

# Lab 3: Panel Models

## US Traffic Fatalities: 1980 - 2004

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## 1 U.S. traffic fatalities: 1980-2004

```
load(file="./data/driving.RData")
```

## 2 (30 points, total) Build and Describe the Data

### 2.1 (5 points) Load the data and produce useful features.

```
# For the fractions, we are taking the majority as a speed limit
# We skipped year_of_observation since there a year column which aligns with dx
df <- data %>%
  mutate(speed_limit = ifelse(sl55 >= 0.5, '55',
                              ifelse(sl65 >= 0.5, '65',
                              ifelse(sl70 >= 0.5, '70',
                              ifelse(sl75 >= 0.5, '75',
                              ifelse(slnone >= 0.5, 'none', '0')
                              ))))) %>%
  mutate(speed_limit=factor(speed_limit,
                             levels=c('55', '65', '70', '75', 'none')),
         blood_alcohol_limit_10 = ifelse(bac10 >= 0.5, 1, 0),
         blood_alcohol_limit_08 = ifelse(bac08 >= 0.5, 1, 0)) %>%
  mutate(bac=ifelse(blood_alcohol_limit_10==1, '10',
                    ifelse(blood_alcohol_limit_08==1, '8', 'none')) %>%
  mutate(bac=factor(bac, levels=c('none', '10', '8'))) %>%
  select(!c((sl55:slnone), (d80:d04), bac10, bac08)) %>% # Excluding
  rename(minimum_drinking_age = minage, zero_tolerance_law = zerotol,
         graduated_drivers_license_law = gdl, per_se_law = perse,
         total_fatalities = totfat, nighttime_fatalities = nghtfat,
         weekend_fatalities = wkndfat, total_fatalities_per_100M_miles = totfatpvm,
         nighttime_fatalities_per_100M_miles = nghtfatpvm,
         weekend_fatalities_per_100M_miles = wkndfatpvm,
         state_population = statepop, total_fatalities_rate = totfatrte,
         nighttime_fatalities_rate = nghtfatrte,
         weekend_fatalities_rate = wkndfatrte,
         vehicle_miles_traveled = vehicmiles, unemployment_rate = unem,
         population_aged_14_to_24_rate = perc14_24,
         speed_limit_70_plus = sl70plus,
         seat_belt = seatbelt,
         primary_seatbelt_law = sbprim, secondary_seatbelt_law = sbsecon,
         miles_driven_per_capita = vehicmilespc) %>%
  mutate(speed_limit_70_plus =
         ifelse(speed_limit_70_plus>0.5, 1, 0)
         ) %>%
  mutate(seat_belt_law =
         ifelse(seat_belt==0, 'none',
         ifelse(seat_belt==2, 'secondary',
         ifelse(seat_belt==1, 'primary', 'na')))) %>%
  mutate(seat_belt_law=factor(seat_belt_law,
```

```

                                levels=c('none', 'secondary', 'primary')),
    ) %>%
mutate(per_se_low=round(per_se_low, 0)) %>%
mutate(per_se_low=factor(per_se_low, levels=c(0, 1))) %>%
mutate(log_total_fatalities_rate = log10(total_fatalities_rate))

# Adding states to the dataframe
state_df <- data.frame("index" = 1:51,
                       "state_name" = sort(c(state.name, "District of Columbia")))
main_df <- merge(df, state_df, by.x = 'state', by.y = 'index')

pdata <- pdata.frame(main_df, index=c("state", "year"))
head(main_df)

```

### 2.1.0.1 Status complete: Checked by Hannah

```

##   state year seat_belt minimum_drinking_age zero_tolerance_low
## 1     1 1980         0             18                0
## 2     1 1981         0             18                0
## 3     1 1982         0             18                0
## 4     1 1983         0             18                0
## 5     1 1984         0             18                0
## 6     1 1985         0             20                0
##   graduated_drivers_license_low per_se_low total_fatalities
## 1                   0           0           940
## 2                   0           0           933
## 3                   0           0           839
## 4                   0           0           930
## 5                   0           0           932
## 6                   0           0           882
##   nighttime_fatalities weekend_fatalities total_fatalities_per_100M_miles
## 1                   422             236                3.20
## 2                   434             248                3.35
## 3                   376             224                2.81
## 4                   397             223                3.00
## 5                   421             237                2.83
## 6                   358             224                2.51
##   nighttime_fatalities_per_100M_miles weekend_fatalities_per_100M_miles
## 1                   1.437                0.803
## 2                   1.558                0.890
## 3                   1.259                0.750
## 4                   1.281                0.719
## 5                   1.278                0.720
## 6                   1.019                0.637
##   state_population total_fatalities_rate nighttime_fatalities_rate
## 1          3893888             24.14             10.84
## 2          3918520             24.07             11.08
## 3          3925218             21.37              9.58
## 4          3934109             23.64             10.09
## 5          3951834             23.58             10.65
## 6          3972527             22.20              9.01
##   weekend_fatalities_rate vehicle_miles_traveled unemployment_rate

```

```

## 1          6.06          29.37500          8.8
## 2          6.33          27.85200          10.7
## 3          5.71          29.85765          14.4
## 4          5.67          31.00000          13.7
## 5          6.00          32.93286          11.1
## 6          5.64          35.13944          8.9
##  population_aged_14_to_24_rate speed_limit_70_plus primary_seatbelt_law
## 1          18.9          0          0
## 2          18.7          0          0
## 3          18.4          0          0
## 4          18.0          0          0
## 5          17.6          0          0
## 6          17.3          0          0
##  secondary_seatbelt_law miles_driven_per_capita speed_limit
## 1          0          7543.874          55
## 2          0          7107.785          55
## 3          0          7606.622          55
## 4          0          7879.802          55
## 5          0          8333.562          55
## 6          0          8845.614          55
##  blood_alcohol_limit_10 blood_alcohol_limit_08 bac seat_belt_law
## 1          1          0 10          none
## 2          1          0 10          none
## 3          1          0 10          none
## 4          1          0 10          none
## 5          1          0 10          none
## 6          1          0 10          none
##  log_total_fatalities_rate state_name
## 1          1.382737      Alabama
## 2          1.381476      Alabama
## 3          1.329805      Alabama
## 4          1.373647      Alabama
## 5          1.372544      Alabama
## 6          1.346353      Alabama

```

## 2.2 (5 points) Provide a description of the basic structure of the dataset.

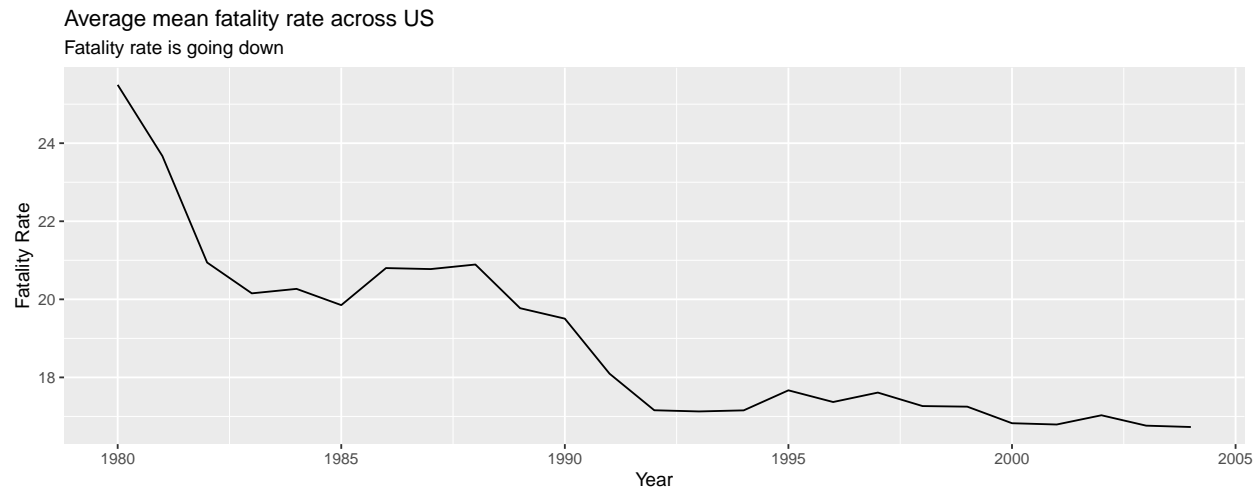
**2.2.0.1 Status Complete: Checked by Hannah** The data contains state-level information on the total traffic fatalities rate in a specific year. The data also contains state law information that could have an impact on the traffic fatalities rate, like the speed limit, blood alcohol legal limit, seat belt laws, etc. The data is likely a census that represents the entire population since it's aggregated on a yearly level. The outcome of interest, `total_fatalities_rate` is defined as the number of fatalities per 100,000 people.

## 2.3 (20 points) EDA

### 2.3.0.1 Status Complete: Add descriptions

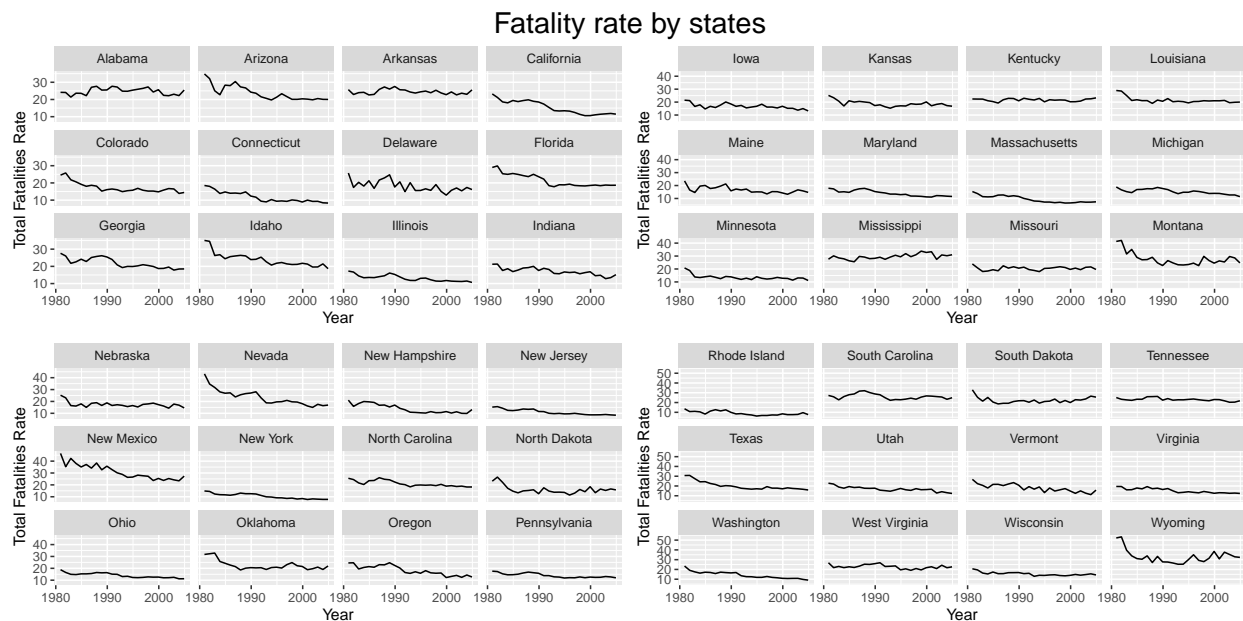
#### 2.3.1 Average and state wide trends

##### 2.3.1.1 Status Complete: Add descriptions.



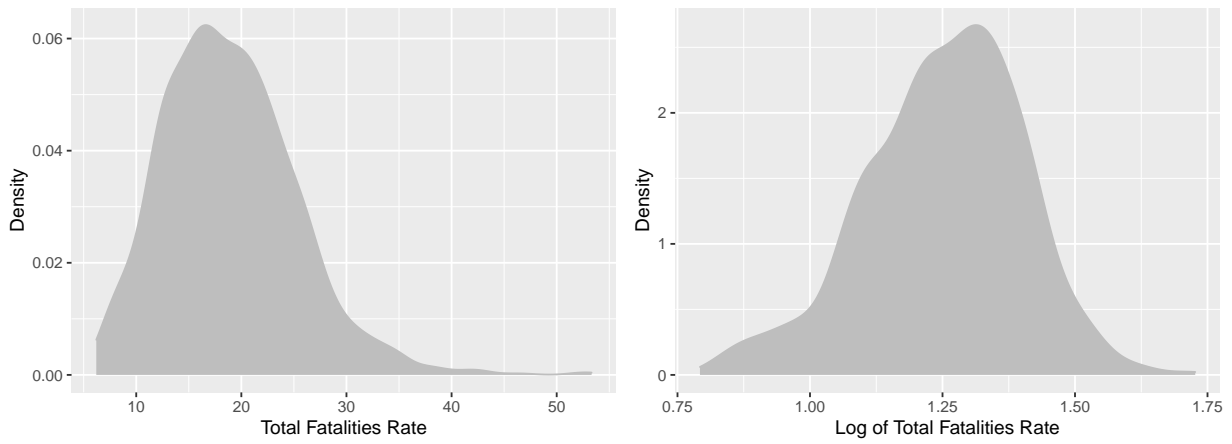
In the plot shown above, the fatality rates across states have been aggregated and the average fatality rate is plotted against time. The plot shows that, over time, average fatality rate has decreased in the United States, beginning at an average of approximately 25 fatalities in 1980 to an average of about 17 fatalities in 2004, per 100,000 people.

However, given that the data is aggregated across states and the fact that the driving conditions and laws vary significantly across states is common knowledge, the graph shown above enables only a limited understanding of the trend in traffic fatalities across the United States over time.



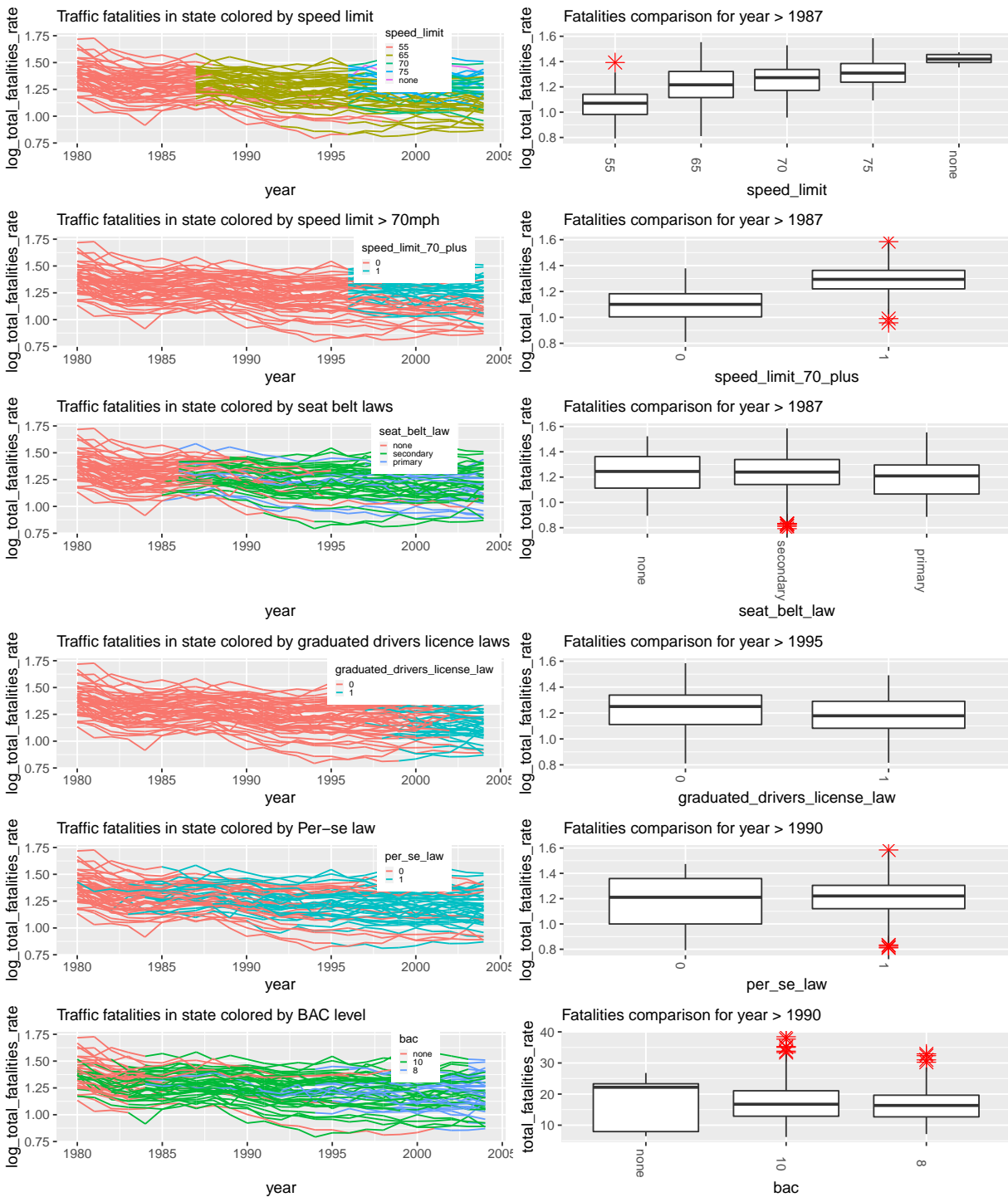
Splitting the data by state provides the additional context needed to understand the trend in traffic fatalities. For most states, as is expected, the fatality rates decreased over the years. However, for some states, like Alabama and Arkansas, the trend is does not show much change over time. Mississippi, on the other hand, shows an increase in fatality rate over time.

Log Transform Normalizes Total Fatalities Rate



The `total_fatalities_rate` variable follows a right-skewed distribution. In the plot shown above, we see that the log-transformation helps make the distribution more normal

## Time series and distribution comparisons of factor variables



TODO: Add takeaways from above graph

## 2.3.2 Description of variables

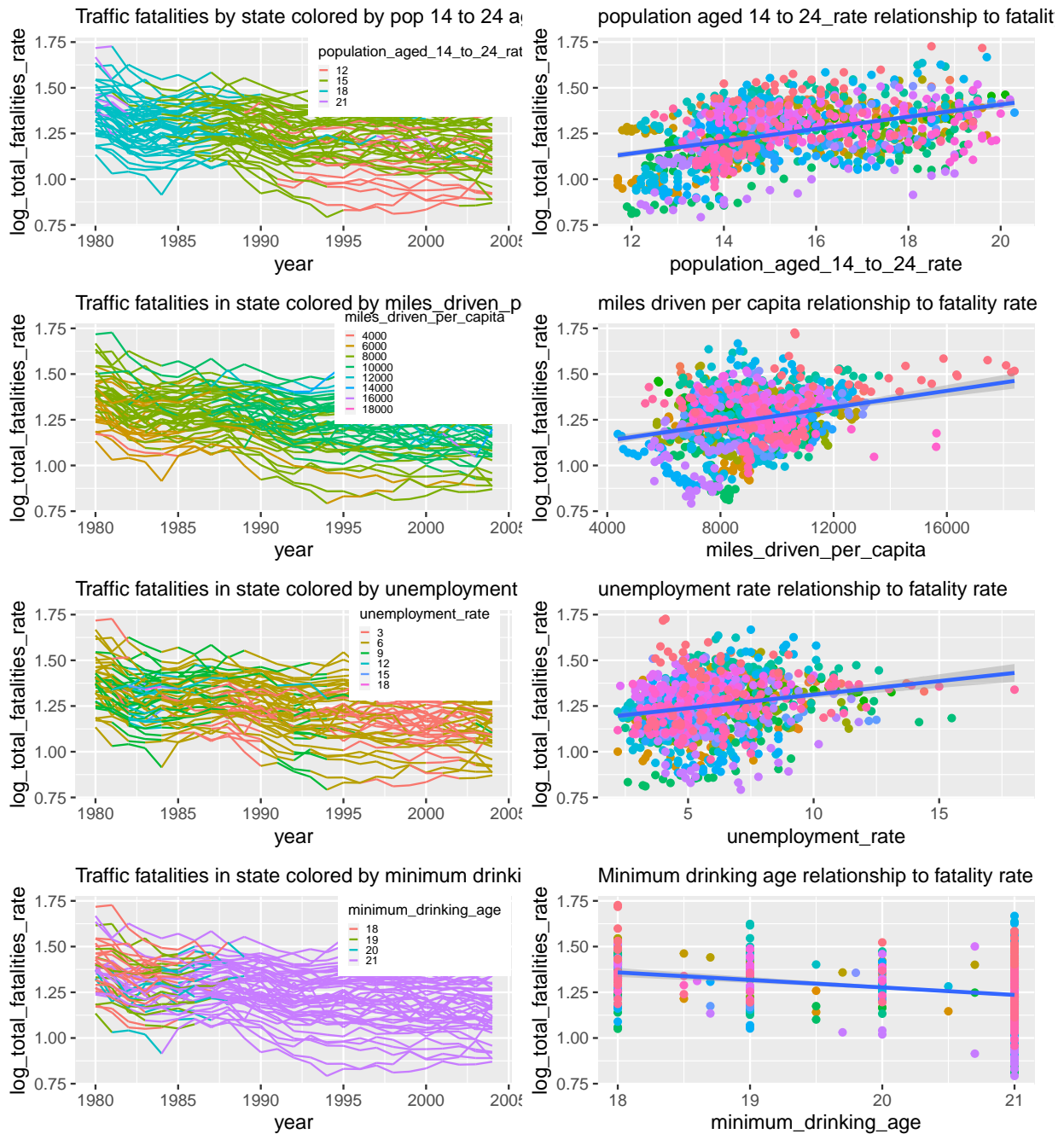
### 2.3.2.1 Status Complete: Format descriptions.



### 2.3.2.2 Factor variables

- The top-left panel shows the relationship between the highway speed limit and the logged `total_fatalities_rate` variable. Before 1987, the highway speed limit was uniformly set to 55mph across all states. Since then, different states have adopted different speed limits. In 1997, there was a significant increase in highway speeds across multiple states. The box plot in the top-right panel compares the fatality rate across different speed limits filtered for years greater than 1987. We see that increasing speed limits are associated with increased fatality rates. As there are states with no speed limit, this variable has been treated as a factor.
- Thresholding speed limits for greater than or lower than 70mph (second panel from the top) shows a similar pattern of higher speeds being associated with higher fatality rates.
- Seat belts started to become mandatory, across states, beginning mid-to-late 80s, and today there is only one state which does not mandate seat belts. Primary laws are the strictest and allow police to ticket drivers and passengers who are not wearing a proper safety restraint, even if that is the only traffic violation they are committing. Secondary seat belt laws, on the other hand, do not grant law enforcement officials the right to ticket drivers or passengers for failing to wear a safety restraint unless another traffic violation has occurred. There are 15 states with secondary seat belt laws. Source: <https://www.cooper-law-firm.com/what-is-the-difference-between-primary-and-secondary-seat-belt-laws/>.
- The graduated drivers licence law was beginning to be introduced in the late 90's. The box plot, which has been filtered for years greater than 1995, suggests that even for that time frame, there is a reduction in fatality rate between the two groups.
- Some states had Per-Se laws before the start of the data in 1980 and some still did not have Per-Se laws in 2004. There is a gradual increase in the adoption of the law from 1980 to about the 2000s. Surprisingly, there is an increase in fatality rates in comparison of data with the Per-Se law as compared to without it.
- Lastly, most states had adopted a blood alcohol limit by the mid 80s, with two states choosing a limit only in 2002.

## Time series and correlation comparison of continuous variables



### 2.3.2.3 Description of Continuous Variables

- There is a decrease in the percentage of 14 to 24 year-olds in the population over time. This is correlated to the decrease in the fatalities during that time period.
- Miles driven per capita has a positive relationship with total fatality rate. An increase in miles driven is associated with an increase in fatality rate
- There is an increase in fatality rate with an increase in unemployment rate.
- The minimum drinking age has been 21 in most states since the late 80s. There is a general decrease

in fatality rate with an increased minimum drinking age but there also has been a general decrease in fatality rates during the time period when the age limits were changed.

### 3 (15 points) Preliminary Model

```
# Pooled OLS model
pooled_ols <- plm(log_total_fatalities_rate ~ year, data = pdata,
                  index = c("state", "year"),
                  effect = "individual", model = "pooling")
summary(pooled_ols)
```

#### 3.0.0.1 Status complete: Checked by Hannah

```
## Pooling Model
##
## Call:
## plm(formula = log_total_fatalities_rate ~ year, data = pdata,
##      effect = "individual", model = "pooling", index = c("state",
##      "year"))
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Residuals:
##      Min.      1st Qu.      Median      3rd Qu.      Max.
## -0.4183307 -0.0961280  0.0043659  0.1008470  0.3770988
##
## Coefficients:
##              Estimate Std. Error t-value Pr(>|t|)
## (Intercept)  1.387907   0.020400  68.0351 < 2.2e-16 ***
## year1981    -0.034213   0.028850  -1.1859  0.2359037
## year1982    -0.086671   0.028850  -3.0042  0.0027191 **
## year1983    -0.102159   0.028850  -3.5411  0.0004141 ***
## year1984    -0.098087   0.028850  -3.3999  0.0006966 ***
## year1985    -0.105539   0.028850  -3.6582  0.0002652 ***
## year1986    -0.085474   0.028850  -2.9627  0.0031107 **
## year1987    -0.086297   0.028850  -2.9912  0.0028363 **
## year1988    -0.082018   0.028850  -2.8429  0.0045473 **
## year1989    -0.107768   0.028850  -3.7355  0.0001963 ***
## year1990    -0.116324   0.028850  -4.0320  5.886e-05 ***
## year1991    -0.149274   0.028850  -5.1742  2.690e-07 ***
## year1992    -0.174714   0.028850  -6.0560  1.875e-09 ***
## year1993    -0.174832   0.028850  -6.0601  1.830e-09 ***
## year1994    -0.177185   0.028850  -6.1416  1.116e-09 ***
## year1995    -0.167169   0.028850  -5.7945  8.794e-09 ***
## year1996    -0.173498   0.028850  -6.0138  2.416e-09 ***
## year1997    -0.167622   0.028850  -5.8102  8.028e-09 ***
## year1998    -0.177863   0.028850  -6.1651  9.666e-10 ***
## year1999    -0.180014   0.028850  -6.2397  6.108e-10 ***
## year2000    -0.189762   0.028850  -6.5776  7.181e-11 ***
## year2001    -0.189010   0.028850  -6.5515  8.500e-11 ***
```

```
## year2002    -0.185324    0.028850 -6.4238 1.927e-10 ***
## year2003    -0.190996    0.028850 -6.6204 5.437e-11 ***
## year2004    -0.194794    0.028850 -6.7520 2.286e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    26.854
## Residual Sum of Squares: 23.471
## R-Squared:    0.12598
## Adj. R-Squared: 0.10813
## F-statistic: 7.05692 on 24 and 1175 DF, p-value: < 2.22e-16
```

- ‘Starting from a linear model gives us an easy and intuitive way to understand the overall trend pattern over the years via the coefficients on the year dummy variables. In later sections, the report details panel data analysis that can be compared against this benchmark.’
- ‘This model explains the log of fatality rate over different years compared to the baseline year, which is 1980. All coefficients except for the 1981 year are statistically significant. From this model, we learn that in all years following the baseline up to 2004, the fatality rate goes down compared to the baseline year 1980. The decline accelerates as the year increases but not consistently, as seen, for example, between 1986 - 1988, where the fatality rate increases compared to previous years. However, it returns to the decline track/trend in 1989. The higher, in absolute value, coefficients over the years means that driving becomes safer as the fatality rate keeps decreasing. For example, the fatality rate, which was 25.5 as of 1980, became 19.5 in 1990, 16.8 in 2000, and 16.7 in 2004, showing that driving over the years has become safer. In other words, around 8.8 fewer people are predicted to be involved in traffic fatalities out of 100,000 people in 2004 than in 1980 as per this model.’
- ‘Note that we are ignoring unobserved Heterogeneity and the group structure by taking each entry as a separate observation. Because of that, residuals generally correlate across time and have heteroskedasticity across and/or within groups. Heteroscedastic residuals are a violation of the OLS Homoscedasticity assumption, which will make it difficult to trust the standard error. As a result, the confidence interval can not be trusted as it can be too wide or narrow. Also, the independence assumption (no autocorrelation) is violated since we did not accommodate the lag/trend component, which makes the OLS estimates to be unreliable; in other words, our OLS estimator is not the Best Linear Unbiased Estimator.’

## 4 (15 points) Expanded Model

### 4.0.0.1 Status complete: Checked by Hannah

### 4.1 Transformation (treatment) of Variables

- As described in a previous section, a log transformation was performed on the response variable to make the distribution closer to normal.
- States where highway speeds were made over 70mph during the middle of the year contained a fractional value for that year. The fraction was thresholded at 0.5 to make this a binary variable. As there is no meaningful interpretation for this variable as a continuous value, this threshold was necessary to convert it into a factor.
- A state can have a primary, secondary or no seat belt laws. The seat\_belt\_law reflects these three factors combined into one variable.

- Graduated drivers licence law and per-se law parameters both have fractional value for years where the law was implemented mid-year. The fractions were thresholded at 0.5 to make this a binary variable. As there is no meaningful interpretation for these variables as a continuous value, this threshold was necessary to convert them into a factor.
- Although Blood alcohol content (BAC) levels of 0.08% or 0.1% lends itself to a numeric interpretation, there is no numeric value associated with no BAC limit. For this reason BAC has been treated as a factor variable with levels none, 10 and 8.
- None of the continuous variables, namely, unemployment rate, miles drive per-capita, proportion of 14 to 24 aged people in population required any transformation. This can be seen in the correlation plots in Figure y where their relationship to log fatality rates appear linear.

#### 4.1.1 Pooled OLS Model Creation

```
expanded.ols.data <- main_df %>% select(
  c(log_total_fatalities_rate, bac, per_se_law, seat_belt_law,
    graduated_drivers_license_law, population_aged_14_to_24_rate,
    minimum_drinking_age, unemployment_rate, speed_limit_70_plus,
    miles_driven_per_capita, year, state))

main_p <- pdata.frame(expanded.ols.data, index=c("state", "year"))
expanded.ols <- plm(log_total_fatalities_rate ~ year + bac +
  population_aged_14_to_24_rate + miles_driven_per_capita +
  unemployment_rate + speed_limit_70_plus + per_se_law +
  seat_belt_law + graduated_drivers_license_law,
  data = main_p,
  index = c("state", "year"),
  effect = "individual", model = "pooling")

summary(expanded.ols)
```

```
## Pooling Model
##
## Call:
## plm(formula = log_total_fatalities_rate ~ year + bac + population_aged_14_to_24_rate +
##     miles_driven_per_capita + unemployment_rate + speed_limit_70_plus +
##     per_se_law + seat_belt_law + graduated_drivers_license_law,
##     data = main_p, effect = "individual", model = "pooling",
##     index = c("state", "year"))
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Residuals:
##      Min.      1st Qu.      Median      3rd Qu.      Max.
## -0.34758836 -0.05686774  0.00052907  0.06279643  0.25888532
##
## Coefficients:
##              Estimate Std. Error t-value Pr(>|t|)
## (Intercept)   6.5776e-01  5.5569e-02  11.8367 < 2.2e-16 ***
## year1981     -4.0821e-02  1.8599e-02  -2.1948  0.02838 *
## year1982     -1.3080e-01  1.9183e-02  -6.8182 1.477e-11 ***
## year1983     -1.5099e-01  1.9581e-02  -7.7113 2.659e-14 ***
## year1984     -1.2006e-01  1.9720e-02  -6.0885 1.545e-09 ***
```

```

## year1985      -1.3316e-01  2.0105e-02  -6.6233  5.354e-11 ***
## year1986      -1.2207e-01  2.0907e-02  -5.8386  6.819e-09 ***
## year1987      -1.3467e-01  2.1723e-02  -6.1997  7.839e-10 ***
## year1988      -1.3907e-01  2.2769e-02  -6.1076  1.376e-09 ***
## year1989      -1.7282e-01  2.3648e-02  -7.3079  5.026e-13 ***
## year1990      -1.9557e-01  2.4190e-02  -8.0846  1.550e-15 ***
## year1991      -2.4396e-01  2.4741e-02  -9.8605 < 2.2e-16 ***
## year1992      -2.8991e-01  2.5218e-02 -11.4964 < 2.2e-16 ***
## year1993      -2.8707e-01  2.5525e-02 -11.2464 < 2.2e-16 ***
## year1994      -2.8368e-01  2.5976e-02 -10.9207 < 2.2e-16 ***
## year1995      -2.7658e-01  2.6580e-02 -10.4057 < 2.2e-16 ***
## year1996      -3.3148e-01  2.7527e-02 -12.0418 < 2.2e-16 ***
## year1997      -3.4014e-01  2.7968e-02 -12.1615 < 2.2e-16 ***
## year1998      -3.6607e-01  2.8402e-02 -12.8887 < 2.2e-16 ***
## year1999      -3.7110e-01  2.8800e-02 -12.8855 < 2.2e-16 ***
## year2000      -3.8060e-01  2.9269e-02 -13.0035 < 2.2e-16 ***
## year2001      -4.0014e-01  2.9859e-02 -13.4009 < 2.2e-16 ***
## year2002      -4.1553e-01  3.0151e-02 -13.7815 < 2.2e-16 ***
## year2003      -4.2378e-01  3.0308e-02 -13.9825 < 2.2e-16 ***
## year2004      -4.2116e-01  3.0978e-02 -13.5954 < 2.2e-16 ***
## bac10         -9.9381e-03  8.7474e-03  -1.1361  0.25614
## bac8          -2.6054e-02  1.1804e-02  -2.2073  0.02749 *
## population_aged_14_to_24_rate  6.8653e-03  2.7564e-03   2.4906  0.01289 *
## miles_driven_per_capita      6.8781e-05  2.1301e-06  32.2903 < 2.2e-16 ***
## unemployment_rate           1.6720e-02  1.7501e-03   9.5533 < 2.2e-16 ***
## speed_limit_70_plus          9.6254e-02  9.7589e-03   9.8632 < 2.2e-16 ***
## per_se_law1                 -6.8721e-03  6.6160e-03  -1.0387  0.29915
## seat_belt_lawsecondary       9.1036e-03  9.6452e-03   0.9438  0.34545
## seat_belt_lawprimary        -8.6245e-04  1.1029e-02  -0.0782  0.93768
## graduated_drivers_license_law -1.2209e-03  1.1840e-02  -0.1031  0.91789
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:      26.854
## Residual Sum of Squares:  9.6296
## R-Squared:                0.64141
## Adj. R-Squared: 0.63095
## F-statistic: 61.29 on 34 and 1165 DF, p-value: < 2.22e-16

```

## 4.2 Interpretation of Results

### 4.2.1 How are the blood alcohol variables defined? Interpret the coefficients that you estimate for this concept.

- In an earlier section we have defined our treatment of the BAC variable as a factor with levels ‘none’, ‘10’ and ‘8’. In this model we note that the base level is no blood alcohol limit. We note that bac value of 0.08% is statistically significant and 0.1% is not statistically significant. The model suggests that setting a blood alcohol limit of 0.1% is associated with a 0.98 times decrease in fatality rate as compared to no BAC limit. The model suggests that a setting a blood alcohol limit of 0.08% is associated with a 0.94 times decrease in fatality rate as compared to no BAC limit.

#### 4.2.2 Do *per se* laws have a negative effect on the fatality rate?

- We note that per-se law is not a statistically significant parameter. The model suggests that having a per-se law is associated with a 0.98 times decrease in fatality rate as compared to not having per-se law.

#### 4.2.3 Does having a primary seat belt law reduce fatality rates?

- We note that the seat belt law factors are not statistically significant. We also note that the implementation of the primary law leads to a 0.998 times decrease in fatality rate which is practically insignificant.

## 5 (15 points) State-Level Fixed Effects

### 5.0.0.1 Status complete: Checked by Hannah

### 5.1 Re-estimate the Expanded Model using fixed effects at the state level.

Model estimation for a fixed effect (within) model.

```
expanded.within <- plm(log_total_fatalities_rate ~ bac + year +
  population_aged_14_to_24_rate + miles_driven_per_capita +
  unemployment_rate + speed_limit_70_plus + per_se_law +
  seat_belt_law + graduated_drivers_license_law,
  data = main_p,
  index = c("state", "year"),
  effect = "individual", model = "within")

summary(expanded.within)
```

```
## Oneway (individual) effect Within Model
##
## Call:
## plm(formula = log_total_fatalities_rate ~ bac + year + population_aged_14_to_24_rate +
##     miles_driven_per_capita + unemployment_rate + speed_limit_70_plus +
##     per_se_law + seat_belt_law + graduated_drivers_license_law,
##     data = main_p, effect = "individual", model = "within", index = c("state",
##     "year"))
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Residuals:
##      Min.      1st Qu.      Median      3rd Qu.      Max.
## -0.1835098 -0.0223288  0.0020551  0.0227251  0.1279559
##
## Coefficients:
##
##              Estimate Std. Error t-value Pr(>|t|)
## bac10             -1.1165e-02  4.9828e-03  -2.2407  0.025241 *
## bac8              -1.6135e-02  7.1737e-03  -2.2492  0.024694 *
## year1981          -2.5783e-02  7.9252e-03  -3.2533  0.001175 **
```

```

## year1982          -5.0669e-02  8.4888e-03  -5.9689  3.204e-09 ***
## year1983          -6.1384e-02  8.7911e-03  -6.9825  4.964e-12 ***
## year1984          -7.8231e-02  8.9205e-03  -8.7698 < 2.2e-16 ***
## year1985          -8.6982e-02  9.2924e-03  -9.3605 < 2.2e-16 ***
## year1986          -6.6274e-02  9.9105e-03  -6.6872  3.585e-11 ***
## year1987          -8.1819e-02  1.0632e-02  -7.6954  3.088e-14 ***
## year1988          -9.1423e-02  1.1516e-02  -7.9387  4.941e-15 ***
## year1989          -1.2221e-01  1.2261e-02  -9.9670 < 2.2e-16 ***
## year1990          -1.2726e-01  1.2730e-02  -9.9971 < 2.2e-16 ***
## year1991          -1.4334e-01  1.3067e-02 -10.9697 < 2.2e-16 ***
## year1992          -1.6845e-01  1.3465e-02 -12.5101 < 2.2e-16 ***
## year1993          -1.7549e-01  1.3715e-02 -12.7957 < 2.2e-16 ***
## year1994          -1.8929e-01  1.4049e-02 -13.4739 < 2.2e-16 ***
## year1995          -1.8602e-01  1.4479e-02 -12.8476 < 2.2e-16 ***
## year1996          -2.0517e-01  1.5272e-02 -13.4345 < 2.2e-16 ***
## year1997          -2.1113e-01  1.5630e-02 -13.5084 < 2.2e-16 ***
## year1998          -2.3185e-01  1.5945e-02 -14.5404 < 2.2e-16 ***
## year1999          -2.3797e-01  1.6125e-02 -14.7580 < 2.2e-16 ***
## year2000          -2.5039e-01  1.6352e-02 -15.3122 < 2.2e-16 ***
## year2001          -2.4326e-01  1.6634e-02 -14.6247 < 2.2e-16 ***
## year2002          -2.2996e-01  1.6803e-02 -13.6862 < 2.2e-16 ***
## year2003          -2.3124e-01  1.6894e-02 -13.6878 < 2.2e-16 ***
## year2004          -2.4447e-01  1.7323e-02 -14.1121 < 2.2e-16 ***
## population_aged_14_to_24_rate  9.0309e-03  1.8219e-03   4.9569  8.270e-07 ***
## miles_driven_per_capita        2.6879e-05  2.1286e-06  12.6277 < 2.2e-16 ***
## unemployment_rate             -1.2761e-02  1.1601e-03 -11.0002 < 2.2e-16 ***
## speed_limit_70_plus            2.3830e-02  4.9909e-03   4.7748  2.038e-06 ***
## per_se_law1                   -2.3217e-02  4.2933e-03  -5.4078  7.801e-08 ***
## seat_belt_lawsecondary         -6.6982e-04  4.8314e-03  -0.1386   0.889762
## seat_belt_lawprimary           -2.0458e-02  6.5736e-03  -3.1122   0.001904 **
## graduated_drivers_license_law -7.3527e-03  5.6051e-03  -1.3118   0.189860
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    6.0213
## Residual Sum of Squares: 1.6682
## R-Squared:              0.72294
## Adj. R-Squared: 0.70287
## F-statistic: 85.8017 on 34 and 1118 DF, p-value: < 2.22e-16

```

## 5.2 Interpretation of the Model

### 5.2.1 What do you estimate for coefficients on the blood alcohol variables? How do the coefficients on the blood alcohol variables change, if at all?

We note that bac value of 0.1% and 0.08% are both statistically significant parameters.

- This model suggests that setting a blood alcohol limit of 0.1% is associated with a 0.97 times decrease in log fatality rate as compared to no BAC limit. Compared to the OLS model which showed that setting a blood alcohol limit of 0.1% is associated with a 0.98 times decrease in fatality rate as compared to no BAC limit.
- This model suggests that a setting a blood alcohol limit of 0.08% is associated with a 0.96 times decrease in fatality rate as compared to no BAC limit. Compared to the OLS model which showed



Table 1:

	log_total_fatalities_rate	
	Pooled OLS	Within
	(1)	(2)
bac10	-0.010 (0.009)	-0.011** (0.005)
bac8	-0.026** (0.012)	-0.016** (0.007)
per_se_law1	-0.007 (0.007)	-0.023*** (0.004)
seat_belt_lawprimary	-0.001 (0.011)	-0.020*** (0.007)
<i>N</i>	1,200	1,200
<i>R</i> <sup>2</sup>	0.641	0.723

*Notes:*

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

that setting a blood alcohol limit of 0.08% is associated with a 0.96 times decrease in fatality rate as compared to no BAC limit.

### 5.2.2 What do you estimate for coefficients on per se laws? How do the coefficients on per se laws change, if at all?

We note that per-se law is a statistically significant parameter. This model suggests that having a per-se law is associated with a 0.95 times decrease in fatality rate as compared to not having per-se law. Compared to the OLS model which showed that havng a per-se law is associated with a 0.98 times decrease in fatality rate as compared to not having per-se law

### 5.2.3 What do you estimate for coefficients on primary seat-belt laws? How do the coefficients on primary seatbelt laws change, if at all?

In this model we note that seat belt primary law is a significant factor. This model suggests that having a primary seat belt law is associated with a 0.95 unit decrease in fatality rate as compared to not having primary seat belt law. Compared to the OLS model for which the parameter was not statistically significant and had a close to 0 value of 1

## 5.3 Model Assumptions

A fundamental assumption in an pooled OLS model is that the data is IID. Let's consider a data set where a sample of a large population was collected on different years. It is unlikely that a particular individual sample is measured twice. In such a circumstance a pooled OLS model would be applicable. However in this data set, the individual is the state and the same state is measured multiple times across years. This violates the assumption of IID in the pooled OLS. A fixed effect model is then expected to be a better model in this

scenario. We perform a F-test between the pooled and the fixed effect model to check for fixed effects. The null hypothesis is that there are no fixed effects and the alternate hypothesis is that there are fixed effects. We test against an alpha of 0.05

```
res <- pFtest(expanded.within, expanded.ols)
```

With a p-value of 0 less than 0.05, we reject the null hypothesis of no fixed effects. This means we should include state and/or time fixed effects in our model. Hence the fixed effect model is better for this scenario.

## 6 (10 points) Consider a Random Effects Model

**6.0.0.1 Status Mostly Complete:** Include consequences about inappropriately estimating a random effects model.

### 6.1 Random Effect Model Assumptions

Assumption for a random effects model is  $cov(x_{it}, a_i) = 0$ , i.e. the fixed effect is uncorrelated to the independent variables at any time period.

### 6.2 Estimating the Random Effect Model

```
expanded.re <- plm(log(log_total_fatalities_rate) ~ bac + year +
  population_aged_14_to_24_rate + miles_driven_per_capita +
  unemployment_rate + speed_limit_70_plus + per_se_law +
  seat_belt_law + graduated_drivers_license_law,
  data = main_p,
  index = c("state", "year"),
  model = "random")

summary(expanded.re)

## Oneway (individual) effect Random Effect Model
## (Swamy-Arora's transformation)
##
## Call:
## plm(formula = log(log_total_fatalities_rate) ~ bac + year + population_aged_14_to_24_rate +
## miles_driven_per_capita + unemployment_rate + speed_limit_70_plus +
## per_se_law + seat_belt_law + graduated_drivers_license_law,
## data = main_p, model = "random", index = c("state", "year"))
##
## Balanced Panel: n = 48, T = 25, N = 1200
##
## Effects:
##               var   std.dev share
## idiosyncratic 0.001039 0.032234 0.224
## individual    0.003590 0.059914 0.776
## theta: 0.893
##
## Residuals:
```

```
##      Min.      1st Qu.      Median      3rd Qu.      Max.
## -0.1660054 -0.0184966  0.0024194  0.0204280  0.0990869
##
## Coefficients:
##              Estimate Std. Error z-value Pr(>|z|)
## (Intercept)    2.6777e-02  3.3896e-02   0.7900  0.429542
## bac10          -6.9546e-03  4.2398e-03  -1.6403  0.100940
## bac8           -9.2990e-03  6.0977e-03  -1.5250  0.127259
## year1981       -1.8385e-02  6.7789e-03  -2.7121  0.006685 **
## year1982       -3.6454e-02  7.2529e-03  -5.0261  5.005e-07 ***
## year1983       -4.4786e-02  7.5088e-03  -5.9645  2.454e-09 ***
## year1984       -5.8153e-02  7.6184e-03  -7.6333  2.289e-14 ***
## year1985       -6.4079e-02  7.9313e-03  -8.0792  6.520e-16 ***
## year1986       -4.8582e-02  8.4542e-03  -5.7466  9.107e-09 ***
## year1987       -6.1580e-02  9.0616e-03  -6.7958  1.077e-11 ***
## year1988       -6.9287e-02  9.8064e-03  -7.0655  1.600e-12 ***
## year1989       -9.3947e-02  1.0435e-02  -9.0034 < 2.2e-16 ***
## year1990       -9.9176e-02  1.0828e-02  -9.1589 < 2.2e-16 ***
## year1991       -1.1235e-01  1.1114e-02 -10.1091 < 2.2e-16 ***
## year1992       -1.3484e-01  1.1448e-02 -11.7785 < 2.2e-16 ***
## year1993       -1.4047e-01  1.1659e-02 -12.0487 < 2.2e-16 ***
## year1994       -1.5331e-01  1.1941e-02 -12.8391 < 2.2e-16 ***
## year1995       -1.5171e-01  1.2304e-02 -12.3305 < 2.2e-16 ***
## year1996       -1.7129e-01  1.2974e-02 -13.2019 < 2.2e-16 ***
## year1997       -1.7747e-01  1.3275e-02 -13.3688 < 2.2e-16 ***
## year1998       -1.9703e-01  1.3540e-02 -14.5516 < 2.2e-16 ***
## year1999       -2.0305e-01  1.3691e-02 -14.8304 < 2.2e-16 ***
## year2000       -2.1366e-01  1.3885e-02 -15.3877 < 2.2e-16 ***
## year2001       -2.0870e-01  1.4122e-02 -14.7788 < 2.2e-16 ***
## year2002       -1.9994e-01  1.4262e-02 -14.0195 < 2.2e-16 ***
## year2003       -2.0133e-01  1.4339e-02 -14.0401 < 2.2e-16 ***
## year2004       -2.1385e-01  1.4704e-02 -14.5436 < 2.2e-16 ***
## population_aged_14_to_24_rate 9.6276e-03  1.5455e-03   6.2293  4.684e-10 ***
## miles_driven_per_capita      2.5922e-05  1.7696e-06  14.6491 < 2.2e-16 ***
## unemployment_rate          -9.7906e-03  9.8326e-04  -9.9573 < 2.2e-16 ***
## speed_limit_70_plus         2.7523e-02  4.2568e-03   6.4658  1.008e-10 ***
## per_se_law1                -1.7036e-02  3.6422e-03  -4.6774  2.905e-06 ***
## seat_belt_lawsecondary       1.0944e-03  4.1220e-03   0.2655  0.790617
## seat_belt_lawprimary        -1.4173e-02  5.5867e-03  -2.5369  0.011185 *
## graduated_drivers_license_law -4.0096e-03  4.7872e-03  -0.8376  0.402278
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    4.3716
## Residual Sum of Squares: 1.2721
## R-Squared:    0.70902
## Adj. R-Squared: 0.70052
## Chisq: 2838.65 on 34 DF, p-value: < 2.22e-16
```

We conduct a Hausman test for random vs. fixed effects using `phptest`. We perform this test with an  $\alpha = 0.05$

```
res <- phptest(expanded.within, expanded.re)
```

With a p-value of  $3.6519259 \times 10^{-51}$  much less than  $\alpha$ , we reject the null hypothesis that random effects are

appropriate, suggesting that we should use the fixed models. The random effects model is not likely to be consistent in this case.

TODO: Comment about consequences

## 7 (10 points) Model Forecasts

```
# Source
# U.S. Federal Highway Administration, Vehicle Miles Traveled [TRFVOLUSM227NFWA],
# retrieved from FRED, Federal Reserve Bank of St. Louis;
# https://fred.stlouisfed.org/series/TRFVOLUSM227NFWA, November 29, 2022.
# Driving mile units in millions
miles.driven <-
  readr::read_csv("./data/TRFVOLUSM227NFWA.csv", show_col_types = FALSE) %>%
  rename(miles = TRFVOLUSM227NFWA, date = DATE)

largest.decrease <- 0
largest.increase <- 0
max <- -Inf
min <- Inf

# Comparing each month miles driven
for (i in 1:12) {
  val.18 <- miles.driven %>%
    filter(date == mdy(paste(i, 1, 2018, sep="/")))

  # Comparing 2018 with 2020 and 2021
  for (j in 2020:2021) {
    val.covid <- miles.driven %>%
      filter(date == mdy(paste(i, 1, j, sep="/")))

    diff <- val.covid$miles - val.18$miles
    if(diff < min) {
      largest.decrease <- mdy(paste(i, 1, j, sep="/"))
      min = diff
    }
    if(diff > max) {
      largest.increase <- mdy(paste(i, 1, j, sep="/"))
      max = diff
    }
  }
}

# Calculating percentage
prev <- miles.driven %>%
  filter(date == largest.decrease)
lower.percentage <- min/prev$miles

prev <- miles.driven %>%
  filter(date == largest.increase)
higher.percentage <- max/prev$miles
```

**7.0.0.1 Status Completed: Checked by Hannah** The largest month-over-month decrease in driving was in April 2020 and it was lower by -64.14%. This was right as the pandemic was starting to make its way through the country and the response was to shut everything down. So a rapid decrease in driving would make sense. In contrast, the largest month-over-month increase in driving was in January 2020 and it was higher by 6.18%. This was right before the pandemic and the increase is not as severe as the pandemic decrease was.

```
# Source
# U.S. Bureau of Economic Analysis, Population [POPTHM],
# Retrieved from FRED, Federal Reserve Bank of St. Louis;
# https://fred.stlouisfed.org/series/POPTHM, December 3, 2022.
# Pop Units in thousands
us.pop.month <-
  readr::read_csv("./data/POPTHM.csv", show_col_types = FALSE) %>%
  rename(total_population = POPTHM, date = DATE) %>%
  mutate(date = as.Date(date, "%m/%d/%Y"))

# Filter to get population on date with largest increase
max_pop <- us.pop.month %>%
  filter(date == largest.increase)

# Filter to get population on date with largest decrease
min_pop <- us.pop.month %>%
  filter(date == largest.decrease)

# Calculate increase/decrease per capita based on min/max drive values and pop.
max_month_pop <- max_pop$total_population * 1000 # Units in thousands
min_month_pop <- min_pop$total_population * 1000
max_miles <- max * 1000000 # Units in millions
min_miles <- min * 1000000

max_miles_driven_pc <- max_miles / max_month_pop
min_miles_driven_pc <- min_miles / min_month_pop

# fatal rate - represents increases/decreases in the fatality rate
fatal_rate_covid_max <- round(coef(expanded.within)['miles_driven_per_capita'] * max_miles_driven_pc, 3)
fatal_rate_covid_min <- round(coef(expanded.within)['miles_driven_per_capita'] * min_miles_driven_pc, 3)
```

The FE model suggests that a one mile increase in the miles driven per capita is associated with a 0.00003 unit increase in the fatality rate. During the COVID boom, the largest increase in driving was on January 2020 and it results in an estimated increase of 48.61 miles driven per capita and this is expected to result in a 0.001 unit increase in the fatality rate.

In contrast, the largest decrease in driving was on April 2020 and it results in an estimated decrease of -324.14 miles driven per capita and this is expected to result in a -0.009 unit decrease in the fatality rate.

## 8 (5 points) Evaluate Error

### 8.0.0.1 Status incomplete

## 8.1 Analysis of Residuals

We test the residuals for serial correlation. The null hypothesis for the test is that the residuals are not serially correlated and the alternate hypothesis is that the residuals are serially correlated. We check against an  $\alpha$  of 0.05.

```
pwd <- pdwtest(expanded.within)
```

With a p-value of  $6.5724615 \times 10^{-46}$ , we reject the null hypothesis of no serial correlation. This suggests that we must use robust standard errors for model parameters.

## 8.2 Heteroskedasticity Test

We perform a Breusch Pagan test for heteroskedasticity. The null hypothesis for the test is that the residuals are homoskedastic and the alternate hypothesis is that the residuals are heteroskedastic. We check against an  $\alpha$  of 0.05.

```
pcd <- pcptest(expanded.within, test = "lm")
```

With a p-value of  $1.4895406 \times 10^{-146}$ , we reject the null hypothesis of homoskedasticity. This suggests that heteroskedasticity is present and our residuals are not distributed with equal variance. We may be able to correct for this by using heteroskedasticity-consistent standard errors or robust standard errors.

We compare the results of the Durbin Watson and Breusch-Godfrey test with order = 2. The null hypothesis is that there is no serial correlation of any order less than or equal to p.

```
pbg <- pbgttest(expanded.within, order = 2)
```

With a p-value of  $3.5077171 \times 10^{-48}$ , we reject the null hypothesis and conclude that autocorrelation exists among the residuals at some order less than or equal to p.

Using `vcovHC`, we calculate robust standard errors (`white1`), cluster robust standard errors (`white2`), arellano standard errors (`arellano`), and newey west standard errors (using `vcovNW`) for the coefficients within our FE model.

```
reg.se <- coef(summary(expanded.within))[1,2]
het.se <- sqrt(vcovHC(expanded.within, method = "white1", type = "HCO")[1,1])
cluster.se <- sqrt(vcovHC(expanded.within, method = "white2", type = "HCO")[1,1])
nw.se <- sqrt(vcovNW(expanded.within, type = "HCO", maxlag = 1)[1,1])
arellano.se <- sqrt(vcovHC(expanded.within, method = "arellano", type = "HCO")[1,1])

data.frame(
  "Type" = c("Regular OLS", "Robust", "Cluster Robust", "Newey West", "Arellano"),
  "SE" = c(reg.se, het.se, cluster.se, nw.se, arellano.se)
)
```

##	Type	SE
## 1	Regular OLS	0.004982780
## 2	Robust	0.005353132
## 3	Cluster Robust	0.004787973
## 4	Newey West	0.006195990
## 5	Arellano	0.008663517

Our analysis shows that the residuals in our model are both heteroskedastic and have serial correlation. The results from the `vcovHC` analysis suggests that cluster robust standard errors are the most robust. Specifically, the standard errors for cluster robust standard errors are slightly smaller than the regular OLS errors and robust standard error, while quite a bit higher (e.g, greater than 0.003) compared to the other standard error types.

When using robust cluster standard errors, our analysis shows that the fixed effects model has the highest R-squared value among the pooled and expanded OLS counterparts, as well as the lowest standard errors.

Table 2:

	log_total_fatalities_rate		
	Pooled	Expanded OLS	Within
	(1)	(2)	(3)
year1981	-0.034 (0.029)	-0.041** (0.018)	-0.026*** (0.008)
year1982	-0.087*** (0.029)	-0.131*** (0.019)	-0.051*** (0.008)
year1983	-0.102*** (0.029)	-0.151*** (0.019)	-0.061*** (0.009)
year1984	-0.098*** (0.029)	-0.120*** (0.019)	-0.078*** (0.009)
year1985	-0.106*** (0.029)	-0.133*** (0.020)	-0.087*** (0.009)
year1986	-0.085*** (0.029)	-0.122*** (0.021)	-0.066*** (0.010)
year1987	-0.086*** (0.029)	-0.135*** (0.022)	-0.082*** (0.011)
year1988	-0.082*** (0.029)	-0.139*** (0.023)	-0.091*** (0.012)
year1989	-0.108*** (0.029)	-0.173*** (0.024)	-0.122*** (0.012)
year1990	-0.116*** (0.029)	-0.196*** (0.025)	-0.127*** (0.013)
year1991	-0.149*** (0.029)	-0.244*** (0.025)	-0.143*** (0.013)
year1992	-0.175*** (0.029)	-0.290*** (0.026)	-0.168*** (0.014)
year1993	-0.175*** (0.029)	-0.287*** (0.026)	-0.175*** (0.014)
year1994	-0.177*** (0.029)	-0.284*** (0.027)	-0.189*** (0.014)
year1995	-0.167*** (0.029)	-0.277*** (0.027)	-0.186*** (0.015)
year1996	-0.173*** (0.029)	-0.331*** (0.028)	-0.205*** (0.015)
year1997	-0.168*** (0.029)	-0.340*** (0.029)	-0.211*** (0.016)
year1998	-0.178*** (0.029)	-0.366*** (0.029)	-0.232*** (0.016)