

Statistical Methods for Discrete Response, Time Series, and Panel Data (W271): Group Lab 3

U.S. traffic fatalities: 1980-2004

In this lab, you are asked to answer the question “**Do changes in traffic laws affect traffic fatalities?**” To do so, you will conduct the tasks specified below using the data set *driving.Rdata*, which includes 25 years of data that cover changes in various state drunk driving, seat belt, and speed limit laws.

Specifically, this data set contains data for the 48 continental U.S. states from 1980 through 2004. Various driving laws are indicated in the data set, such as the alcohol level at which drivers are considered legally intoxicated. There are also indicators for “per se” laws—where licenses can be revoked without a trial—and seat belt laws. A few economics and demographic variables are also included. The description of each of the variables in the dataset is come with the dataste.

```
library(foreign)
library(gplots)
library(ggplot2)
library(dplyr)
library(corrplot)
library(lattice)
library(plm)
library(viridis)
library(tsibble)
library(forecast)
#library(tidyverse)
library(gridExtra)
```

Exercises:

1. (30%) Load the data. Provide a description of the basic structure of the dataset, as we have done throughout the semester. Conduct a very thorough EDA, which should include both graphical and tabular techniques, on the dataset, including both the dependent variable *totfatrte* and the potential explanatory variables. You need to write a detailed narrative of your observations of your EDA. *Reminder: giving an “output dump” (i.e. providing a bunch of graphs and tables without description and hoping your audience will interpret them) will receive a zero in this exercise.*

```
#load data
load('driving.RData');driving.df <- data

#check rows and columns
dim(driving.df)
```

```
## [1] 1200 56
```

```
#check for gaps in panel
table(data$state)
```

```
##
## 1 3 4 5 6 7 8 10 11 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
## 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25
## 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
## 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25
```

```
table(data$year)
```

```
##
## 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
## 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
## 1996 1997 1998 1999 2000 2001 2002 2003 2004
## 48 48 48 48 48 48 48 48 48
```

The Dataset is panel data, that contains observations about different US states from year 1980 to 2004. There are 1200 observations in total, with 56 columns . The data has 25 observations each, one per year, from 48 continental states except state ids 2,9 and 12 (which we will later identify as Alaska, District Of Columbia and Hawaii that are not part of continental US States). All variables are observed for all states and over all time periods, hence the panel is balanced. Important variables are:

Panel Index

year: 1980 through 2004

state: numeric id of 48 continental states, ordered alphabetically, ranging from 1 to 51.

Dependent Variable

totfatrte: total fatalities per 100,000 population by year by state. Values range from 6.2 to 53.32

Speed Limit Variables

sl55: 1 if speed limit == 55 for the whole year. If the law was in effect only during part of the year, it is set to fractions of 12. This applies for all indicator variables.

sl65: 1 if speed limit == 65

sl70: 1 if speed limit == 70

sl75: 1 if speed limit == 75

slnone: 1 if no speed limit

sl70plus: sl70 + sl75 + slnone

Drinking Laws

minage: minimum drinking age, ranges from 18 years to 21 years.

zerotol: 1 if zero tolerance law was in effect, and 0 if not. If the law was in effect only during part of the year, it is set to fractions of 12.

bac10: 1 if blood alcohol limit .10 in effect, and 0 if not. Fractions used to denote partial years, as above.

bac08: 1 if blood alcohol limit .08 in effect, and 0 if not. Fractions used to denote partial years, as above.

per se: 1 if administrative license revocation (per se law) in effect, and 0 if not. Fractions used to denote partial years, as above.

Seatbelt Laws

sbprim: 1 if primary seatbelt law was in effect, 0 otherwise. There are no fractions in this variable. sbsecon: 1 if secondary seatbelt law was in effect, 0 otherwise. There are no fractions in this variable.

seatbelt: 0 if none, =1 if primary, =2 if secondary. There are no fractions in this variable.

Age iimit Laws

gdl: 1 if graduated drivers license law was in effect, and 0 if not. Fractions used to denote partial years, similar to speed limit.

Demographic variables

statepop: state population by year by state. Values range from 453,401 to 35,894,000

vehicmiles: vehicle miles traveled, billions. Values range from 3.7027 to 329.6

unem: unemployment rate, percent. Values range from 3.2 to 18

perc14_24: percent population aged 14 through 24. Values range from 11.7 to 20.3

Year Dummy

Dummy variables *d80* - *d04* indicating years

It will be useful to add more context around the state information, in addition to the state id. Since we know the id is alphabetical, we get the alphabetical list of US states with two letter abbreviated code, and match with the state variable in fatality data.

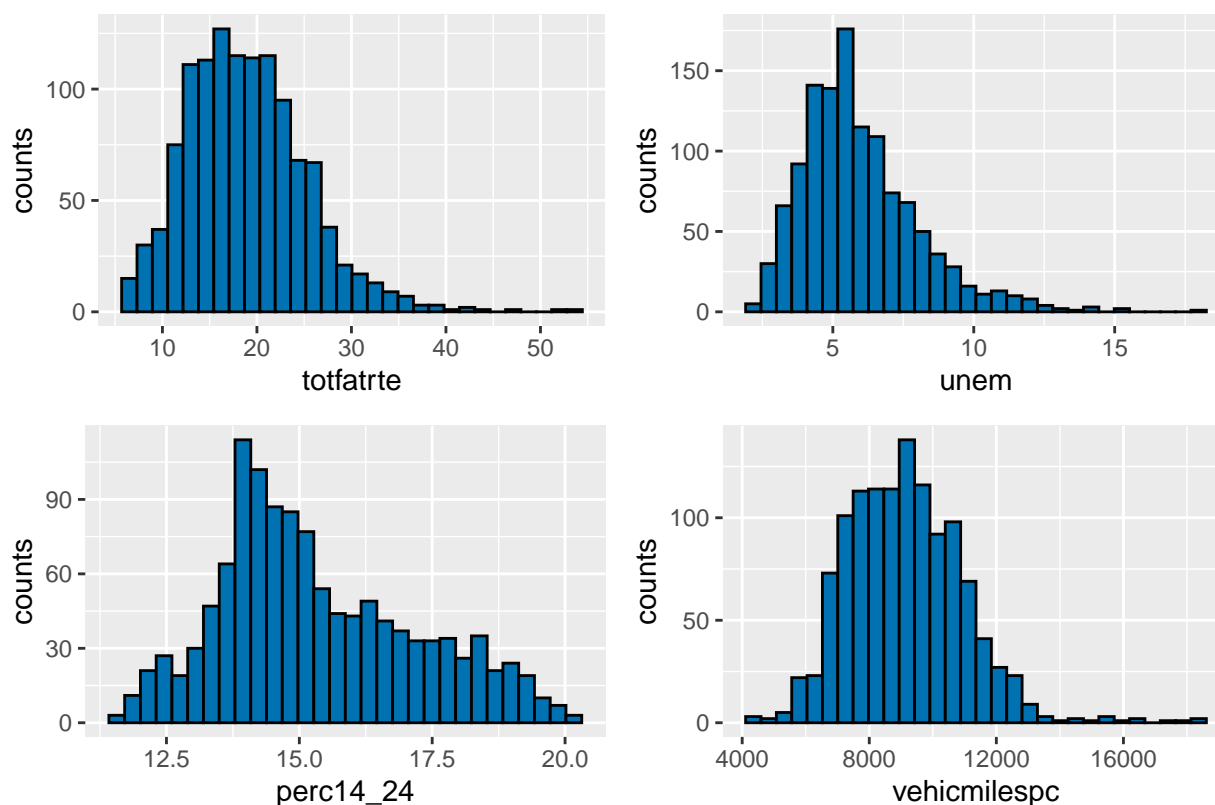
```
#get state name
```

```
us.states = read.csv("usstates.csv", header = TRUE, sep = ",", dec = ".")  
data.with.name <- merge(data, us.states, by=c("state","state"))
```

To start EDA, we perform univariate analyses of important variables fatality rate, unemployment, % of younger population, and vehicmilespc to examine the distribution.

```
totfatrte.hist <- ggplot(driving.df, aes(x = totfatrte)) + geom_histogram(bins = 30, fill="#0072B2", col="#0072B2")  
unem.hist <- ggplot(driving.df, aes(x = unem)) + geom_histogram(bins = 30, fill="#0072B2", col="#0072B2")  
perc14_24.hist <- ggplot(driving.df, aes(x = perc14_24)) + geom_histogram(bins = 30, fill="#0072B2", col="#0072B2")  
vehicmilespc.hist <- ggplot(driving.df, aes(x = vehicmilespc)) + geom_histogram(bins = 30, fill="#0072B2", col="#0072B2")  
grid.arrange( totfatrte.hist, unem.hist, perc14_24.hist, vehicmilespc.hist, ncol = 2, nrow = 2)
```

Univariate Analysis of key Variables



The distribution looks approximately normal with some tail for *totfatrte*, *unem*, and *vehicmilespc*. It looks normal with higher slope at the top and lower slope at the bottom for *perc14 – 24*.

Next, we examine the bivariate relationship between some of the important explanatory variables and fatality rate.

```
totfatrte.unem.scatter <- ggplot(driving.df, aes(unem, totfatrte)) +
  geom_point() +
  geom_smooth(method = "lm", formula = y ~ x, se = FALSE) + theme(axis.text.x = element_text(alignment = "right",
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
totfatrte.perc14_24.scatter <- ggplot(driving.df, aes(perc14_24, totfatrte)) +
  geom_point() +
  geom_smooth(method = "lm", formula = y ~ x, se = FALSE) + theme(axis.text.x = element_text(alignment = "right",
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
totfatrte.vehicmilespc.scatter <- ggplot(driving.df, aes(vehicmilespc, totfatrte)) +
  geom_point() +
  geom_smooth(method = "lm", formula = y ~ x, se = FALSE) + theme(axis.text.x = element_text(alignment = "right",
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")

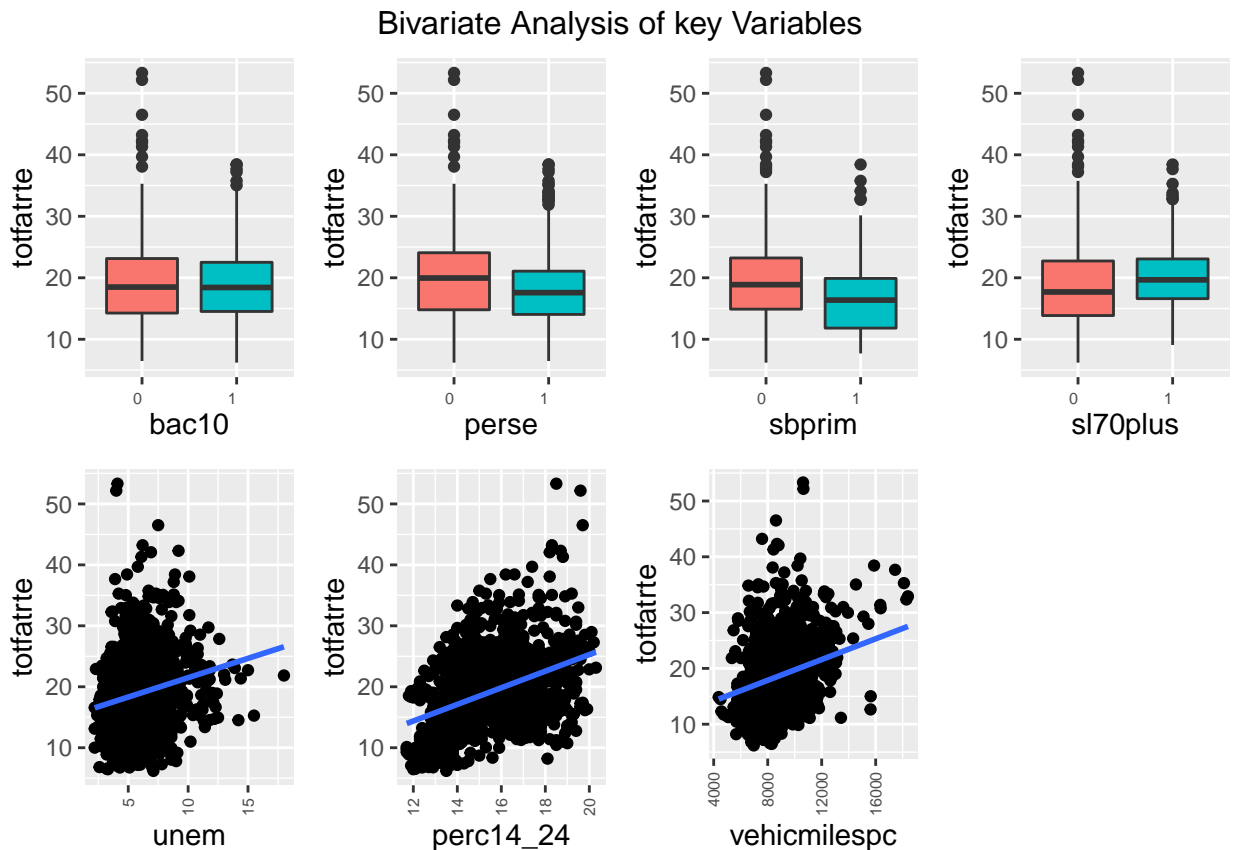
driving.df.mutate <- driving.df %>%
  mutate(bac08 = ifelse(bac08 > 0.5, 1, 0)) %>%
  mutate(bac10 = ifelse(bac10 > 0.5, 1, 0)) %>%
  mutate(perse = ifelse(perse > 0.5, 1, 0)) %>%
```

```

mutate(sl70plus = ifelse(sl70plus > 0.5,1,0)) %>%
mutate(gdl = ifelse(gdl > 0.5,1,0))

totfatrte.bac10.box <- ggplot(driving.df.mutate, aes(x = factor(bac10), y = totfatrte)) +
  geom_boxplot(aes(fill = factor(bac10))) + xlab("bac10") + theme(axis.text.x = element_text(al
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
totfatrte.perse.box <- ggplot(driving.df.mutate, aes(x = factor(perse), y = totfatrte)) +
  geom_boxplot(aes(fill = factor(perse))) + xlab("perse") + theme(axis.text.x = element_text(al
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
totfatrte.sbprim.box <- ggplot(driving.df.mutate, aes(x = factor(sbprim), y = totfatrte)) +
  geom_boxplot(aes(fill = factor(sbprim)))+ xlab("sbprim") + theme(axis.text.x = element_text(al
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
totfatrte.sl70plus.box <- ggplot(driving.df.mutate, aes(x = factor(sl70plus), y = totfatrte)) +
  geom_boxplot(aes(fill = factor(sl70plus)))+ xlab("sl70plus") + theme(axis.text.x = element_t
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
grid.arrange( totfatrte.bac10.box, totfatrte.perse.box, totfatrte.sbprim.box, totfatrte.sl70pl
  ncol = 4, nrow = 2,
  top="Bivariate Analysis of key Variables")

```



We see that blood alcohol limit 10 have a muted effect while per se , primary seatbelt have reducing effect on the fatality rate. Also note the higher fatality rate on the states with speed limit 70 and above or none. We also see a slight positive correlation between fatality rate and variables *unem*, *perc14_24* and *vehicmilespc*.

Then, to examine both the overall fatality pattern and individual fixed effect of US States across time, we'll analyze the aggregate of traffic laws in US across time and across states.

Below we analyze the fatality rate change by year and overall change by state .

```
#fatality change by year
traffic.yearly.aggr <- data %>%   group_by(year) %>%   summarise_at(vars(totfatrte, nghtfatrte,

#fatality change by state
traffic.state.perc.aggr <- data.with.name %>%
  group_by(shortname) %>%
  summarise_at(vars(totfatrte,nghtfatrte,wkndfatrte), funs(mean))

year.plot <- ggplot(traffic.yearly.aggr, aes(year, totfatrte)) +
  geom_bar(aes(fill = factor(year)), position = "dodge", stat="identity") + ggtitle("Fatalities
  #geom_abline(intercept, slope, linetype, color, size) +
  geom_smooth(method = "lm", formula = y ~ x, se = FALSE) + geom_text(data = traffic.yearly.aggr,
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")

state.plot <- ggplot(traffic.state.perc.aggr, aes(shortname, totfatrte)) +
  geom_bar(aes(fill = factor(shortname)), position = "dodge", stat="identity") + ggtitle("Fatal
  scale_fill_hue(c=45,l=80) + theme(plot.title = element_text(size = 8, hjust = 0.5)) +
  theme(axis.text.x = element_text(angle = 90, size = 6, vjust = 0.5, hjust=1)) +
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none") +

conditional_plot = function(data, plotvar, condvar, title) {
  g <- ggplot(data, aes(as.factor(condvar), plotvar, color = as.factor(condvar)))
  g + geom_boxplot() + geom_jitter(width = 0.2) + ggtitle(title) + theme(axis.text.x = element
}

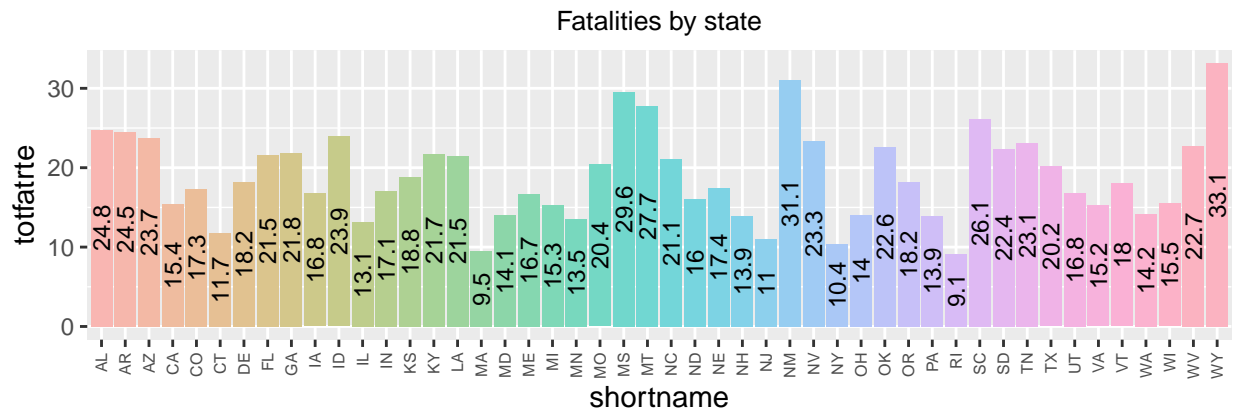
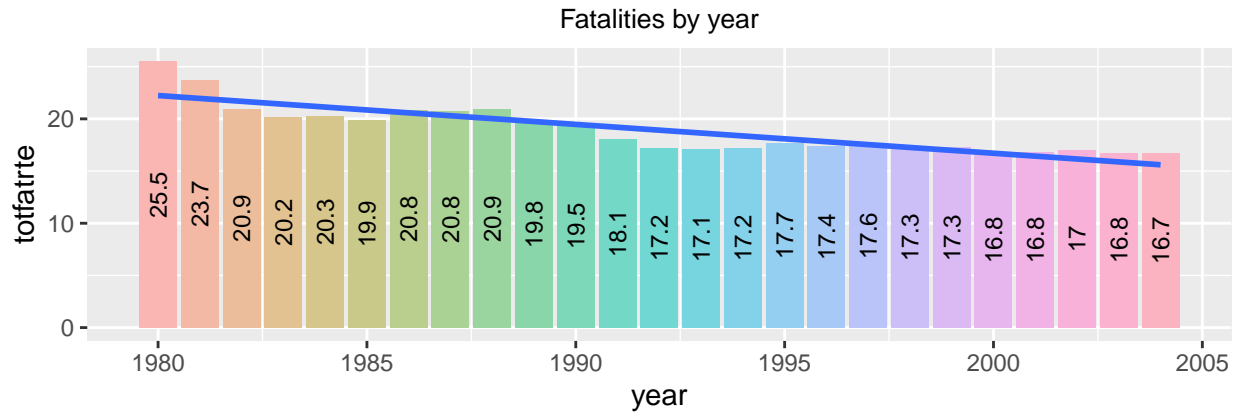
# yIndex by year (Heterogeineity across year)
cplot.1 <- conditional_plot(data.with.name, data.with.name$totfatrte, data.with.name$year, "Tot

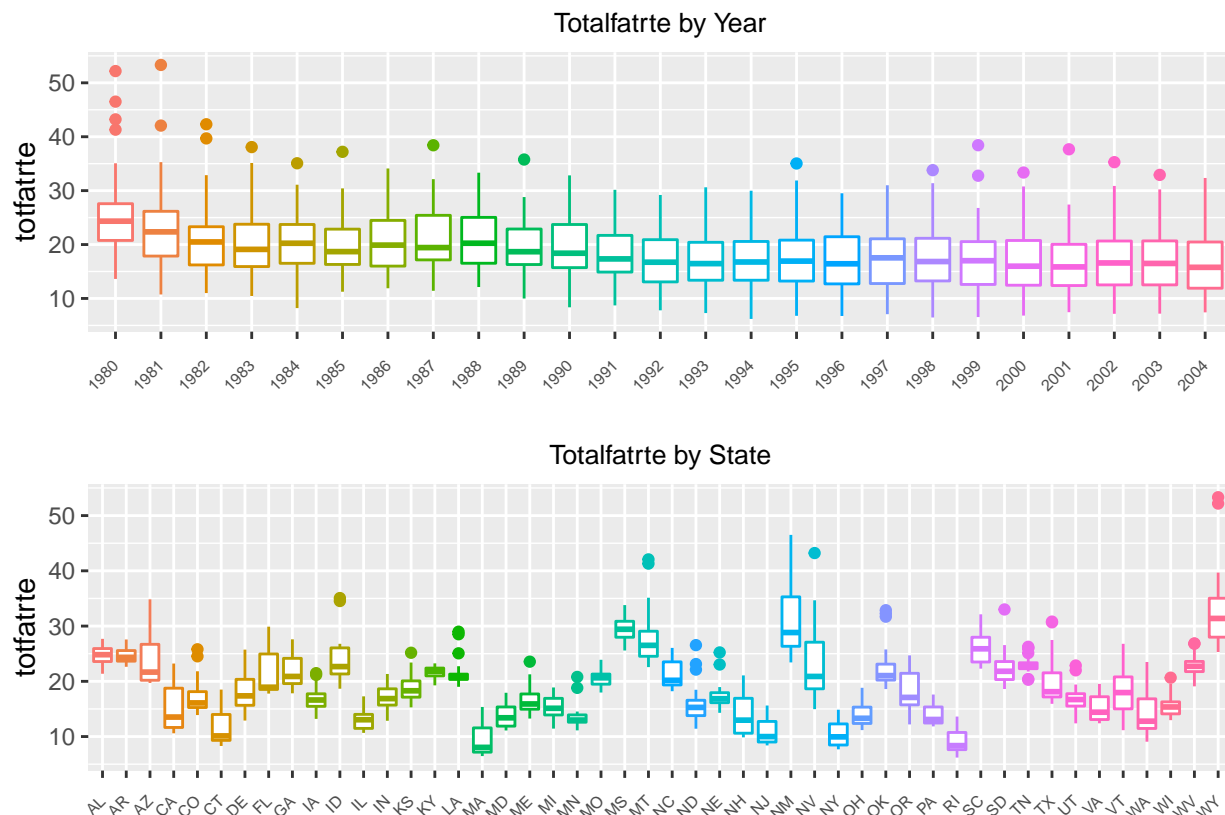
# yIndex by country (Heterogeineity across countries)
cplot.2 <- conditional_plot(data.with.name, data.with.name$totfatrte, data.with.name$name, "Tot

cplot.1 <- data.with.name %>%
  ggplot(aes(x = factor(year), y = totfatrte,color = as.factor(year))) +
  geom_boxplot() + ggtitle("Totalfatrte by Year") + theme(axis.text.x = element_text(angle = 4

cplot.2 <- data.with.name %>%
  ggplot(aes(x = factor(shortname), y = totfatrte,color = as.factor(name))) +
  geom_boxplot() + ggtitle("Totalfatrte by State") + theme(axis.text.x = element_text(angle = 4

grid.arrange(year.plot, state.plot, nrow = 2, ncol = 1);grid.arrange(cplot.1, cplot.2, nrow =
```



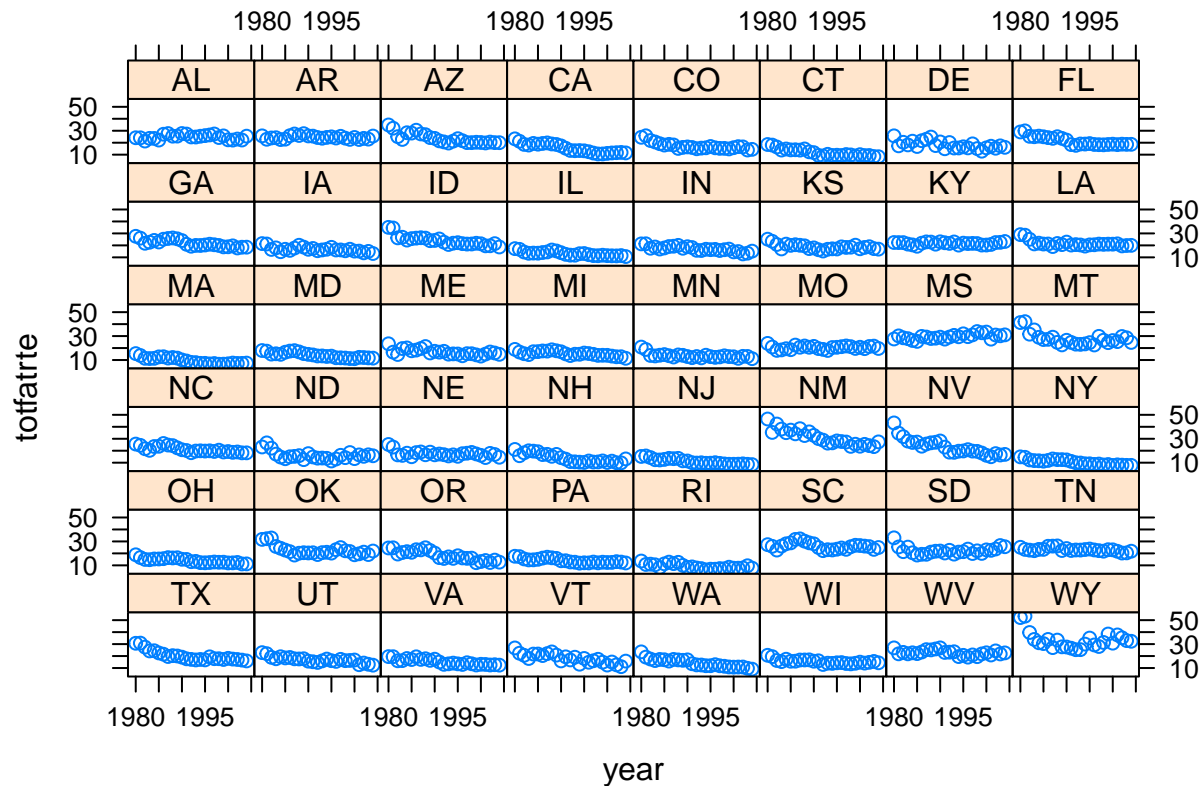


We can see that the fatality rate is largely decreasing from 1980 to 2004. The fatality rates range from ~9 to ~34. Wyoming, New Mexico, Mississippi, Montana, and South Carolina are the states with highest fatality rates while New York, New Jersey and Rhode Island are the states with lowest fatality rates. The pattern shows that the states with more rural roads have higher fatality rates - the geography and road conditions are thus important omitted variables in the dataset. In addition, the fatality split by cause (drunk driving, speeding) by state by year could be an important predictor. Another omitted variable could be the a measure of compliance to the traffic laws - speed limit, seat belt - at the state level.

The boxplots graph shows there is heterogeneity across states, but very little heterogeneity across years.

Next we analyze how the fatality rates varied over the years, in individual states.

```
xyplot(totfatrtte ~ year | shortname, data=data.with.name, as.table=T)
```

The above xyplot confirms that most of the States shows an overall decrease in the traffic fatality rate, except states like *Mississippi*. We can see that New Mexico(NM) and Wyoming(WY) has high variance in the data, with NM consistently reducing the traffic fatality rate over years. However, WY reduced the fatality rate from 80's to mid 90's and had a gradual increase after. One interesting point is that the traffic fatality rate is not dependent on the state area or population - the top 2 states with size and population, Texas and California, are not among the top states in traffic fatality rate.

Below, we explore how the traffic laws over the years across states, and whether they show a correlation with fatality rate. We first plot the fatality rate over years, and then plot the count of states that adopt the traffic laws, grouped by year and specific law after. We hypothesize that the fatality rate is influenced the most by drinking and overspeeding and proceed to examine the applicable laws.

```
# summarize the number of states adopting specific traffic laws
data <- data %>% mutate( sball = case_when(sbprim + sbsecon >= 0.5 ~ 1, TRUE ~ 0 ))
bac.df <- data %>% group_by(year) %>%
summarise(bac10 = sum(bac10), bac08 = sum(bac08), bac.all = sum(bac08 + bac10), perse = sum(perse))

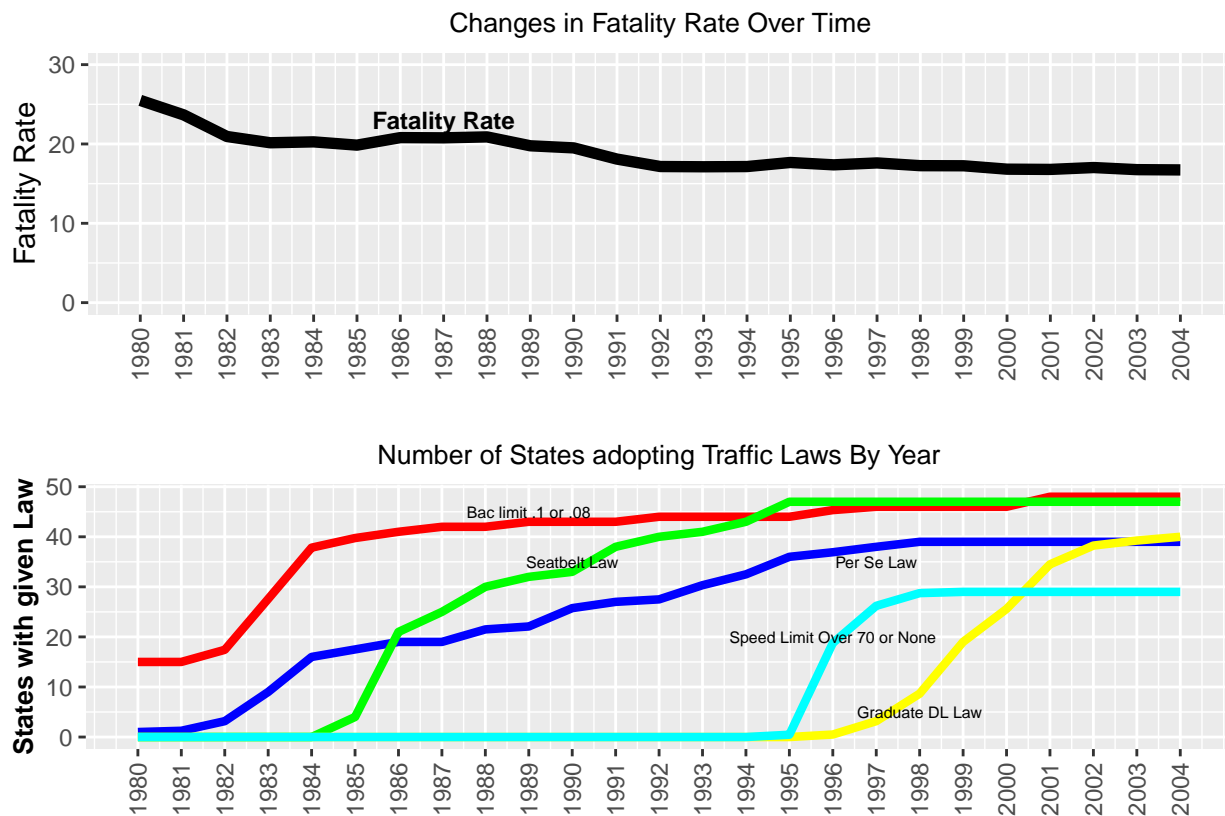
bac.plot.f <- ggplot(bac.df, aes(x = year)) +
  geom_line(aes(y=totfatrate, color='totfatrate'), size = 2, group = 1) + ylim(0,30)+
  scale_x_continuous(breaks = seq(min(bac.df$year), max(bac.df$year), 1)) + theme(axis.text.x = "none") +
  annotate("text", x = 1987, y = 23, label = "Fatality Rate", size = 3, fontface = "bold") +
  theme(plot.title = element_text(size = 10, hjust = 0.5)) + theme(legend.position = "none")
```

```

bac.plot <- ggplot(bac.df, aes(x = year)) +
  geom_line(aes(y = bac.all, color='bac.all'), size = 1.5, group = 1) + geom_line(aes(y=perse,
  geom_line(aes(y=sball, color='sball'), size = 1.5, group = 1) + geom_line(aes(y=gdl, color='gdl',
    values = c( bac.all="red", perse="blue", sball="green", gdl = "yellow", sl70plus = "cyan"
x = "",size = 2) +
  annotate("text", x = 1998, y = 5, label = "Graduate DL Law", size = 2) + annotate("text", x =
  annotate("text", x = 1990, y = 35, label = "Seatbelt Law", size = 2) + annotate("text", x =
  annotate("text", x = 1989, y = 45, label = "Bac limit .1 or .08", size = 2) + theme(plot.titl

grid.arrange(bac.plot.f, bac.plot, nrow = 2, ncol = 1)

```



Over the years, more states are adopting stricter alcohol limits. In 2004, over 45 states have a bac limit of 0.08 or 0.1, compared to ~10 in 1980. Similarly, ~40 states have adopted the Per Se law and Graduate DL law in 2004 compared to 0 states in 1980. We see a similar trend in seatbelt adoption as well. This is consistent with the decrease in fatality rates over time that observed before. Regarding speed limit, states had lower speed limit in 1980 - however, the speed limits were more relaxed in the later years as can be seen by the increase in the number of states with speed limit 70 or above, as seen in the above graph.

Lets proceed to examine the individual state behavior in the panel. First, we'll examine how the traffic fatality rates changed over years for the first 3 States from the top and bottom of the fatality rate.

```
#fatality change by state
```

```
traffic.state.aggr <- data.with.name %>% group_by(shortname) %>% summarise_at(vars(totfat,
top.3.fatalities <- traffic.state.perc.aggr %>% filter(rank(desc(totfatrte))<=3) %>% arrange(
bottom.3.fatalities <- traffic.state.perc.aggr %>% filter(rank((totfatrte))<=3) %>% arrange((t
cbind(top.3.fatalities[,1:2],bottom.3.fatalities[,1:2])
```

```
## shortname totfatrte shortname totfatrte
## 1      WY    33.1408      RI    9.0900
## 2      NM    31.0608      MA    9.4512
## 3      MS    29.5548      NY   10.4380
```

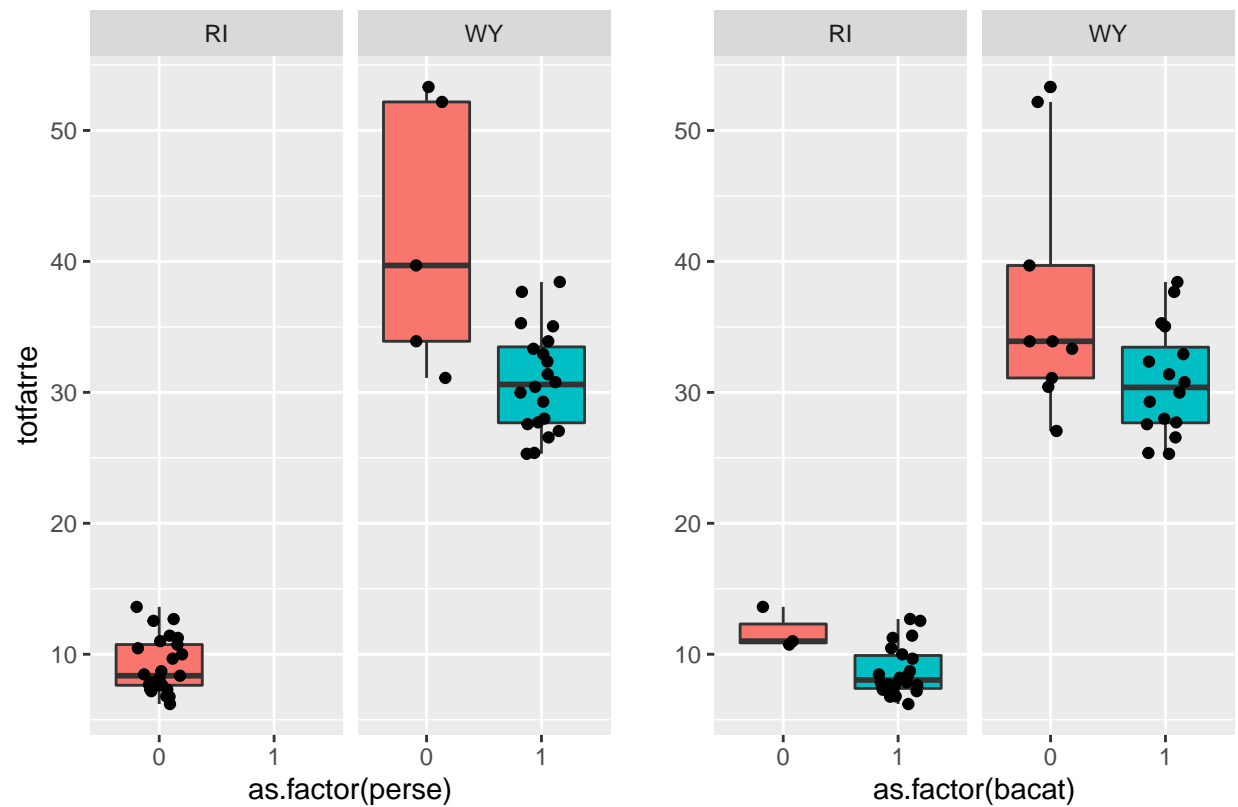
```
data.top.filtered <- data.with.name %>% filter(shortname %in% c("WY"))
data.bottom.filtered <- data.with.name %>% filter(shortname %in% c("RI"))

data.merged <- union(data.top.filtered,data.bottom.filtered)
```

The top 3 are Wyoming, New Mexico and Mississippi. The bottom 3 are Rhode Island, New York and Massachussets. To put this in context, in 2004, in Wyoming, the probability of dying in a motor vehicle accident is nearly 5 times as high as in Rhode Island, the state with the lowest death rate. Below, we see the average fatality rate for each state across years.

```
df.transformed <- data.merged %>% mutate( perse = case_when(perse >= 0.5 ~ 1,TRUE ~ 0),bacat
g.1 <- ggplot(df.transformed, aes(as.factor(perse), totfatrte)) + geom_boxplot(aes(fill = facto
g.2 <- ggplot(df.transformed, aes(as.factor(bacat), totfatrte)) + geom_boxplot(aes(fill = facto
grid.arrange(g.1, g.2, nrow = 1, ncol = 2)
```

r Se Law and Fatality Rate Change for Top and Botto Bac and Fatality Rate Change for Top and Bottom S



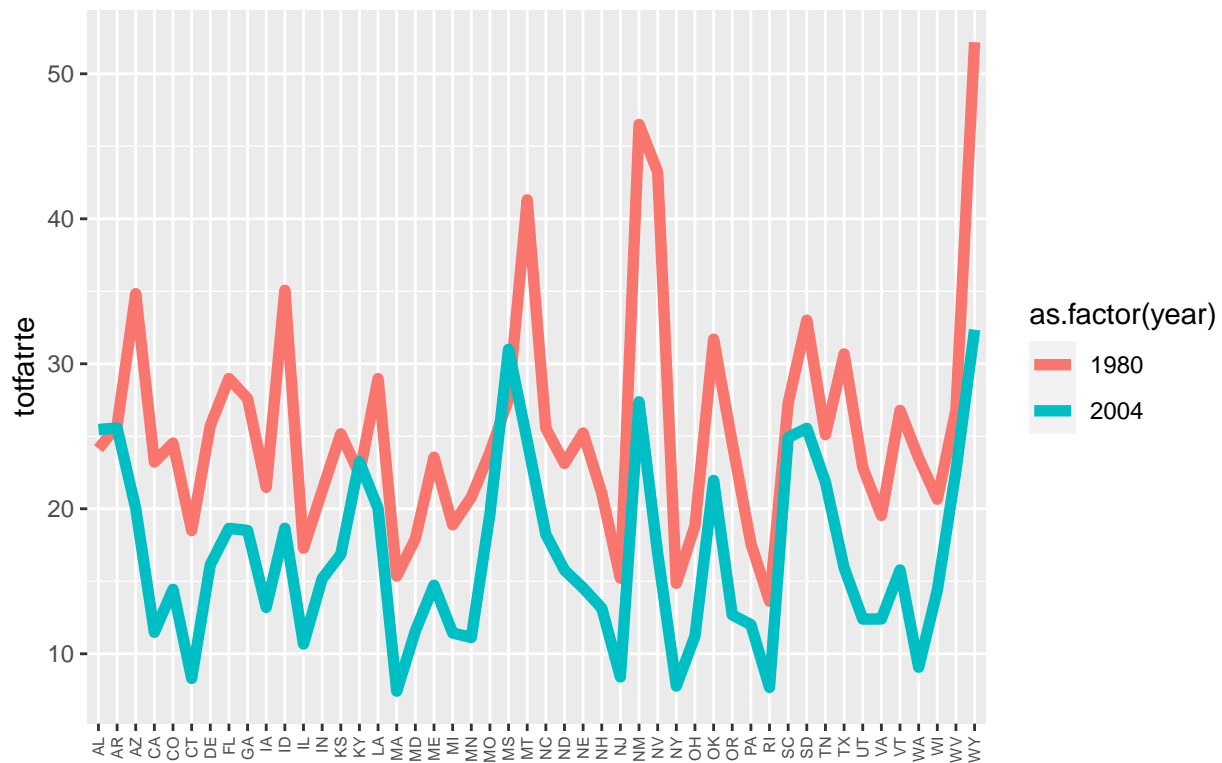
```
g.1 <- ggplot(df.transformed, aes(as.factor(sball), totfatrte)) + geom_boxplot(aes(fill = factor(sball)))
g.2 <- ggplot(df.transformed, aes(as.factor(gdl), totfatrte)) + geom_boxplot(aes(fill = factor(gdl)))
grid.arrange(g.1, g.2, nrow = 1, ncol = 2)
```



```
df.80.04 <- data.with.name %>% filter(year %in% c('1980', '2004')) %>% dplyr::select(year, shortname, totfatrate)

ggplot(df.80.04, aes(shortname, totfatrate, group = year, colour = as.factor(year))) +
  geom_line(aes(y=totfatrate), size = 2) + ggtitle("Growth Curve by Year") + theme(axis.text.x =
```

Growth Curve by Year



We can see that in the years WY has lower fatality rate in the years they adopted the Per Se, Bac, and Seatbelt laws. They are yet to adopt the gdl law (perhaps they should!). RI shows a similar pattern, eventhough the fatality rate was already low.

Thus both the overall and state level EDA indicates that there is a reduction in fatality rate that is consistent with traffic laws adoption.

2. (15%) How is the our dependent variable of interest *totfatrte* defined? What is the average of this variable in each of the years in the time period covered in this dataset? Estimate a linear regression model of *totfatrte* on a set of dummy variables for the years 1981 through 2004. What does this model explain? Describe what you find in this model. Did driving become safer over this period? Please provide a detailed explanation.

The dependent variable *totfatrte* is defined as the total fatalities per 100,000 population. The average of this *totfatrte* variable per year is computed below.

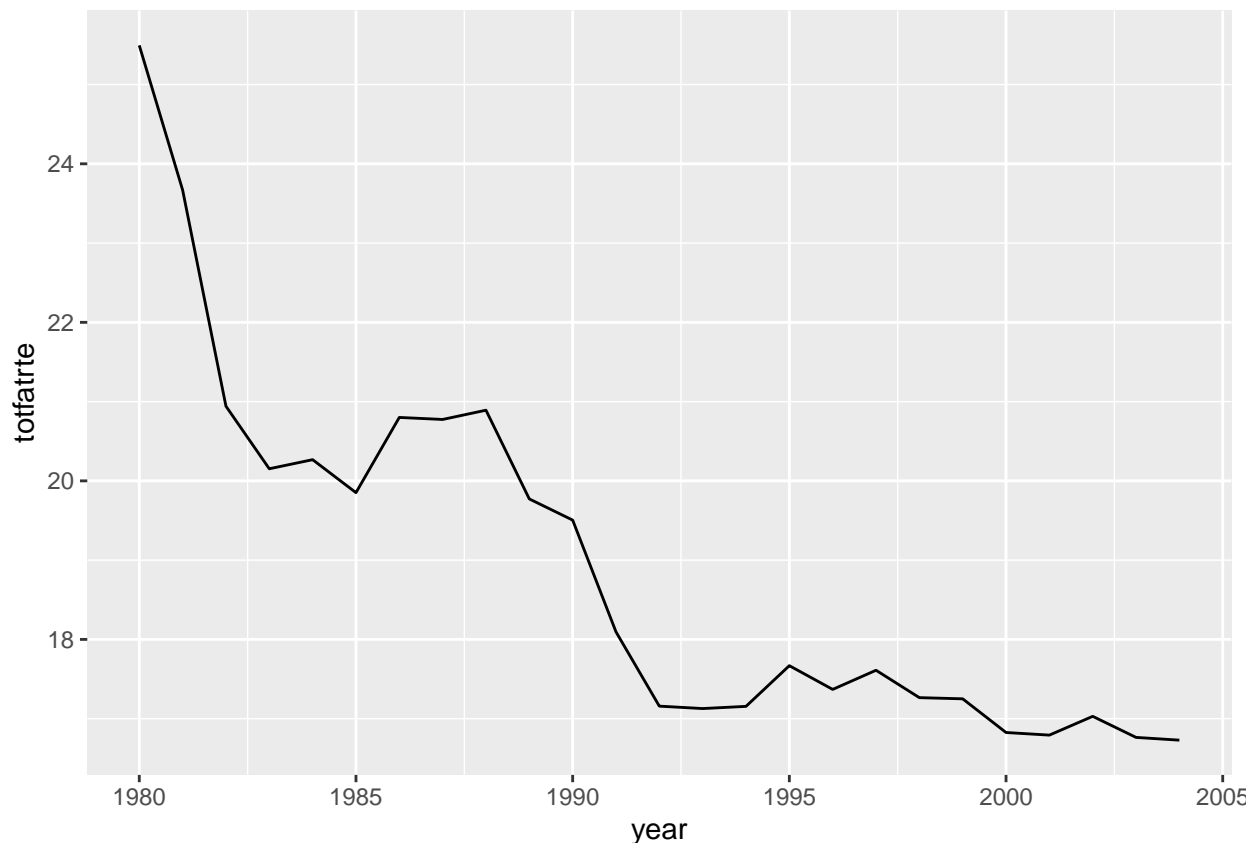
```
yearlyavg <- aggregate(totfatrte~year, driving.df, mean)

# Printing the yearly average for total fatality rate
yearlyavg
```

```
##   year totfatrte
## 1  1980  25.49458
```

```
## 2 1981 23.67021
## 3 1982 20.94250
## 4 1983 20.15292
## 5 1984 20.26750
## 6 1985 19.85146
## 7 1986 20.80042
## 8 1987 20.77479
## 9 1988 20.89167
## 10 1989 19.77229
## 11 1990 19.50521
## 12 1991 18.09479
## 13 1992 17.15792
## 14 1993 17.12771
## 15 1994 17.15521
## 16 1995 17.66854
## 17 1996 17.36938
## 18 1997 17.61062
## 19 1998 17.26542
## 20 1999 17.25042
## 21 2000 16.82562
## 22 2001 16.79271
## 23 2002 17.02958
## 24 2003 16.76354
## 25 2004 16.72896
```

```
# Plotting the yearly total fatality rate
ggplot(yearlyavg) +
  geom_line(
    mapping = aes(x = year, y = totfatrte)
  )
```



Let's estimating the linear regression for the dummy variables from 1981 to 2004 below. This model explains the impact of time on the total fatality rate. All the dummy variables to be highly statistically significant except for 1981. We see a downward trending total fatality rate increasing with time and it proves that the driving became safer over this period.

```
lm.fit1 <- lm(totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 +
              d90 + d91 + d92 + d93 + d94 + d95 + d96 + d97 + d98 + d99 +
              d00 + d01 + d02 + d03 + d04, data=driving.df)
summary(lm.fit1)
```

```
##
## Call:
## lm(formula = totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 +
##      d87 + d88 + d89 + d90 + d91 + d92 + d93 + d94 + d95 + d96 +
##      d97 + d98 + d99 + d00 + d01 + d02 + d03 + d04, data = driving.df)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -12.9302  -4.3468  -0.7305   3.7488  29.6498
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  25.4946     0.8671  29.401  < 2e-16 ***
```



```
## d81          -1.8244      1.2263  -1.488  0.137094
## d82          -4.5521      1.2263  -3.712  0.000215 ***
## d83          -5.3417      1.2263  -4.356  1.44e-05 ***
## d84          -5.2271      1.2263  -4.263  2.18e-05 ***
## d85          -5.6431      1.2263  -4.602  4.64e-06 ***
## d86          -4.6942      1.2263  -3.828  0.000136 ***
## d87          -4.7198      1.2263  -3.849  0.000125 ***
## d88          -4.6029      1.2263  -3.754  0.000183 ***
## d89          -5.7223      1.2263  -4.666  3.42e-06 ***
## d90          -5.9894      1.2263  -4.884  1.18e-06 ***
## d91          -7.3998      1.2263  -6.034  2.14e-09 ***
## d92          -8.3367      1.2263  -6.798  1.68e-11 ***
## d93          -8.3669      1.2263  -6.823  1.43e-11 ***
## d94          -8.3394      1.2263  -6.800  1.66e-11 ***
## d95          -7.8260      1.2263  -6.382  2.51e-10 ***
## d96          -8.1252      1.2263  -6.626  5.25e-11 ***
## d97          -7.8840      1.2263  -6.429  1.86e-10 ***
## d98          -8.2292      1.2263  -6.711  3.01e-11 ***
## d99          -8.2442      1.2263  -6.723  2.77e-11 ***
## d00          -8.6690      1.2263  -7.069  2.67e-12 ***
## d01          -8.7019      1.2263  -7.096  2.21e-12 ***
## d02          -8.4650      1.2263  -6.903  8.32e-12 ***
## d03          -8.7310      1.2263  -7.120  1.88e-12 ***
## d04          -8.7656      1.2263  -7.148  1.54e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.008 on 1175 degrees of freedom
## Multiple R-squared:  0.1276, Adjusted R-squared:  0.1098
## F-statistic: 7.164 on 24 and 1175 DF,  p-value: < 2.2e-16
```

3. (15%) Expand your model in *Exercise 2* by adding variables *bac08*, *bac10*, *perse*, *sbprim*, *sbsecon*, *sl70plus*, *gdl*, *perc14_24*, *unem*, *vehicmilespc*, and perhaps *transformations of some or all of these variables*. Please explain carefully your rationale, which should be based on your EDA, behind any transformation you made. If no transformation is made, explain why transformation is not needed. How are the variables *bac8* and *bac10* defined? Interpret the coefficients on *bac8* and *bac10*. Do *per se laws* have a negative effect on the fatality rate? What about having a primary seat belt law? (Note that if a law was enacted sometime within a year the fraction of the year is recorded in place of the zero-one indicator.)

Is Transformation needed?

The variables *bac08*, *bac10*, *perse*, *sbprim*, *sbsecon*, *sl70plus*, *gdl* define the year in which the law has become effective. It ranges from 0-1 with decimals as the law could the change in the middle of the year. We don't want to transform this variable into binary as we might lose some important information about changes that happened in the middle of the year.

Variables like *perc14_24*, *unem*, *vehicmilespc* are already normalized and so no transformation is necessary.

Definition of bac08 and bac10 variables and their interpretation

bac10 is defined as the blood alcohol limit of .10 and *bac08* is defined as the blood alcohol limit of .08. Both the variables *bac08* and *bac10* have the negative coefficients of -2.498 and -1.418 respectively. They are statistically significant and it implies that they have a strong negative correlation to the total fatality rate. If we come up with a stricter law and decrease the blood alcohol limit to .10 then the fatalities rate decreases more.

Effect of perse law on fatality rate

Yes. *perse* variable has a statistically significant negative correlation with the total fatality rate. The coefficient value is -0.6201 which implies a small change in the rate.

Effect of primary seat belt law on fatality rate

We are not able to find any statistically significant effect of the primary seat belt law on the fatality rate based on the regression coefficients shown below.

```
lm.fit2 <- lm(totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 + d90 +
              d91 + d92 + d93 + d94 + d95 + d96 + d97 + d98 + d99 + d00 + d01 + d02 +
              d03 + d04 + bac08 + bac10 + perse + sbprim + sbsecon + sl70plus + gdl +
              perc14_24 + unem + vehicmiles, data=driving.df)
summary(lm.fit2)
```

```
##
## Call:
## lm(formula = totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 +
##      d87 + d88 + d89 + d90 + d91 + d92 + d93 + d94 + d95 + d96 +
##      d97 + d98 + d99 + d00 + d01 + d02 + d03 + d04 + bac08 + bac10 +
##      perse + sbprim + sbsecon + sl70plus + gdl + perc14_24 + unem +
##      vehicmiles, data = driving.df)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -14.9160  -2.7384  -0.2778   2.2859  21.4203
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -2.716e+00  2.476e+00  -1.097  0.272847
## d81          -2.175e+00  8.276e-01  -2.629  0.008686 **
## d82          -6.596e+00  8.534e-01  -7.729  2.33e-14 ***
## d83          -7.397e+00  8.690e-01  -8.512  < 2e-16 ***
## d84          -5.850e+00  8.763e-01  -6.676  3.79e-11 ***
## d85          -6.483e+00  8.948e-01  -7.245  7.82e-13 ***
## d86          -5.853e+00  9.307e-01  -6.289  4.52e-10 ***
## d87          -6.367e+00  9.670e-01  -6.585  6.87e-11 ***
## d88          -6.592e+00  1.014e+00  -6.502  1.17e-10 ***
## d89          -8.071e+00  1.053e+00  -7.667  3.68e-14 ***
## d90          -8.959e+00  1.077e+00  -8.319  2.46e-16 ***
## d91          -1.107e+01  1.101e+00 -10.052  < 2e-16 ***
```

```
## d92          -1.288e+01  1.123e+00 -11.473 < 2e-16 ***
## d93          -1.273e+01  1.136e+00 -11.204 < 2e-16 ***
## d94          -1.236e+01  1.157e+00 -10.685 < 2e-16 ***
## d95          -1.195e+01  1.184e+00 -10.098 < 2e-16 ***
## d96          -1.388e+01  1.223e+00 -11.343 < 2e-16 ***
## d97          -1.426e+01  1.250e+00 -11.408 < 2e-16 ***
## d98          -1.504e+01  1.265e+00 -11.886 < 2e-16 ***
## d99          -1.509e+01  1.284e+00 -11.750 < 2e-16 ***
## d00          -1.544e+01  1.305e+00 -11.831 < 2e-16 ***
## d01          -1.618e+01  1.334e+00 -12.131 < 2e-16 ***
## d02          -1.672e+01  1.348e+00 -12.406 < 2e-16 ***
## d03          -1.702e+01  1.359e+00 -12.521 < 2e-16 ***
## d04          -1.671e+01  1.387e+00 -12.049 < 2e-16 ***
## bac08        -2.498e+00  5.375e-01  -4.648 3.73e-06 ***
## bac10        -1.418e+00  3.963e-01  -3.577 0.000362 ***
## perse        -6.201e-01  2.982e-01  -2.079 0.037791 *
## sbprim       -7.533e-02  4.908e-01  -0.153 0.878032
## sbsecon       6.728e-02  4.293e-01   0.157 0.875492
## sl70plus      3.348e+00  4.452e-01   7.521 1.09e-13 ***
## gdl          -4.269e-01  5.269e-01  -0.810 0.417978
## perc14_24     1.416e-01  1.227e-01   1.154 0.248675
## unem          7.571e-01  7.791e-02   9.718 < 2e-16 ***
## vehicmilespc  2.925e-03  9.497e-05  30.804 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.046 on 1165 degrees of freedom
## Multiple R-squared:  0.6078, Adjusted R-squared:  0.5963
## F-statistic:  53.1 on 34 and 1165 DF,  p-value: < 2.2e-16
```

4. (15%) Reestimate the model from *Exercise 3* using a fixed effects (at the state level) model. How do the coefficients on *bac08*, *bac10*, *perse*, and *sbprim* compare with the pooled OLS estimates? Which set of estimates do you think is more reliable? What assumptions are needed in each of these models? Are these assumptions reasonable in the current context?

```
# Creating a panel with 'State' and 'Year' variables.
pnldata <- pdata.frame(driving.df, c("state", "year"))

model.fe <- plm(totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 + d90 +
  d91 + d92 + d93 + d94 + d95 + d96 + d97 + d98 + d99 + d00 + d01 + d02 +
  d03 + d04 + bac08 + bac10 + perse + sbprim + sbsecon + sl70plus + gdl +
  perc14_24 + unem + vehicmilespc, data=pnldata, model = "within")
summary(model.fe)

## Oneway (individual) effect Within Model
##
## Call:
```

```
## plm(formula = totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 +
##       d87 + d88 + d89 + d90 + d91 + d92 + d93 + d94 + d95 + d96 +
##       d97 + d98 + d99 + d00 + d01 + d02 + d03 + d04 + bac08 + bac10 +
##       perse + sbprim + sbsecon + sl70plus + gdl + perc14_24 + unem +
##       vehicmilespc, data = pnldata, model = "within")
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Residuals:
##      Min.      1st Qu.      Median      3rd Qu.      Max.
## -8.4273592 -1.0258600 -0.0029547  0.9572345 14.8109310
##
## Coefficients:
##              Estimate Std. Error t-value Pr(>|t|)
## d81             -1.51107133  0.41321486  -3.6569 0.0002672 ***
## d82             -3.02549578  0.44243119  -6.8383 1.316e-11 ***
## d83             -3.50360069  0.45657705  -7.6736 3.628e-14 ***
## d84             -4.25936110  0.46494255  -9.1610 < 2.2e-16 ***
## d85             -4.72679311  0.48547032  -9.7365 < 2.2e-16 ***
## d86             -3.66118539  0.51769787  -7.0721 2.686e-12 ***
## d87             -4.30578838  0.55532856  -7.7536 2.001e-14 ***
## d88             -4.76712131  0.60155650  -7.9246 5.501e-15 ***
## d89             -6.12997263  0.64019069  -9.5752 < 2.2e-16 ***
## d90             -6.22973766  0.66485076  -9.3701 < 2.2e-16 ***
## d91             -6.91714040  0.68195432 -10.1431 < 2.2e-16 ***
## d92             -7.77417239  0.70288580 -11.0604 < 2.2e-16 ***
## d93             -8.09410864  0.71594741 -11.3055 < 2.2e-16 ***
## d94             -8.50421668  0.73410866 -11.5844 < 2.2e-16 ***
## d95             -8.25540198  0.75623634 -10.9164 < 2.2e-16 ***
## d96             -8.60661913  0.79594975 -10.8130 < 2.2e-16 ***
## d97             -8.70781739  0.81975686 -10.6224 < 2.2e-16 ***
## d98             -9.34924025  0.83373487 -11.2137 < 2.2e-16 ***
## d99             -9.47489124  0.84399083 -11.2263 < 2.2e-16 ***
## d00             -9.99185979  0.85606370 -11.6719 < 2.2e-16 ***
## d01             -9.63121721  0.87255395 -11.0380 < 2.2e-16 ***
## d02             -8.90673015  0.88205263 -10.0977 < 2.2e-16 ***
## d03             -8.93650263  0.88994687 -10.0416 < 2.2e-16 ***
## d04             -9.33936116  0.91107045 -10.2510 < 2.2e-16 ***
## bac08           -1.43722116  0.39421213  -3.6458 0.0002788 ***
## bac10           -1.06266776  0.26883763  -3.9528 8.208e-05 ***
## perse           -1.15161719  0.23398721  -4.9217 9.867e-07 ***
## sbprim          -1.22739974  0.34271485  -3.5814 0.0003564 ***
## sbsecon         -0.34970784  0.25217091  -1.3868 0.1657826
## sl70plus        -0.06253283  0.26931063  -0.2322 0.8164283
## gdl             -0.41177619  0.29257391  -1.4074 0.1595790
## perc14_24       0.18712169  0.09509969   1.9676 0.0493567 *
## unem            -0.57183997  0.06057851  -9.4397 < 2.2e-16 ***
## vehicmilespc    0.00094005  0.00011104   8.4656 < 2.2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    12134
## Residual Sum of Squares: 4535.3
## R-Squared:              0.62624
## Adj. R-Squared: 0.59916
## F-statistic: 55.0943 on 34 and 1118 DF, p-value: < 2.22e-16
```

5. (10%) Would you prefer to use a random effects model instead of the fixed effects model you built in *Exercise 4*? Please explain.

We will fit the random effects model to the data as shown below.

```
model.re <- plm(totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 + d90 +
  d91 + d92 + d93 + d94 + d95 + d96 + d97 + d98 + d99 + d00 + d01 + d02 +
  d03 + d04 + bac08 + bac10 + perse + sbprim + sbsecon + sl70plus + gdl +
  perc14_24 + unem + vehicmiles, data=pnldata, model = "random")
summary(model.re)
```

```
## Oneway (individual) effect Random Effect Model
## (Swamy-Arora's transformation)
##
## Call:
## plm(formula = totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 +
## d87 + d88 + d89 + d90 + d91 + d92 + d93 + d94 + d95 + d96 +
## d97 + d98 + d99 + d00 + d01 + d02 + d03 + d04 + bac08 + bac10 +
## perse + sbprim + sbsecon + sl70plus + gdl + perc14_24 + unem +
## vehicmiles, data = pnldata, model = "random")
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Effects:
##               var std.dev share
## idiosyncratic 4.057   2.014 0.328
## individual    8.294   2.880 0.672
## theta: 0.8615
##
## Residuals:
##      Min.   1st Qu.   Median   3rd Qu.    Max.
## -8.25582 -1.15221 -0.15787  0.93086 16.45691
##
## Coefficients:
##              Estimate Std. Error z-value Pr(>|z|)
## (Intercept)  1.7149e+01 2.0964e+00  8.1801 2.835e-16 ***
## d81          -1.5489e+00 4.2830e-01 -3.6164 0.0002988 ***
## d82          -3.2433e+00 4.5772e-01 -7.0858 1.383e-12 ***
```

```

## d83          -3.7447e+00  4.7212e-01  -7.9318  2.161e-15 ***
## d84          -4.3729e+00  4.8064e-01  -9.0981 < 2.2e-16 ***
## d85          -4.8609e+00  5.0136e-01  -9.6954 < 2.2e-16 ***
## d86          -3.8295e+00  5.3416e-01  -7.1693  7.539e-13 ***
## d87          -4.5014e+00  5.7213e-01  -7.8678  3.610e-15 ***
## d88          -4.9819e+00  6.1887e-01  -8.0500  8.279e-16 ***
## d89          -6.3713e+00  6.5797e-01  -9.6833 < 2.2e-16 ***
## d90          -6.5357e+00  6.8279e-01  -9.5720 < 2.2e-16 ***
## d91          -7.3027e+00  7.0030e-01 -10.4279 < 2.2e-16 ***
## d92          -8.2390e+00  7.2126e-01 -11.4230 < 2.2e-16 ***
## d93          -8.5418e+00  7.3449e-01 -11.6296 < 2.2e-16 ***
## d94          -8.9183e+00  7.5297e-01 -11.8442 < 2.2e-16 ***
## d95          -8.6769e+00  7.7541e-01 -11.1902 < 2.2e-16 ***
## d96          -9.0969e+00  8.1573e-01 -11.1518 < 2.2e-16 ***
## d97          -9.2203e+00  8.3984e-01 -10.9786 < 2.2e-16 ***
## d98          -9.8922e+00  8.5380e-01 -11.5860 < 2.2e-16 ***
## d99          -1.0032e+01  8.6426e-01 -11.6071 < 2.2e-16 ***
## d00          -1.0549e+01  8.7667e-01 -12.0330 < 2.2e-16 ***
## d01          -1.0274e+01  8.9336e-01 -11.5000 < 2.2e-16 ***
## d02          -9.6376e+00  9.0278e-01 -10.6755 < 2.2e-16 ***
## d03          -9.6828e+00  9.1090e-01 -10.6300 < 2.2e-16 ***
## d04          -1.0054e+01  9.3254e-01 -10.7816 < 2.2e-16 ***
## bac08        -1.5693e+00  4.0384e-01  -3.8860  0.0001019 ***
## bac10        -1.1380e+00  2.7604e-01  -4.1227  3.744e-05 ***
## perse        -1.0933e+00  2.3885e-01  -4.5772  4.712e-06 ***
## sbprim       -1.1761e+00  3.5144e-01  -3.3465  0.0008184 ***
## sbsecon      -3.4758e-01  2.6024e-01  -1.3356  0.1816862
## sl70plus     2.9969e-02  2.7772e-01   0.1079  0.9140655
## gdl          -3.8524e-01  3.0249e-01  -1.2736  0.2028095
## perc14_24    1.9695e-01  9.7213e-02   2.0259  0.0427722 *
## unem         -4.9238e-01  6.1839e-02  -7.9622  1.690e-15 ***
## vehicmilespc 1.1744e-03  1.0983e-04  10.6933 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    12834
## Residual Sum of Squares: 5078.6
## R-Squared:      0.60429
## Adj. R-Squared: 0.59274
## Chisq: 1779.05 on 34 DF, p-value: < 2.22e-16

```

Comparing the random effect model to the fixed effect model using the Hausman's test.

```
phtest(model.fe, model.re)
```

```

##
## Hausman Test

```

```
##
## data:  totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 + ...
## chisq = 148.69, df = 34, p-value = 2.727e-16
## alternative hypothesis: one model is inconsistent
```

p-value is statistically significant and we can reject the null hypothesis that the unobserved fixed effects are uncorrelated with the explanatory variables. Therefore, We will prefer the Fixed effect model instead of the random effects model in this scenario.

6. (10%) Suppose that *vehicmilespc*, the number of miles driven per capita, increases by 1,000. Using the FE estimates, what is the estimated effect on *totfatrte*? Please interpret the estimate.

The coefficient for the *vehicmilespc* variable is 0.00094005 using the FE estimates and it is highly statistically significant. In other words, There will be an increase of 0.94 fatalities per 100k for an increase of 1000 vehicle miles driven per capita.

7. (5%) If there is serial correlation or heteroskedasticity in the idiosyncratic errors of the model, what would be the consequences on the estimators and their standard errors?

There is no serial correlation in the idiosyncratic errors of our model as shown in the p-value below. However if there is Serial correlation then it will not affect the unbiasedness or consistency of OLS estimators, but it does affect their efficiency. With positive serial correlation, the OLS estimates of the standard errors will be smaller than the true standard errors. This will lead to the conclusion that the parameter estimates are more precise than they really are. There will be a tendency to reject the null hypothesis when it should not be rejected.

```
pbgtest(model.fe)
```

```
##
## Breusch-Godfrey/Wooldridge test for serial correlation in panel models
##
## data:  totfatrte ~ d81 + d82 + d83 + d84 + d85 + d86 + d87 + d88 + d89 +      d90 + d91 + d92
## chisq = 340.4, df = 25, p-value < 2.2e-16
## alternative hypothesis: serial correlation in idiosyncratic errors
```