MPGTransmissionStudy.Rmd

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Executive Summary

This project is intended to answer the following two questions:

1. "Is an automatic or manual transmission better for MPG?"

2. "Quantify the MPG difference between automatic and manual transmissions?"

using statistical regression analysis in **R** on the **"Motor Trend"**, **"mtcars"** data set included with the **R** system. This study does not show transmission type (automatic vs. manual) to be significant once one accounts for weight and number of engine cylinders. This result, however, may represent a flaw in the study design; this regression study, in effect uses group averages and not paired data. Paired data would be closer to the consumer experience of evaluating one model of car with manual or automatic transmission. There may be a more distinct effect when one examines one model of car with manual or automatic transmission rather than pooling several models of cars together in one data set.

Data Vintage

The source of the **"mtcars"** data set (as described in the documentation **help(mtcars)**) is Henderson and Velleman (1981), **Building multiple regression models interactively.** Biometrics, 37, 391–411. http://www.mortality.org/INdb/2008/02/12/8/document.pdf

The **help(mtcars)** documentation states:

> "The data was extracted from the **1974 Motor Trend** US magazine,
> and comprises fuel consumption and 10 aspects of automobile design and performance
> for 32 automobiles (**1973–74 models**)."

So, it should be noted the **"mtcars"** data set is vintage **mid-1970s** and is therefore unlikely to be representative of the contemporary state of the automotive art.

Exploratory Data Analysis

According to the **help(mtcars)** documentation, **"mtcars"** is

> "A **data frame** with 32 observations on 11 variables.
>
> [, 1] **mpg** Miles/(US) gallon
> [, 2] **cyl** Number of cylinders
> [, 3] **disp** Displacement (cu.in.)
> [, 4] **hp** Gross horsepower
> [, 5] **drat** Rear axle ratio
> [, 6] **wt** Weight (lb/1000)
> [, 7] **qsec** 1/4 mile time
> [, 8] **vs** V/S
> [, 9] **am** Transmission (0 = automatic, 1 = manual)
> [,10] **gear** Number of forward gears
> [,11] **carb** Number of carburetors"

The documentation is confirmed using the **str()** (structure) function in **R**:

```
data(mtcars)
str(mtcars)
```

```
## 'data.frame':    32 obs. of  11 variables:
##  $ mpg : num  21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
##  $ cyl : num  6 6 4 6 8 6 8 4 4 6 ...
##  $ disp: num  160 160 108 258 360 ...
##  $ hp  : num  110 110 93 110 175 105 245 62 95 123 ...
##  $ drat: num  3.9 3.9 3.85 3.08 3.15 2.76 3.21 3.69 3.92 3.92 ...
##  $ wt  : num  2.62 2.88 2.32 3.21 3.44 ...
##  $ qsec: num  16.5 17 18.6 19.4 17 ...
##  $ vs  : num  0 0 1 1 0 1 0 1 1 1 ...
##  $ am  : num  1 1 1 0 0 0 0 0 0 0 ...
##  $ gear: num  4 4 4 3 3 3 3 4 4 4 ...
##  $ carb: num  4 4 1 1 2 1 4 2 2 4 ...
```

Preliminary Analysis

On the surface the minimum requirements of this project are trivially simple:
1. Convert the zero-one transmission indicator variable, **"am"** to an **R "factor"**.
2. Run a regression with mpg = f(am) or in **R** notation **lm(mpg ~ am))**

```
# MPG Model zero "000" -- our "quick and dirty" literal regression
MPGmod000 <- lm(mpg ~ as.factor(am), data=mtcars)
MPGmod000
```

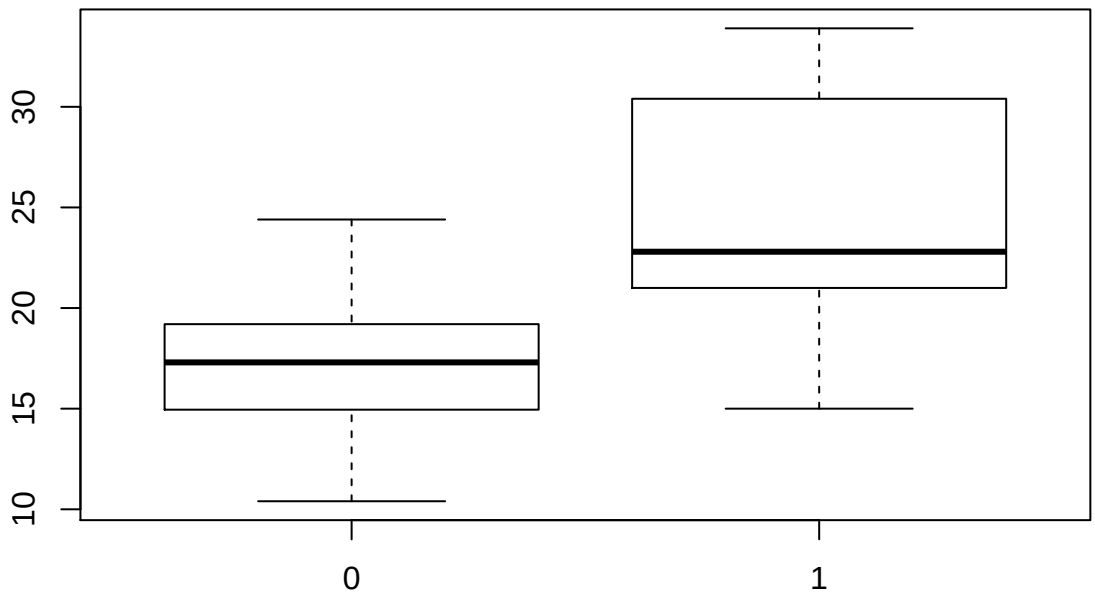
```
##
## Call:
## lm(formula = mpg ~ as.factor(am), data = mtcars)
##
## Coefficients:
##    (Intercept)  as.factor(am)1
##         17.147           7.245
```

According to the documention (help(mtcars)) the coding for **"am"** variable is
zero(0) = automatic transmission and one(1) = manual transmission.

So, the "quick and dirty" interpretation our base model zero, would be that
the average 1980 vintage car with automatic transmission gets 17 miles per gallon while the average 1980 vintage car with manual transmisson gets an additional 7 miles per gallon for a total of 24 miles per gallon.

We can picture this with a box plot.

```
plot(as.factor(mtcars$am), mtcars$mpg)
abline(mtcars$mpg ~ as.factor(mtcars$am))
```



Of course to accept this analysis at face value, one would have to invoke the economist's assumption of "***ceteris paribus***" (all other things being equal).

Of course we know all other things are **NOT EQUAL**. There are **confounding variables**. For instance, the cars vary in weight, number of cylinders in their engines and the size of their engines measured in cubic inch displacement.

```
# wt = Weight (lb/1000)
summary( mtcars$wt )
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.513   2.581   3.325   3.217   3.610   5.424
```

```
# cyl = Number of cylinders
summary( as.factor(mtcars$cyl) )
```

```
##  4  6  8
## 11  7 14
```

```
# disp = Displacement (cu.in.)
summary( mtcars$disp )
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    71.1   120.8   196.3   230.7   326.0   472.0
```

Historical Context

Moreover, keep in mind the historical context, this is the late 1970s/early 1980s when there was still a huge difference between American, European and Japanese auto technology.

> "In the mid-1980s, Toyota took over the Fremont [,California] plant, one of GM's worst, a factory known for sex, drugs and defective vehicles. And as part of an historic joint venture [NUMMI], Toyota turned the plant into one of GM's best, practically overnight.
> Along the way — remarkably — Toyota even shared its production secrets. ... In 1985, after NUMMI opened, Car and Driver magazine ran the following
> headline: **'Hell Freezes Over.'**"
> **"The End Of The Line For GM-Toyota Joint Venture"** by Frank Langfitt,
> National Public Radio (NPR), MARCH 26, 2010 3:00 PM ET
> http://www.npr.org/templates/story/story.php?storyId=125229157

GM's Saturn was not introduced until the 1991 model year, ten years after the 1981 vintage of the "mtcars" data set.
https://en.wikipedia.org/wiki/Saturn_Corporation

Electric vehicle hybrids, such as Toyota's Prius NHW11, were not introduced to the US market until the 2001 model year.
https://en.wikipedia.org/wiki/Toyota_Prius

A Web search for ggplot2 facet examples found a QuickR blog post, "Graphics with ggplot2" by Robert I. Kabacoff, PhD. http://www.statmethods.net/advgraphs/ggplot2.html

```
# Separate regressions of mpg on weight for each number of cylinders
# create factors with value labels
library(ggplot2)
data(mtcars)
mtcars$gear <- factor(mtcars$gear,levels=c(3,4,5),
                      labels=c("3gears","4gears","5gears"))
mtcars$am <- factor(mtcars$am,levels=c(0,1),
                    labels=c("Automatic","Manual"))
mtcars$cyl <- factor(mtcars$cyl,levels=c(4,6,8),
                     labels=c("4 cylinder","6 cylinder","8 cylinder"))

# All -- use everything
MPGModAll <- lm(mpg  ~ . , data = mtcars);
summary(MPGModAll)
```

```
##
## Call:
## lm(formula = mpg ~ ., data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.2015 -1.2319  0.1033  1.1953  4.3085
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)   15.09262   17.13627   0.881   0.3895
## cyl6 cylinder -1.19940    2.38736  -0.502   0.6212
## cyl8 cylinder  3.05492    4.82987   0.633   0.5346
```

```
## disp          0.01257    0.01774   0.708   0.4873
## hp           -0.05712    0.03175  -1.799   0.0879 .
## drat          0.73577    1.98461   0.371   0.7149
## wt           -3.54512    1.90895  -1.857   0.0789 .
## qsec          0.76801    0.75222   1.021   0.3201
## vs            2.48849    2.54015   0.980   0.3396
## amManual      3.34736    2.28948   1.462   0.1601
## gear4gears   -0.99922    2.94658  -0.339   0.7382
## gear5gears    1.06455    3.02730   0.352   0.7290
## carb          0.78703    1.03599   0.760   0.4568
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.616 on 19 degrees of freedom
## Multiple R-squared:  0.8845, Adjusted R-squared:  0.8116
## F-statistic: 12.13 on 12 and 19 DF,  p-value: 1.764e-06
```

```
# Weignt is significant
MPGmod001 <- lm(mpg ~ as.factor(am)+wt, data=mtcars)
summary(MPGmod001)
```

```
##
## Call:
## lm(formula = mpg ~ as.factor(am) + wt, data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.5295 -2.3619 -0.1317  1.4025  6.8782
##
## Coefficients:
##                     Estimate Std. Error t value Pr(>|t|)
## (Intercept)         37.32155    3.05464  12.218 5.84e-13 ***
## as.factor(am)Manual -0.02362    1.54565  -0.015    0.988
## wt                  -5.35281    0.78824  -6.791 1.87e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.098 on 29 degrees of freedom
## Multiple R-squared:  0.7528, Adjusted R-squared:  0.7358
## F-statistic: 44.17 on 2 and 29 DF,  p-value: 1.579e-09
```

```
# Cylinders helps
MPGmod002 <- lm(mpg ~ as.factor(am)+wt+as.factor(cyl), data=mtcars)
summary(MPGmod002)
```

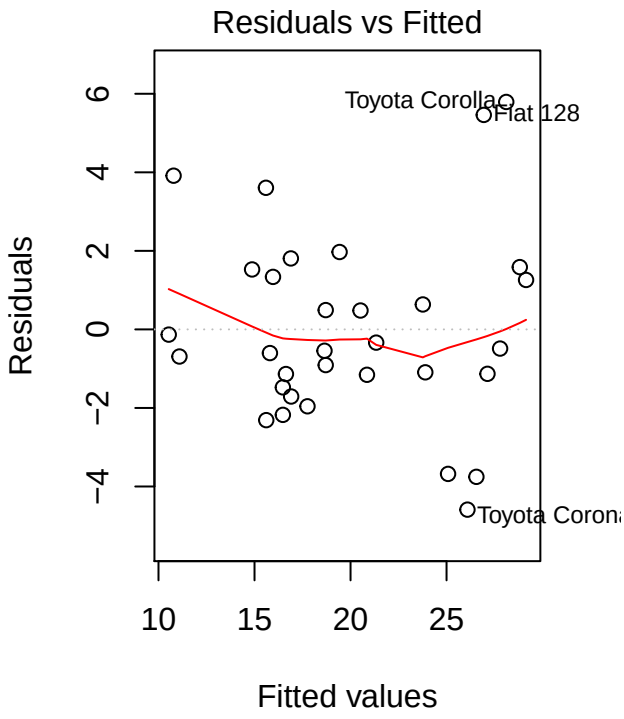
```
##
## Call:
## lm(formula = mpg ~ as.factor(am) + wt + as.factor(cyl), data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.4898 -1.3116 -0.5039  1.4162  5.7758
##
```

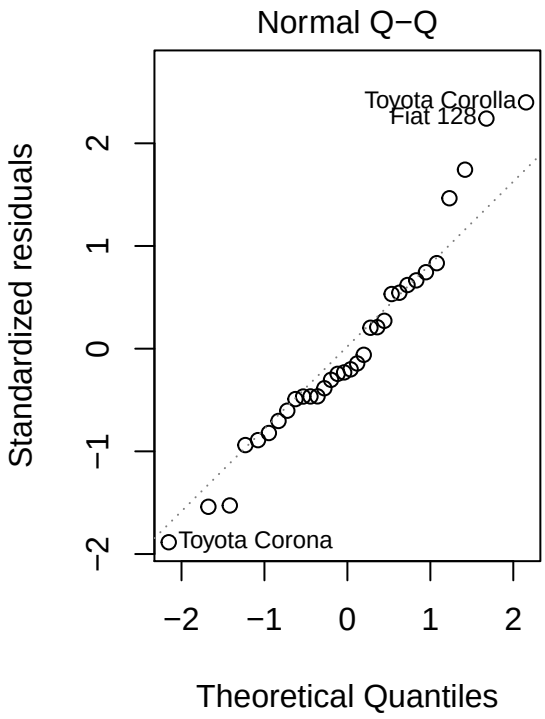
```
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                33.7536     2.8135  11.997  2.5e-12 ***
## as.factor(am)Manual         0.1501     1.3002   0.115  0.90895
## wt                         -3.1496     0.9080  -3.469  0.00177 **
## as.factor(cyl)6 cylinder   -4.2573     1.4112  -3.017  0.00551 **
## as.factor(cyl)8 cylinder   -6.0791     1.6837  -3.611  0.00123 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.603 on 27 degrees of freedom
## Multiple R-squared:  0.8375, Adjusted R-squared:  0.8134
## F-statistic: 34.79 on 4 and 27 DF,  p-value: 2.73e-10
```

```
# drop Transmission (am) *** BEST MODEL ***
par(mfrow = c(1,2))
MPGmod003 <- lm(mpg ~ wt+as.factor(cyl), data=mtcars)
summary(MPGmod003)
```

```
##
## Call:
## lm(formula = mpg ~ wt + as.factor(cyl), data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.5890 -1.2357 -0.5159  1.3845  5.7915
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                33.9908     1.8878  18.006  < 2e-16 ***
## wt                         -3.2056     0.7539  -4.252 0.000213 ***
## as.factor(cyl)6 cylinder   -4.2556     1.3861  -3.070 0.004718 **
## as.factor(cyl)8 cylinder   -6.0709     1.6523  -3.674 0.000999 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.557 on 28 degrees of freedom
## Multiple R-squared:  0.8374, Adjusted R-squared:   0.82
## F-statistic: 48.08 on 3 and 28 DF,  p-value: 3.594e-11
```

```
plot(MPGmod003, which = 1)
plot(MPGmod003, which = 2)
```





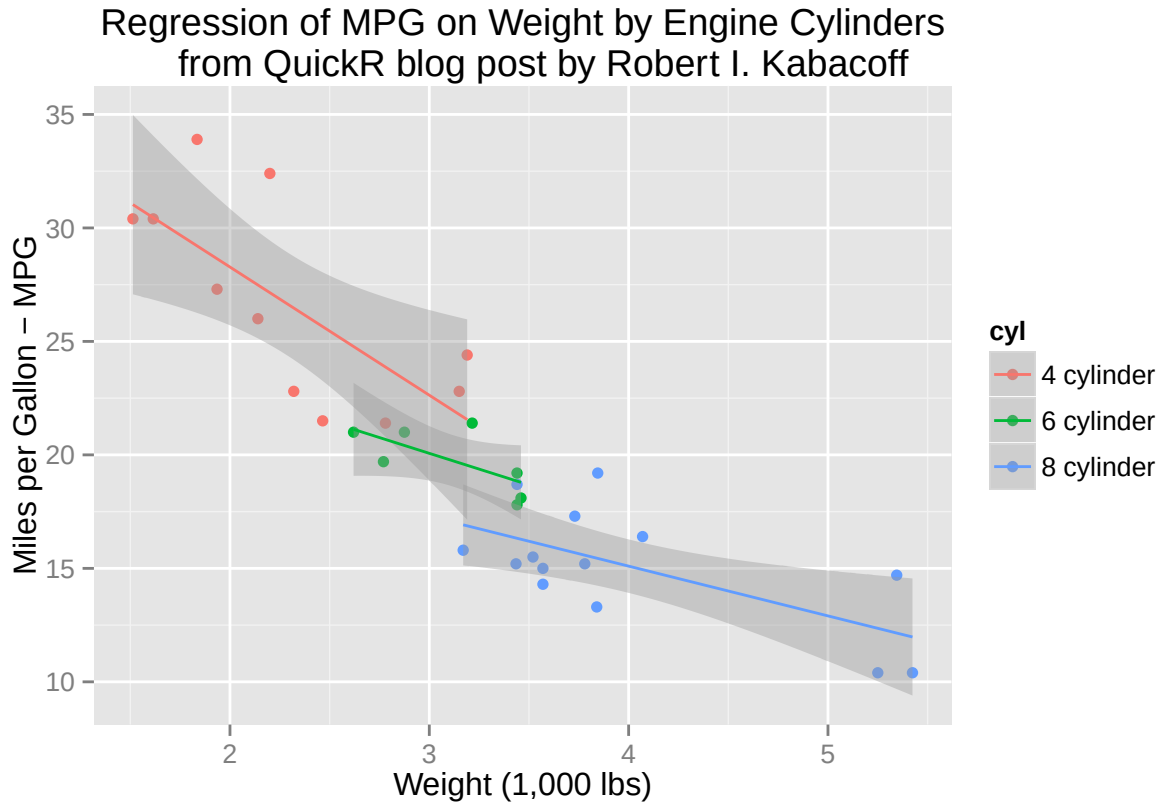

```
MPGmod005 <- lm(mpg ~ log(wt), data=mtcars)
summary(MPGmod005)
```

```
##
## Call:
## lm(formula = mpg ~ log(wt), data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.7440 -2.0954 -0.3672  1.0709  6.6150
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   39.257      1.758   22.32  < 2e-16 ***
## log(wt)      -17.086      1.510  -11.31 2.39e-12 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.669 on 30 degrees of freedom
## Multiple R-squared:  0.8101, Adjusted R-squared:  0.8038
## F-statistic:   128 on 1 and 30 DF,  p-value: 2.391e-12
```

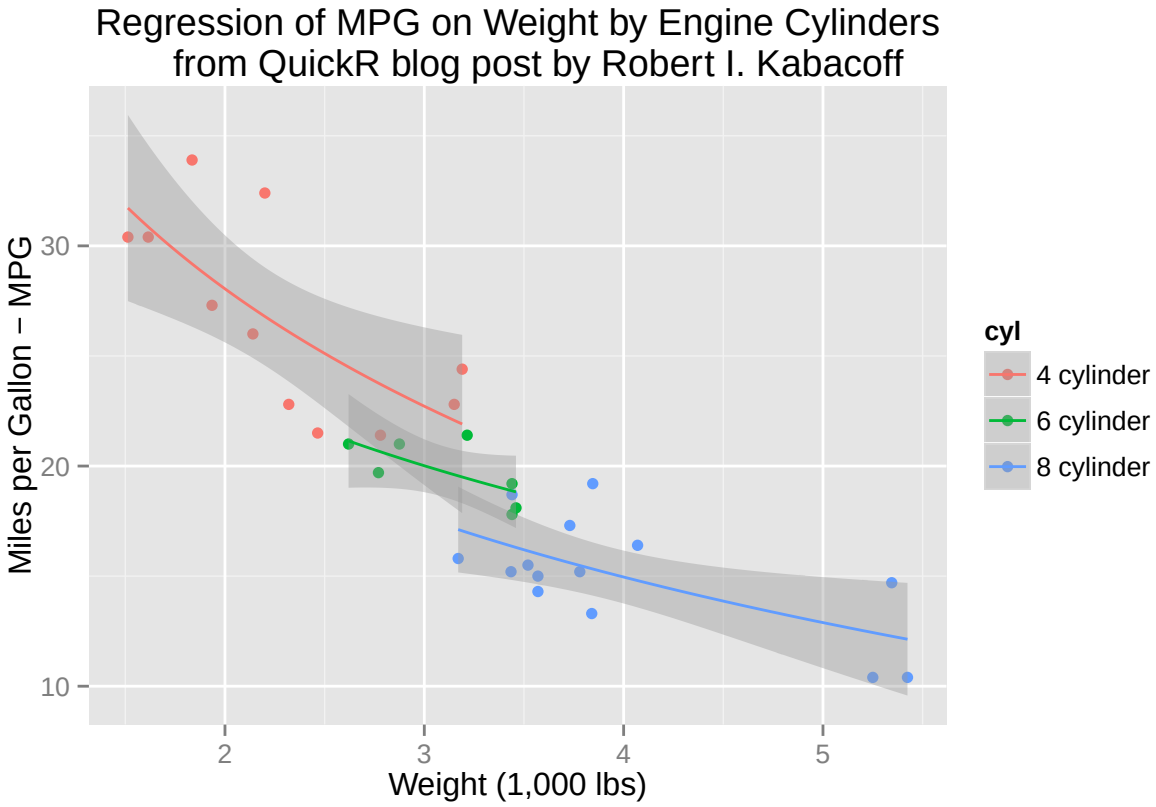
```
MPGmod005 <- lm(mpg ~ log(wt)+as.factor(cyl), data=mtcars)
summary(MPGmod005)
```

```
##
## Call:
## lm(formula = mpg ~ log(wt) + as.factor(cyl), data = mtcars)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.9830 -1.3486 -0.6479  1.6017  5.6220
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 35.755      1.941  18.418  < 2e-16 ***
## log(wt)                    -11.386      2.260  -5.039  2.5e-05 ***
## as.factor(cyl)6 cylinder    -3.133      1.373  -2.283  0.03025 *
## as.factor(cyl)8 cylinder    -5.045      1.609  -3.135  0.00401 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.375 on 28 degrees of freedom
## Multiple R-squared:  0.8597, Adjusted R-squared:  0.8446
## F-statistic: 57.18 on 3 and 28 DF,  p-value: 4.633e-12
```

```
qplot(wt, mpg, data=mtcars, geom=c("point", "smooth"),
      method="lm", formula=y~x, color=cyl,
      main="Regression of MPG on Weight by Engine Cylinders
    from QuickR blog post by Robert I. Kabacoff",
      xlab="Weight (1,000 lbs)",
      ylab="Miles per Gallon - MPG")
```




```
qplot(wt, mpg, data=mtcars, geom=c("point", "smooth"),
      method="lm", formula=y~log(x), color=cyl,
      main="Regression of MPG on Weight by Engine Cylinders
    from QuickR blog post by Robert I. Kabacoff",
      xlab="Weight (1,000 lbs)",
      ylab="Miles per Gallon - MPG")
```


Regression of MPG on Weight by Engine Cylinders
from QuickR blog post by Robert I. Kabacoff
Miles per Gallon – MPG
30
20
10
2
3
4
5
Weight (1,000 lbs)
cyl
4 cylinder
6 cylinder
8 cylinder