = 7, p-value = 0.1273
```

```
ncvTest(model2)
```

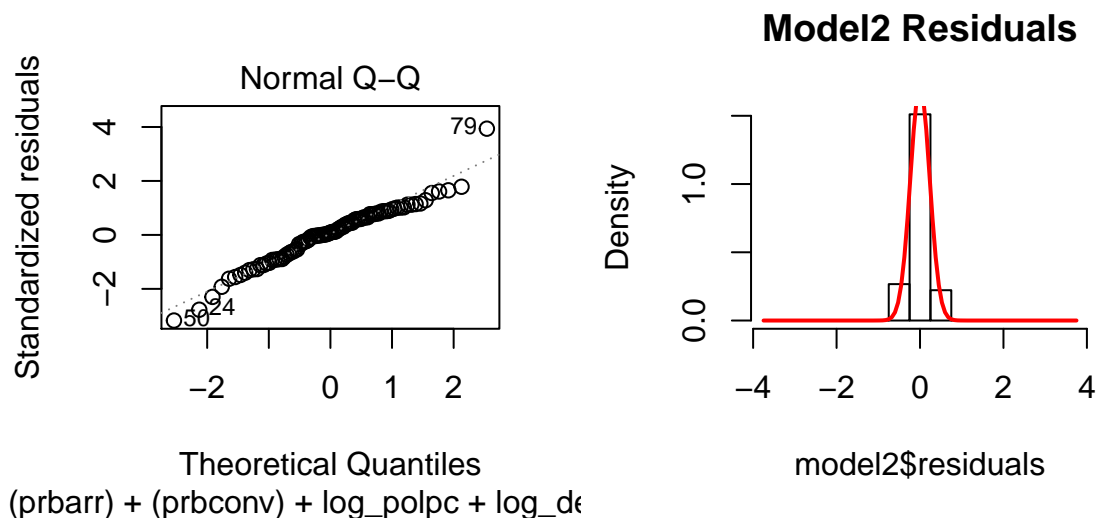
```
## Non-constant Variance Score Test
## Variance formula: ~ fitted.values
## Chisquare = 0.2935739, Df = 1, p = 0.58794
```

For both tests, we fail to reject the null hypothesis of homoscedasticity.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 6: Normality of Residuals

```
plot(model2, which=2)
hist(model2$residuals, main="Model2 Residuals", breaks = seq(-3.75, 3.75, 0.5), freq=FALSE)
curve(dnorm(x, mean=0, sd=sd(model2$residuals)), col="red", lwd=2, add=TRUE)
```

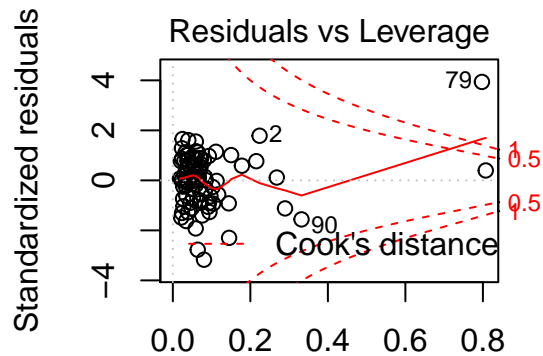
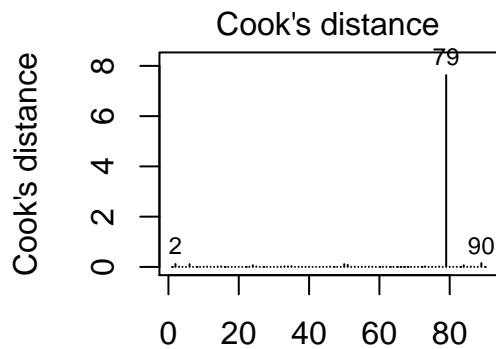


(prbarr) + (prbconv) + log_polpc + log_dk

Other than a few outliers, the distribution is relatively normal for our given sample size. We do see some outliers in the Q-Q plot indicating that there is some skew because of the outlier values at the ends. **We have not uncovered evidence that would lead us to question the validity of assumption.*

Cook's Distance:

```
plot(model2, which=4)
plot(model2, which=5)
```



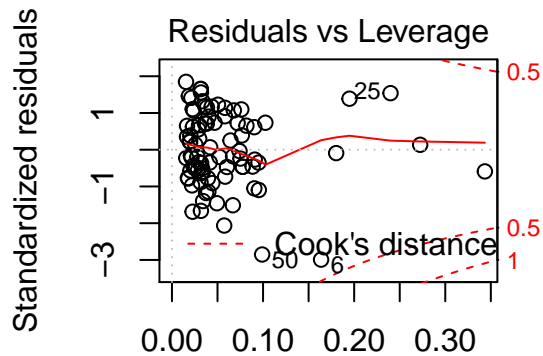
Obs. number Leverage
 (prbarr) + (prbconv) + log_polpc + log_density (prbarr) + (prbconv) + log_polpc + log_density

Observations 51, 79 and 90 are influential.

The density and polpc are very low, whereas the crime rate, probability of arrest, probability of conviction and the percent of minority are similar to other counties. These outliers are all in western counties.

If we remove those values and plot the graph:

```
model2.c <- lm(log_crmrte ~ (prbarr) + (prbconv) +
               log_polpc + log_density, data = crime[c(-51,-79,-90),])
plot(model2.c, which=5)
```



Leverage
 rmrte ~ (prbarr) + (prbconv) + log_polpc

| | Model.2.Coefficients | Interpretation |
|--------------------|----------------------|---|
| (Intercept) | 1.9190 | |
| prbarr | -1.8208 | For ~ 1 unit increase in probability of arrest, crime rate decreases by ~ 1.82% |
| prbconv | -0.6904 | For ~ 1 unit increase in probability of conviction, crime rate decreases by ~ 0.69% |
| log_polpc | 0.7363 | For ~ 1% increase in polpc, crime rate increases by ~ 0.73% |
| log_density | 0.1044 | For ~ 1 unit increase (100 people per square mile) in density, crime rate increases by ~ 0.104% |
| pctmin80 | 0.0100 | For ~ 1 unit increase in percent minority, crime rate increases by ~ 1% |
| westTRUE | -1.8103 | For all western counties crime rate decreases by ~ 1.81% ~ compared to other counties |
| log_polpc:westTRUE | -0.2604 | For all western counties, an ~ 1% increase in polpc reduces the crime rate by ~ 0.26% |

Most of the coefficients are highly statistically significant except density when we look at heteroskedastic-robust errors: This indicates that, after controlling for the impact of being a western county, density doesn't have a statistically significant impact - thus reflecting a bias in our previous model specification.

Coefficient-Significance (Heteroskedastic-Robust Errors)

```
coeftest(model2, vcov = vcovHC, level = 0.05)
```

```
##
## t test of coefficients:
##
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.9189561  1.4091365   1.3618 0.1769920
## prbarr         -1.8208009  0.3830028  -4.7540 8.409e-06 ***
## prbconv        -0.6904069  0.1415946  -4.8759 5.227e-06 ***
## log_polpc       0.7362866  0.1988147   3.7034 0.0003846 ***
## log_density     0.1043966  0.1519063   0.6872 0.4938687
## pctmin80        0.0100138  0.0021665   4.6220 1.398e-05 ***
## westTRUE       -1.8103246  1.2834530  -1.4105 0.1621711
## log_polpc:westTRUE -0.2603535  0.1955745  -1.3312 0.1868047
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model conclusion - Probability of arrest has more impact on crime rate. One is more likely to be arrested than convicted, which is expected as an arrest is usually necessary for a trial. From the arrests, we can see 50% are not convicted. Also, We observed that crime rate is low for western counties and high for eastern counties. This confirms our intuition.

The adjusted R^2 for this model is 0.8068387% which means a lot of the variation of the dependent variable is explained by this model.

The Akaike information criterion (AIC) indicates that the relative quality of predicting crime rate based on our variables is 9.0279987.

Model 3 - Sub-optimal Specification

In addition to the variables included in model 2, we analyzed the effects of percentage of young males and tax revenue per capita on crime rate. Next, based on the analysis of wages above, we include wcon and wfed in our model due to their strong explanatory power as an example why they and other wages were not included in our optimal specification in model 2. We are not using any interaction terms here and want to check how crime rate varies across all regions for these variables.

$$\begin{aligned} \log(\text{crmte}) = & \beta_0 + \beta_1 \log(\text{prbarr}) + \beta_2 \log(\text{prbconv}) + \\ & \beta_3 \log(\text{polpc}) + \beta_4 \log(\text{density}) + \beta_5 (\text{pctmin80}) + \\ & \beta_6 \log(\text{pctymle}) + \beta_7 \log(\text{taxpc}) + \beta_8 (\text{wcon}) + \beta_9 (\text{wfed}) + u \end{aligned}$$

```
model3 = lm(log_crmte ~ (prbarr) + (prbconv) +
            log_polpc + log_density + pctmin80
            + log_pctymle + log_taxpc + wcon + wfed, data = crime)
(model3$coefficients)
```

```
##      (Intercept)      prbarr      prbconv      log_polpc      log_density
## 0.1861357787 -1.8781188626 -0.7001301544 0.5623523453 0.0905239339
##      pctmin80      log_pctymle      log_taxpc      wcon      wfed
## 0.0118914982 0.0743049895 0.0098133796 0.0009643015 0.0009523985
```

Intuition of the effects of potential data issues in county 115 on the model

County 115 has high prbarr and low crime and low polpc and very low density this new model will allow us to see the effects on the model above.

```
model3.a = lm(log_crmte ~ (prbarr) + (prbconv) +
              log_polpc + log_density + pctmin80
              + log_pctymle + log_taxpc + wcon + wfed, data = crime[crime$county != 115,])
(model3.a$coefficients)
```

```
##      (Intercept)      prbarr      prbconv      log_polpc      log_density
## 0.2611456276 -1.8452057210 -0.6930713953 0.5721926350 0.0917819362
##      pctmin80      log_pctymle      log_taxpc      wcon      wfed
## 0.0118372394 0.0733529718 0.0048324894 0.0009534671 0.0009432399
```

From the above two coefficients summaries, we can observe that the county 115 doesn't have any big impact on our coefficients.

Testing the Validity of the 6 CLM assumptions

CLM 1: Linear model

Our views are identical to the previous model.

CLM 2: Random Sampling

Our views are identical to the previous model.

CLM 3: Multicollinearity

Table 6: Correlation Matrix: Model 3

| | prbarr | prbconv | log_polpc | log_density | pctmin80 | log_pctymle | log_taxpc | wcon | wfed |
|-----------|--------|---------|-----------|-------------|----------|-------------|-----------|--------|--------|
| prbarr | 1.000 | -0.056 | 0.216 | -0.348 | 0.049 | -0.207 | -0.131 | -0.252 | -0.208 |
| prbconv | -0.056 | 1.000 | -0.008 | -0.086 | 0.062 | -0.185 | -0.133 | -0.117 | -0.061 |
| log_polpc | 0.216 | -0.008 | 1.000 | 0.023 | -0.146 | 0.176 | 0.383 | 0.103 | 0.314 |
| log_densi | -0.348 | -0.086 | 0.023 | 1.000 | -0.097 | 0.175 | 0.108 | 0.371 | 0.525 |
| pctmin80 | 0.049 | 0.062 | -0.146 | -0.097 | 1.000 | -0.012 | 0.029 | -0.108 | 0.031 |

Table 6: Correlation Matrix: Model 3 (*continued*)

| | prbarr | prbconv | log_polpc | log_density | pctmin80 | log_pctymle | log_taxpc | wcon | wfed |
|-------------|--------|---------|-----------|-------------|----------|-------------|-----------|-------|-------|
| log_pctymle | -0.207 | -0.185 | 0.176 | 0.175 | -0.012 | 1.000 | -0.074 | 0.008 | 0.004 |
| log_taxpc | -0.131 | -0.133 | 0.383 | 0.108 | 0.029 | -0.074 | 1.000 | 0.271 | 0.102 |
| wcon | -0.252 | -0.117 | 0.103 | 0.371 | -0.108 | 0.008 | 0.271 | 1.000 | 0.507 |
| wfed | -0.208 | -0.061 | 0.314 | 0.525 | 0.031 | 0.004 | 0.102 | 0.507 | 1.000 |

We do see strong correlation between wfed and wcon 0.5066639 along with polpc and density. We examine how these variables affect crime rate:

```
model3.b = lm(log_crmrte ~ (wcon) + (wfed) + log_density + log_polpc, data = crime)
(model3.b$coefficients)
```

```
## (Intercept)          wcon          wfed  log_density  log_polpc
## -3.078138710  0.001638614  0.002040546  0.127538735  0.282328074
```

```
f <- summary(model3.b)$statistic
```

The p-value of the entire model 9.0164669×10^{-9} indicates that these variables are jointly significant. But the coefficients of wcon and wfed are close to zero.

```
vif(model3)
```

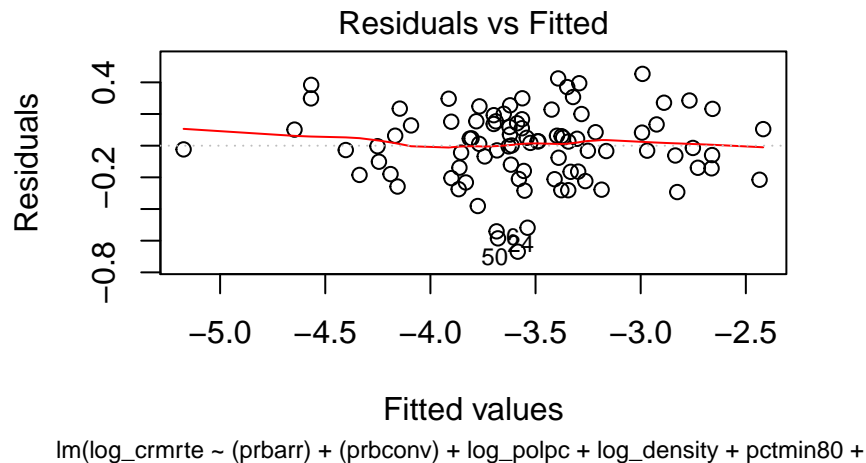
```
##      prbarr      prbconv  log_polpc log_density  pctmin80 log_pctymle
##      1.530657  1.146751  2.055567  1.659918  1.158265  1.391718
##      log_taxpc          wcon          wfed
##      1.622171  1.564755  2.273048
```

Based on pairwise correlation in the dependent variables and the fact that no variance inflation factor nears 10, we do not detect evidence of multicollinearity negatively impacting our specification.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 4: Zero conditional mean

```
plot(model3, which=1, cex.sub=0.75)
```



From the residuals vs fitted plot, the residuals are largely centered on 0.

We have not uncovered evidence that would lead us to question the validity of assumption.

CLM 5: Homoscedasticity

It is not easy to determine Homoscedasticity from the residuals vs fitted values plot alone, so we run some additional tests.

```
bptest(model3)
```

```
##  
## studentized Breusch-Pagan test  
##  
## data: model3  
## BP = 22.417, df = 9, p-value = 0.007648
```

```
ncvTest(model3)
```

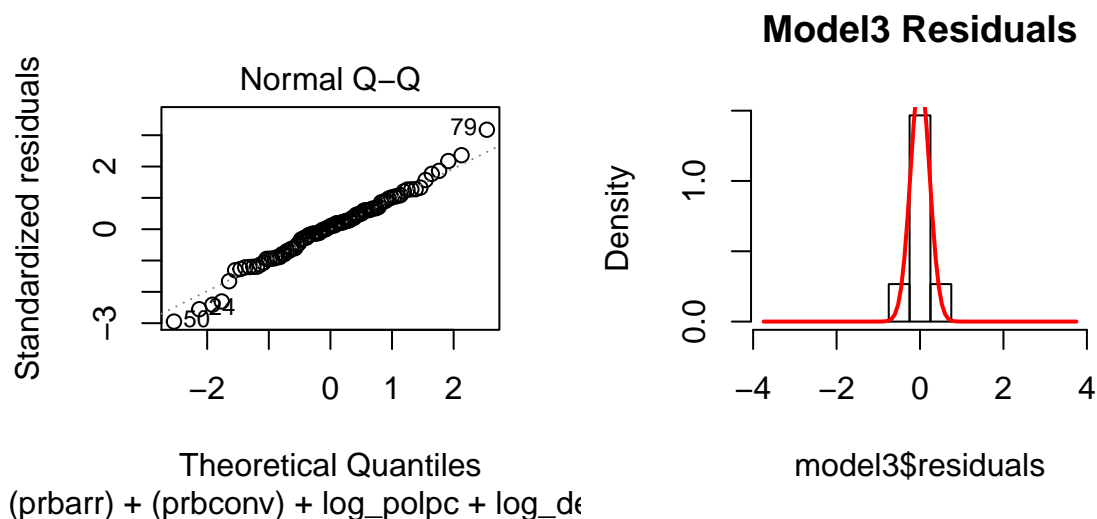
```
## Non-constant Variance Score Test  
## Variance formula: ~ fitted.values  
## Chisquare = 0.002576534, Df = 1, p = 0.95952
```

For both tests, we fail to reject the null hypothesis of homoscedasticity.

****We have not uncovered evidence that would lead us to question the validity of assumption.***

CLM 6: Normality of Residuals

```
plot(model3, which=2)  
hist(model3$residuals, main="Model3 Residuals", breaks = seq(-3.75, 3.75, 0.5), freq=FALSE)  
curve(dnorm(x, mean=0, sd=sd(model3$residuals)), col="red", lwd=2, add=TRUE)
```

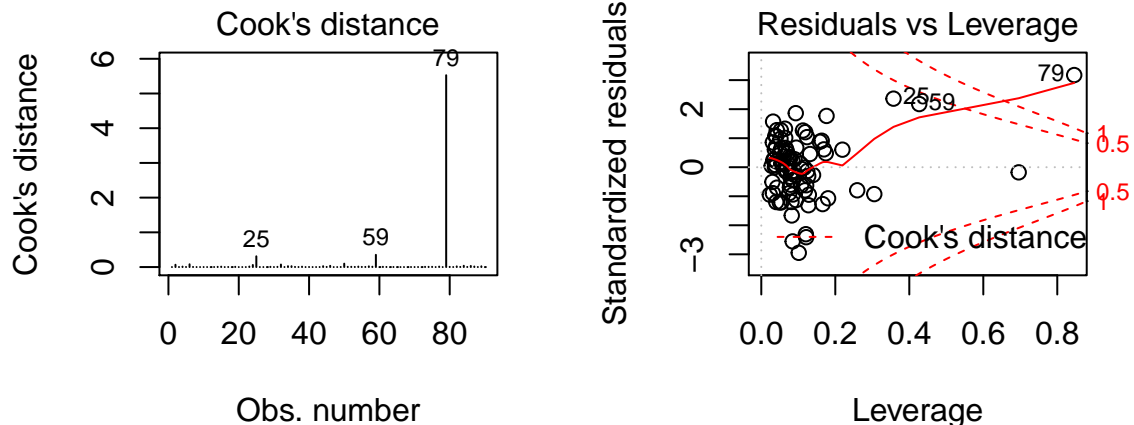


Other than a few outliers, the distribution is relatively normal for our given sample size. We do see some outliers in the Q-Q plot indicating that there is some skew because of the outlier values at the ends.

We have not uncovered evidence that would lead us to question the validity of assumption.

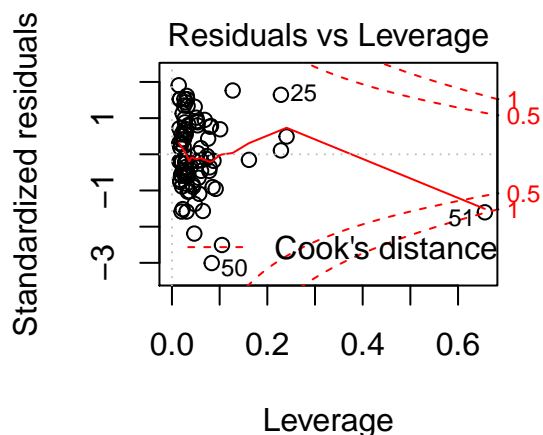
Cook's Distance:

```
plot(model3, which=4)
plot(model3, which=5)
```



There are some influential values - values 59 and 79. #####if we remove those values and plot the graph, we could see Cook's distance is within the bounds.

```
model3.c <- lm(log_crmrte ~ (prbarr) + (prbconv) +
               log_polpc + log_density, data = crime[c(-79,-59),])
plot(model3.c, which=5)
```



$\text{rmrte} \sim (\text{prbarr}) + (\text{prbconv}) + \log_polpc$

Index 59 - This is an eastern county with low crime rate and low polpc, differing from many other observations in our model. We do not think that this observation merits exclusion.

| | Model.3.Coefficients | Interpretation |
|-------------|----------------------|--|
| (Intercept) | 0.1861 | |
| prbarr | -1.8781 | For ~ each 1 unit increase in probability of arrest, crime rate decreases by 1.87% |
| prbconv | -0.7001 | For ~ each 1 unit increase in probability of conviction, crime rate decreases by 0.7% |
| log_polpc | 0.5624 | For ~ 1% increase in polpc, crime rate increases by 0.562% |
| log_density | 0.0905 | For ~ 1 unit increase (100 people per square mile) in density, crime rate increases by 0.09% |
| pctmin80 | 0.0119 | For ~ 1 unit increase of percent minority, crime rate increases by ~ 1.12% |
| log_pctymle | 0.0743 | For ~ 1% increase in pctymle, crime rate increases by ~ 0.07% |
| log_taxpc | 0.0098 | For ~ 1% increase in taxpc, crime rate increases by ~ 0.009% |
| wcon | 0.0010 | For ~ 1 unit increase in wcon, crime rate increases by ~ .01% |
| wfed | 0.0010 | For ~ 1 unit increase in wfed, crime rate increases by ~ 0.01% |

All of the coefficients are highly statistically significant for prbarr, prbconv, polpc, density and pctmin80 when we look at heteroskedastic-robust errors. But taxpc, pctymle, wcon and wfed don't have much significance. But all these variables are jointly significant:

Coefficient-Significance (Heteroskedastic-Robust Errors)

```
coeftest(model3, vcov = vcovHC, level = 0.05)

##
## t test of coefficients:
##
##      Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.18613578  1.39110035  0.1338  0.893893
## prbarr      -1.87811886  0.32608991 -5.7595 1.505e-07 ***
## prbconv     -0.70013015  0.11734215 -5.9666 6.293e-08 ***
## log_polpc    0.56235235  0.15252989  3.6868  0.000412 ***
## log_density  0.09052393  0.15972295  0.5668  0.572467
## pctmin80     0.01189150  0.00179810  6.6134 3.885e-09 ***
## log_pctymle  0.07430499  0.26662725  0.2787  0.781206
## log_taxpc    0.00981338  0.15625430  0.0628  0.950079
## wcon         0.00096430  0.00071112  1.3560  0.178902
## wfed        0.00095240  0.00121401  0.7845  0.435061
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model3 conclusion -

Probability of arrest is consistently estimated to have an effect on crime rate.

The Akaike information criterion (AIC) indicates that the relative quality of predicting crime rate based on our variables is 9.5031292 .

The adjusted R^2 for this model is 0.8096141% which means a lot of the the variation in the dependent variable is explained by this model. That said, we have hit the point of diminishing returns from adding more variables as these values are quite close to those for the more parsimoneous model 2.

We run a Wald Test to see if these additional variables has any signifiacnce.

```
waldtest(model3, model1, vcov = vcovHC)
```

```
## Wald test
##
```

```
## Model 1: log_crmrte ~ (prbarr) + (prbconv) + log_polpc + log_density +
##      pctmin80 + log_pctymle + log_taxpc + wcon + wfed
## Model 2: log_crmrte ~ prbarr + prbconv + log_polpc + log_density
##      Res.Df Df      F      Pr(>F)
## 1      80
## 2      85 -5 12.904 3.314e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The Wald test reveals that variables added to model 3 jointly have no effect on crime rate.

Now let's compare the coefficients of all models and also adding standard errors to the models:

```
se.model1 <- sqrt(diag(vcovHC(model1)))
se.model2 <- sqrt(diag(vcovHC(model2)))
se.model3 <- sqrt(diag(vcovHC(model3)))
stargazer(model1,model2,model3,
  title="Linear Models Predicting Crime Rate",
  column.labels=c("Model 1","Model 2","Model 3"),
  se = list(se.model1, se.model2, se.model3),
  single.row=TRUE,
  star.cutoffs = c(0.05, 0.01, 0.001),
  dep.var.caption = "Measuring Crime Rate",
  keep.stat = c("adj.rsq","n"),
  dep.var.labels = "Crime Rate",
  no.space = TRUE
)
```

% Table created by stargazer v.5.2.2 by Marek Hlavac, Harvard University. E-mail: hlavac at fas.harvard.edu
 % Date and time: Mon, Dec 10, 2018 - 8:52:21 PM

Table 7: Linear Models Predicting Crime Rate

| | Measuring Crime Rate | | |
|-------------------------|----------------------|-----------------------|-------------------|
| | Model 1 | Crime Rate Model 2 | Model 3 |
| | (1) | (2) | (3) |
| prbarr | -1.924** (0.615) | -1.821*** (0.383) | -1.878*** (0.326) |
| prbconv | -0.692*** (0.158) | -0.690*** (0.142) | -0.700*** (0.117) |
| log_polpc | 0.556** (0.188) | 0.736*** (0.199) | 0.562*** (0.153) |
| log_density | 0.111 (0.130) | 0.104 (0.152) | 0.091 (0.160) |
| pctmin80 | | 0.010*** (0.002) | 0.012*** (0.002) |
| west | | -1.810 (1.283) | |
| log_polpc:west | | -0.260 (0.196) | |
| log_pctymle | | | 0.074 (0.267) |
| log_taxpc | | | 0.010 (0.156) |
| wcon | | | 0.001 (0.001) |
| wfed | | | 0.001 (0.001) |
| Constant | 1.008 (1.260) | 1.919 (1.409) | 0.186 (1.391) |
| Observations | 90 | 90 | 90 |
| Adjusted R ² | 0.658 | 0.807 | 0.810 |

Note:

*p<0.05; **p<0.01; ***p<0.001

This table demonstrates the following:

- The key Variables **prbarr** and **prbconv** have robust estimates in all models. Co-efficient of **prbarr** is always further from zero than **prbconv**.
- The coefficient for **density** decreases as we add more variables that likely interact with it. Eg. **west**. From the correlation matrix, we do see west is correlated with density.
- **polpc** maintains its statistically significant coefficient with low standard error and low coefficient in model 3.
- **pctmin80** is also robust as its coefficient stays statistically significant in models 2 and 3.
- All other variables in model3 are not statistically significant. We can conclude these variables are not robust enough to introduce them in our main model.

Omitted Variables

In order to make valid policy recommendations, we need confidence that our estimated coefficients for policy-relevant variables are unbiased, statistically significant, and practically significant. Statistical software makes it quite easy to determine if there is a relationship between a given variable and the dependent variable that is statistically significantly different from zero. Practical significance of our estimates requires just one extra step to interpret the meaning of the estimate for each variable under consideration. Accounting for elements which could bias our estimates is more difficult and, to some degree, not a solvable problem.

We only have observational data available. Moreover, we are not able to design or even infer experiments for our data generating process. As such, we are left to reason about counterfactuals, rather than conduct experiments to verify the implications of our model. Additionally, we have a flawed data collection process, which we also have limited ability to correct for. Our desired population variables are by-in-large not included in the dataset we were provided. Some of these desired variables are practically or ethically unobservable. Others were operationalized in a flawed manner, with a negative impact on our ability to model relationships with a causal interpretation. We address some of these issues here.

Our ideal model of the causes of the crime rate would be something like:

$$\begin{aligned} \text{crime_rate} = & \beta_0 + \beta_1 \text{crtty_punish} + \beta_2 \text{svrty_punish} + \beta_3 \text{poverty_rate} + \\ & \beta_4 \text{educ} + \beta_5 \text{social_cohesion} + \beta_6 \text{weapon_availability} + \beta_7 \text{real_wage} + \\ & \beta_8 \text{low_skill_unemployment_rate} + \beta_9 \text{age_15_to_30_proportion_population} + \\ & \beta_{10} \text{percent_of_population_previously_committed_crime} + \\ & \beta_{11} \text{percent_of_population_previously_imprisoned} + \dots + \text{error} \end{aligned}$$

We believe it should be relatively straightforward to add in variables operationalizing education, poverty rate, real wage, proportion of population that is young, the low skill unemployment rate, the proportion of the population that previously committed a crime, and the portion that was previously imprisoned. Unfortunately, we are unable to observe the rest of our desired concepts.

Some concepts have been operationalized in our dataset. For example, certainty of punishment has been operationalized through three variables: 1) the percent of the population which are police, 2) the ratio of arrests to crimes, and 3) the ratio of convictions to arrest. This is among the most effective operationalizations in this dataset. Severity of punishment is also operationalized through 1) the proportion of convictions that result in a prison sentence and 2) the average length of a prison sentence. Nominal wages are operationalized in the dataset with average wages for certain industry groupings. None of poverty rate, education, social cohesion, weapon availability, cost of living, or the low skill unemployment rate are operationalized within this dataset.

Moreover, certain variables that are included in our dataset are likely correlated with many of our desired variables, but actually measure something distinct - introducing the possibility for model estimates based on those variables to be biased and thus misleading. For example, the pctmin80 variable measures the percent of a county that was minority in 1980 - 7 years prior to our other observations. Setting the time divergence aside and extrapolating from national trends in the U.S. in the 1980s, the percentage of a county that belongs to a minority class could be the result of red lining, a segregating practice which reinforced poverty and low-quality education, both positively correlated with crime rate. It may also exhibit a parabolic relation with social cohesion. If we were to include pctmin80 in our regression, we would expect the model estimate to be biased as we have not adjusted for the impacts of education, poverty, or social cohesion. Examining the impact of education alone on the estimator for pctmin80 - as education was likely negatively correlated with pctmin80, and we expect education to be negatively related to the crime rate, the model's estimate of the impact of the percent of a county which was minority in 1980 would be upwardly biased. In other words, the estimator for pctmin80 in the underspecified model would imply a much larger relationship between pctmin80 and crime rate than actually exists.

Similarly, our dataset contains a variable density which is likely correlated with two of our desired but unobserved explanatory variables: social cohesion and poverty. In practice, in the U.S. in the 1980s, we would expect social cohesion to be negatively correlated with density, while poverty may be positively correlated with density. We expect the beta for social cohesion to crime rate to be negative, while the beta for poverty to crime rate is expected to be positive. The impact of both of these omitted variables is that the model's estimate for density is likely upwardly biased. As with pctmin80, the model would again overestimate the impact of density on crime rate.

Our ability to interpret the variable polpc in our dataset is also compromised by omitted variable bias. While we understand the idea that increased police presence should increase the certainty of punishment (more likely to be detected and more likely to be caught) *ceteris paribus*, in our current dataset, we do not have the ability to use polpc in this way. We are unable to observe the counterfactual of the same location with the same characteristics at the same point in time having more or less police. Rather, the variable in our dataset is the current level of police as a percent of the population. Given that we expect local governments to respond to increased crime by highering more police, our model is more likely to reflect that higher crime rate locations also have higher police concentrations. Given an alternate work environment where we could retrieve more data, we might think about attempting to compensate for this by locating police concentration and crime rate statistics for previous years, then using them to create variables for the percentage point change in police concentration, which we could use to explain a newly created variable for the percentage point change in crime rate for a given location. However, in their current single point in time forms, our model is likely to estimate the relationship between police percentage and crime rate as positive, thus providing a misleading estimate for the relationship we would actually like to observe.

Finally, our dataset contains several variables with nominal wages for certain industries. Including these in our model is likely to be somewhat misleading, producing biased estimators because these measures are not adjusted for cost of living. Said in other terms, each of the nominal wage indicators is likely positively correlated with our desired explanatory variable - real wages. Conceptually, we expect the relationship between real wages and crime rate to be negative, while the relationship between real wages and nominal wages is positive. As such our model's estimator for wages is likely to understate the impact of wages on crime rate. As such, these nominal wage variables are an imperfect proxy for the desired variable real wages

Conclusion

We examined several models of crime rate and found a directionally consistent, statistically significant negative relationship for the probability of arrest and the probability of conviction on crime rate. As such, policies adopted should focus on increasing the certainty of punishment for committing crimes. One such policy could focus on improving information flow from local communities to police and judicial officials. A good model to build off of is community policing, where police focus on developing ties to the local community to build trust and thereby promote flow of needed information.

That said, our ability to draw policy prescriptions from our models is limited due to notable omitted variable bias, which leads our model's estimators to be biased. These omitted variable biases are not possible to overcome while limited to the current data collection process. Should more work requiring causal inference be desired on these relationships in the future, we would seek input into the data collecting process in order to correct for some of our omitted variable biases.

For future analyses, the availability of poverty rate, number of years of education and percentage of convicts, and the availability of these data as a regularly collected time series would aid in removing the above biases from the analysis and allow for more concrete policy recommendations.