511-LM

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Linear Regression

The goal of linear regression, in short, is to predict the value of a chosen response variable based on the value of another variable or variables, which are called “predictors”. The equations of multiple linear regression models, which consider multiple predictor variables, take the following form:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \epsilon$, where ϵ represents the error present in the model.

Research Question

1. Can the elements of a car’s design be used to predict its CO_2 output?
2. Which elements of a car’s design are best at predicting CO_2 output?

Assumptions of Linear Regression

1. Individual observations are independent from each other
2. A linear relationship exists between the independent predictor variables X_i and the dependent response variable Y
3. Homoscedasticity, or homogeneity of variance
4. The residuals of the model are normally distributed

In this section, we are going use multiple linear regression to determine which elements of a car’s design (predictor variables $X_1, X_2, \ldots, X_n$) are good predictors of a car’s CO_2 emissions (response variable Y).

Since electric cars do not give off CO_2 emissions, I am going to start by reading in our cleaned non-electric, or fuel-based cars, dataset.

```
setwd("..")
getwd()
```

```
## [1] "/Users/smithnatalie/ANLY511-Final-Project"
```

```
nonelectric = read.csv("data/cardata_nonelectric_clean.csv")
```

```
library(caret)
```

```
## Loading required package: ggplot2
```

```
## Loading required package: lattice
```

```
library(tidyverse)
```

```
## ── Attaching packages
## ─────────────────────────────────────
## tidyverse 1.3.2 ──
```

```
## ✔ tibble  3.1.8     ✔ dplyr   1.0.9
## ✔ tidyr   1.2.0     ✔ stringr 1.4.0
## ✔ readr   2.1.2     ✔ forcats 0.5.1
## ✔ purrr   0.3.4
## ── Conflicts ──────────────────────────────────────── tidyverse_conflicts() ──
## ✖ dplyr::filter() masks stats::filter()
## ✖ dplyr::lag()    masks stats::lag()
## ✖ purrr::lift()   masks caret::lift()
```

```
library(car)
```

```
## Loading required package: carData
##
## Attaching package: 'car'
##
## The following object is masked from 'package:dplyr':
##
##     recode
##
## The following object is masked from 'package:purrr':
##
##     some
```

```
library(ISLR2)
library(leaps)
```

Before splitting into training and testing, I want to ensure the predictor of Model Year can be considered as categorical for the regression model by adding a categorical column with the same data to the dataset.

```
dplyr::count(nonelectric, Model.Year, sort = TRUE)
```

```
##   Model.Year    n
## 1       2018 4607
## 2       2019 4559
## 3       2020 4298
## 4       2022 4191
## 5       2021 4083
```

```
nonelectric$Model.Year.Cat = as.character(nonelectric$Model.Year)
```

Next, the data will be split into training and testing datasets with an 80/20 split.

```
set.seed(101)

training.samples = nonelectric$CO2..g.mi. %>%
  createDataPartition(p = 0.8, list = FALSE)

training.data = nonelectric[training.samples,]
testing.data = nonelectric[-training.samples, ]
```

```
dim(training.data)
```

```
## [1] 17392    39
```

```
dim(testing.data)
```

```
## [1] 4346   39
```

```
head(training.data)
```

```
##   X Model.Year Vehicle.Manufacturer.Name Veh.Mfr.Code Represented.Test.Veh.Make
## 1 1       2018              aston martin          ASX              Aston Martin
## 2 2       2018              aston martin          ASX              Aston Martin
## 3 3       2018              aston martin          ASX              Aston Martin
## 4 4       2018              aston martin          ASX              Aston Martin
## 5 5       2018              aston martin          ASX              Aston Martin
## 6 6       2018              aston martin          ASX              Aston Martin
##   Represented.Test.Veh.Model Test.Veh.Displacement..L. Vehicle.Type
## 1                       DB11                       5.2          Car
## 2                       DB11                       5.2          Car
## 3                    DB11 V8                       4.0          Car
## 4                    DB11 V8                       4.0          Car
## 5                   Rapide S                       6.0          Car
## 6                   Rapide S                       6.0          Car
##   Rated.Horsepower X..of.Cylinders.and.Rotors Tested.Transmission.Type.Code
## 1              600                        12                           SA
## 2              600                        12                           SA
## 3              503                         8                           SA
## 4              503                         8                           SA
## 5              552                        12                           SA
## 6              552                        12                           SA
##   Tested.Transmission.Type X..of.Gears Transmission.Lockup. Drive.System.Code
## 1           Semi-Automatic           8                    Y                 R
## 2           Semi-Automatic           8                    Y                 R
## 3           Semi-Automatic           8                    Y                 R
## 4           Semi-Automatic           8                    Y                 R
## 5           Semi-Automatic           8                    Y                 R
## 6           Semi-Automatic           8                    Y                 R
##   Drive.System.Description Equivalent.Test.Weight..lbs.. Axle.Ratio N.V.Ratio
## 1      2-Wheel Drive, Rear                          4500       2.70      22.2
## 2      2-Wheel Drive, Rear                          4500       2.70      22.2
## 3      2-Wheel Drive, Rear                          4500       2.70      22.2
## 4      2-Wheel Drive, Rear                          4500       2.70      22.2
## 5      2-Wheel Drive, Rear                          4750       2.73      22.4
## 6      2-Wheel Drive, Rear                          4750       2.73      22.4
##   Test.Fuel.Type.Description THC..g.mi. CO..g.mi. CO2..g.mi. RND_ADJ_FE
## 1       Tier 2 Cert Gasoline   0.024700  0.418000     466.87       18.8
## 2       Tier 2 Cert Gasoline   0.001155  0.067334     285.00       30.9
## 3       Tier 2 Cert Gasoline   0.026500  0.070000     386.66       22.7
## 4       Tier 2 Cert Gasoline   0.000500  0.030000     259.74       33.8
## 5       Tier 2 Cert Gasoline   0.026900  0.500000     511.93       17.3
## 6       Tier 2 Cert Gasoline   0.000800  0.060000     296.63       29.9
##   DT.Inertia.Work.Ratio.Rating DT.Absolute.Speed.Change.Ratg
## 1                   -2.5300000                   -1.7300000
## 2                    1.3600000                    0.4400000
## 3                  -11.9900000                   -9.2600000
## 4                   -3.6400000                   -3.2100000
## 5                    0.5655838                    0.4420405
## 6                    0.5655838                    0.4420405
##   DT.Energy.Economy.Rating Target.Coef.A..lbf. Target.Coef.B..lbf.mph.
## 1               -1.7100000               40.94                  0.0169
## 2               -0.5900000               40.94                  0.0169
## 3               -7.7100000               40.94                  0.0169
## 4               -0.9600000               40.94                  0.0169
## 5               -0.2002973               32.66                  0.6085
## 6               -0.2002973               32.66                  0.6085
##   Target.Coef.C..lbf.mph..2. Set.Coef.A..lbf. Set.Coef.B..lbf.mph.
## 1                     0.0271            6.810               0.0807
## 2                     0.0271            6.810               0.0807
## 3                     0.0271           11.260               0.0919
## 4                     0.0271           11.260               0.0919
## 5                     0.0198            1.093               2.1980
## 6                     0.0198            1.093               2.1980
##   Set.Coef.C..lbf.mph..2. Aftertreatment.Device.Cd Aftertreatment.Device.Desc
## 1                  0.0245                      TWC         Three-way catalyst
## 2                  0.0245                      TWC         Three-way catalyst
## 3                  0.0251                      TWC         Three-way catalyst
## 4                  0.0251                      TWC         Three-way catalyst
```

```
## 5                  0.0280                      TWC         Three-way catalyst
## 6                  0.0280                      TWC         Three-way catalyst
##   Police...Emergency.Vehicle. Averaging.Method.Cd Averging.Method.Desc
## 1                           N                   N         No averaging
## 2                           N                   N         No averaging
## 3                           N                   N         No averaging
## 4                           N                   N         No averaging
## 5                           N                   N         No averaging
## 6                           N                   N         No averaging
##   Model.Year.Cat
## 1           2018
## 2           2018
## 3           2018
## 4           2018
## 5           2018
## 6           2018
```

```
head(testing.data)
```

```
##     X Model.Year Vehicle.Manufacturer.Name Veh.Mfr.Code
## 10 10       2018                  Bentley          BEX
## 26 26       2018                      BMW          BMX
## 29 29       2018                      BMW          BMX
## 30 30       2018                      BMW          BMX
## 49 49       2018                      BMW          BMX
## 51 51       2018                      BMW          BMX
##    Represented.Test.Veh.Make Represented.Test.Veh.Model
## 10                   BENTLEY             Continental GT
## 26                       BMW                 230i Coupe
## 29                       BMW                 230i Coupe
## 30                       BMW                 230i Coupe
## 49                       BMW                       320i
## 51                       BMW                       320i
##    Test.Veh.Displacement..L. Vehicle.Type Rated.Horsepower
## 10                     5.998          Car              616
## 26                     2.000          Car              248
## 29                     2.000          Car              248
## 30                     2.000          Car              248
## 49                     2.000         Both              181
## 51                     2.000         Both              180
##    X..of.Cylinders.and.Rotors Tested.Transmission.Type.Code
## 10                         12                            SA
## 26                          4                            SA
## 29                          4                            SA
## 30                          4                            SA
## 49                          4                             A
## 51                          4                             M
##    Tested.Transmission.Type X..of.Gears Transmission.Lockup. Drive.System.Code
## 10           Semi-Automatic           8                    Y                 F
## 26           Semi-Automatic           8                    Y                 R
## 29           Semi-Automatic           8                    Y                 R
## 30           Semi-Automatic           8                    Y                 R
## 49                Automatic           8                    Y                 R
## 51                   Manual           6                    N                 R
##    Drive.System.Description Equivalent.Test.Weight..lbs.. Axle.Ratio N.V.Ratio
## 10     2-Wheel Drive, Front                          6000       2.85      24.9
## 26      2-Wheel Drive, Rear                          3625       2.81      25.2
## 29      2-Wheel Drive, Rear                          3625       2.81      24.8
## 30      2-Wheel Drive, Rear                          3625       2.81      24.8
## 49      2-Wheel Drive, Rear                          3625       3.20      28.0
## 51      2-Wheel Drive, Rear                          3625       3.08      34.1
##    Test.Fuel.Type.Description THC..g.mi. CO..g.mi. CO2..g.mi. RND_ADJ_FE
## 10       Tier 2 Cert Gasoline  0.0711000 0.7680000   625.0000       14.2
## 26       Tier 2 Cert Gasoline  0.0049414 0.2191188   279.6962       31.8
## 29       Tier 2 Cert Gasoline  0.0010600 0.0609000   174.5200       50.5
## 30       Tier 2 Cert Gasoline  0.0054200 0.3940000   294.2200       30.0
## 49       Tier 2 Cert Gasoline  0.0173200 0.3219000   315.5700       28.2
## 51       Tier 2 Cert Gasoline  0.0095300 0.3500000   300.9900       29.5
##    DT.Inertia.Work.Ratio.Rating DT.Absolute.Speed.Change.Ratg
## 10                    0.5655838                    0.4420405
## 26                    2.8484370                    1.6135490
## 29                    2.1140000                    1.4250000
## 30                    0.0610000                   -0.1900000
## 49                    0.5655838                    0.4420405
## 51                    0.5655838                    0.4420405
##    DT.Energy.Economy.Rating Target.Coef.A..lbf. Target.Coef.B..lbf.mph.
## 10               -0.2002973              54.853                 0.04883
## 26                1.6329070              49.900                -0.20400
## 29               -0.6110000              46.300                -0.21500
## 30               -1.1230000              46.300                -0.21500
## 49               -0.2002973              46.200                -0.33400
## 51               -0.2002973              28.900                 0.11400
##    Target.Coef.C..lbf.mph..2. Set.Coef.A..lbf. Set.Coef.B..lbf.mph.
## 10                   0.022116           7.614              -0.0083
## 26                   0.020220          18.500               0.2390
## 29                   0.020230          15.000               0.2170
## 30                   0.020230          15.000               0.2170
```

```
## 49                   0.020270           21.000              -0.2680
## 51                   0.016280           16.400              -0.0940
##    Set.Coef.C..lbf.mph..2. Aftertreatment.Device.Cd Aftertreatment.Device.Desc
## 10                0.020935                      TWC         Three-way catalyst
## 26                0.014530                      TWC         Three-way catalyst
## 29                0.014640                      TWC         Three-way catalyst
## 30                0.014640                      TWC         Three-way catalyst
## 49                0.019040                      TWC         Three-way catalyst
## 51                0.015080                      TWC         Three-way catalyst
##    Police...Emergency.Vehicle. Averaging.Method.Cd Averging.Method.Desc
## 10                           N                   N         No averaging
## 26                           N                   N         No averaging
## 29                           N                   N         No averaging
## 30                           N                   N         No averaging
## 49                           N                   N         No averaging
## 51                           N                   N         No averaging
##    Model.Year.Cat
## 10           2018
## 26           2018
## 29           2018
## 30           2018
## 49           2018
## 51           2018
```

Next, it is important to check the data for any missing values before proceeding.

```
colSums(is.na(training.data))
```

```
##                             X                    Model.Year
##                             0                             0
##     Vehicle.Manufacturer.Name                  Veh.Mfr.Code
##                             0                             0
##     Represented.Test.Veh.Make    Represented.Test.Veh.Model
##                             0                             0
##     Test.Veh.Displacement..L.                  Vehicle.Type
##                             0                             0
##              Rated.Horsepower    X..of.Cylinders.and.Rotors
##                             0                             0
## Tested.Transmission.Type.Code      Tested.Transmission.Type
##                             0                             0
##                   X..of.Gears          Transmission.Lockup.
##                             0                             0
##             Drive.System.Code      Drive.System.Description
##                             0                             0
## Equivalent.Test.Weight..lbs..                    Axle.Ratio
##                             0                             0
##                      N.V.Ratio    Test.Fuel.Type.Description
##                             0                             0
##                    THC..g.mi.                     CO..g.mi.
##                             0                             0
##                    CO2..g.mi.                    RND_ADJ_FE
##                             0                             0
##  DT.Inertia.Work.Ratio.Rating DT.Absolute.Speed.Change.Ratg
##                             0                             0
##      DT.Energy.Economy.Rating           Target.Coef.A..lbf.
##                             0                             0
##       Target.Coef.B..lbf.mph.    Target.Coef.C..lbf.mph..2.
##                             0                             0
##              Set.Coef.A..lbf.          Set.Coef.B..lbf.mph.
##                             0                             0
##       Set.Coef.C..lbf.mph..2.      Aftertreatment.Device.Cd
##                             0                           158
##    Aftertreatment.Device.Desc   Police...Emergency.Vehicle.
##                           158                             0
##           Averaging.Method.Cd          Averging.Method.Desc
##                             0                             0
##                Model.Year.Cat
##                             0
```

```
colSums(is.na(testing.data))
```

```
##                             X                    Model.Year
##                             0                             0
##     Vehicle.Manufacturer.Name                 Veh.Mfr.Code
##                             0                             0
##     Represented.Test.Veh.Make   Represented.Test.Veh.Model
##                             0                             0
##     Test.Veh.Displacement..L.                 Vehicle.Type
##                             0                             0
##              Rated.Horsepower   X..of.Cylinders.and.Rotors
##                             0                             0
## Tested.Transmission.Type.Code     Tested.Transmission.Type
##                             0                             0
##                   X..of.Gears         Transmission.Lockup.
##                             0                             0
##             Drive.System.Code     Drive.System.Description
##                             0                             0
## Equivalent.Test.Weight..lbs..                   Axle.Ratio
##                             0                             0
##                      N.V.Ratio   Test.Fuel.Type.Description
##                             0                             0
##                    THC..g.mi.                    CO..g.mi.
##                             0                             0
##                    CO2..g.mi.                   RND_ADJ_FE
##                             0                             0
##  DT.Inertia.Work.Ratio.Rating DT.Absolute.Speed.Change.Ratg
##                             0                             0
##      DT.Energy.Economy.Rating          Target.Coef.A..lbf.
##                             0                             0
##       Target.Coef.B..lbf.mph.   Target.Coef.C..lbf.mph..2.
##                             0                             0
##              Set.Coef.A..lbf.         Set.Coef.B..lbf.mph.
##                             0                             0
##       Set.Coef.C..lbf.mph..2.     Aftertreatment.Device.Cd
##                             0                            35
##    Aftertreatment.Device.Desc  Police...Emergency.Vehicle.
##                            35                             0
##           Averaging.Method.Cd         Averging.Method.Desc
##                             0                             0
##                Model.Year.Cat
##                             0
```

Above, it can be seen that the Aftertreatment.Device.Cd and the Aftertreatment.Device.Desc have missing values. Because these columns may be significant in the model and because there are still many rows in the dataset, I will remove these rows from the original dataset and run the train/test split again.

```
nonelectric = nonelectric %>% drop_na()
```

Now, the split will be done again before proceeding to the linear regression model.

```
set.seed(101)

training.samples = nonelectric$CO2..g.mi. %>%
  createDataPartition(p = 0.8, list = FALSE)

training.data = nonelectric[training.samples,]
testing.data = nonelectric[-training.samples, ]
```

There are some initial unnecessary variables that can be removed before running the multiple linear regression model: - X (This is just an index) - Veh.Mfr.Code, Represented.Test.Veh.Make, Tested.Transmission.Type.Code, Drive.System.Code, and Aftertreatment.Device.Cd (We have the full name for all of these) - Police…Emergency.Vehicle (All “no’s” throughout and doesn’t apply to this dataset and what we are looking for at all) - Averaging.Method.Cd (This is just the way things are calculated rather than an actual metric - categorical)

Additionally, the two variables of Vehicle.Manufacturer.Name and Represented.Test.Veh.Model, which detail the make and model of each respective car, need to be left out. The reason for this is that the multiple linear regression model is unable to predict emissions for makes and models of cars that appear in the testing set but not the training set, preventing the model from working.

Other than those columns, all other terms will be used predict a full model and will tweaked based on results for additional models.

The following will be considered as categorical “dummy” variables in the model:

- Model.Year
- Vehicle.Type
- Tested.Transmission.Type
- Transmission.Lockup.
- Drive.System.Description
- Test.Fuel.Type.Description
- Averaging.Method.Desc

Emissions Model 1: Full model with all columns as predictors

```
emissions.model = lm(CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. + Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors + Tested.Transmission.Type + X..of.Gears + Transmission.Lockup. + Drive.System.Description + Equivalent.Test.Weight..lbs.. + Axle.Ratio + N.V.Ratio + Test.Fuel.Type.Description + THC..g.mi. + CO..g.mi. + RND_ADJ_FE + DT.Inertia.Work.Ratio.Rating + DT.Absolute.Speed.Change.Ratg + Target.Coef.A..lbf. + Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. + Set.Coef.B..lbf.mph. + Set.Coef.C..lbf.mph..2. + Aftertreatment.Device.Desc, data = training.data)
```

```
options(max.print=999999)
```

```
summary(emissions.model)
```

```
##
## Call:
## lm(formula = CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. +
##     Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors +
##     Tested.Transmission.Type + X..of.Gears + Transmission.Lockup. +
##     Drive.System.Description + Equivalent.Test.Weight..lbs.. +
##     Axle.Ratio + N.V.Ratio + Test.Fuel.Type.Description + THC..g.mi. +
##     CO..g.mi. + RND_ADJ_FE + DT.Inertia.Work.Ratio.Rating + DT.Absolute.Speed.Change.Ratg +
##     Target.Coef.A..lbf. + Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. +
##     Set.Coef.A..lbf. + Set.Coef.B..lbf.mph. + Set.Coef.C..lbf.mph..2. +
##     Aftertreatment.Device.Desc, data = training.data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -400.31  -23.82   -4.84   16.11  650.26
##
## Coefficients:
##                                                                                 Estimate
## (Intercept)                                                                    5.092e+02
## Model.Year.Cat2019                                                             1.406e+00
## Model.Year.Cat2020                                                             3.491e+00
## Model.Year.Cat2021                                                             2.929e+00
## Model.Year.Cat2022                                                             4.811e+00
## Test.Veh.Displacement..L.                                                      6.268e+00
## Vehicle.TypeCar                                                                6.482e+00
## Vehicle.TypeTruck                                                             -6.079e+00
## Rated.Horsepower                                                               3.851e-02
## X..of.Cylinders.and.Rotors                                                     6.081e+00
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) -7.612e+00
## Tested.Transmission.TypeAutomatic                                             -1.846e+00
## Tested.Transmission.TypeContinuously Variable                                  1.437e+01
## Tested.Transmission.TypeManual                                                -1.095e+01
## Tested.Transmission.TypeOther                                                 -1.380e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  8.761e+00
## Tested.Transmission.TypeSemi-Automatic                                        -8.860e-01
## X..of.Gears                                                                   -1.247e+00
## Transmission.Lockup.Y                                                         -4.032e+00
## Drive.System.Description2-Wheel Drive, Rear                                   -7.233e+00
## Drive.System.Description4-Wheel Drive                                         -1.259e+00
## Drive.System.DescriptionAll Wheel Drive                                       -3.997e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                               -2.087e+01
## Equivalent.Test.Weight..lbs..                                                 -7.149e-03
## Axle.Ratio                                                                    -5.767e+00
## N.V.Ratio                                                                      8.384e-01
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                              -1.113e+02
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                       4.280e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                7.728e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                            -1.117e+02
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                            -1.612e+02
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)         -1.700e+02
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                 -3.053e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                -1.056e+02
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)        5.256e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)       -1.725e+02
## THC..g.mi.                                                                     3.665e+02
## CO..g.mi.                                                                     -1.886e-03
## RND_ADJ_FE                                                                    -6.987e+00
## DT.Inertia.Work.Ratio.Rating                                                  -8.829e-01
## DT.Absolute.Speed.Change.Ratg                                                 -7.190e-01
## Target.Coef.A..lbf.                                                            5.970e-01
## Target.Coef.B..lbf.mph.                                                        3.866e+01
## Target.Coef.C..lbf.mph..2.                                                     1.545e+03
## Set.Coef.A..lbf.                                                              -2.414e-01
## Set.Coef.B..lbf.mph.                                                          -5.216e+00
## Set.Coef.C..lbf.mph..2.                                                        4.624e+01
## Aftertreatment.Device.DescNOx Adsorber                                         4.424e-01
## Aftertreatment.Device.DescOther                                               -1.989e+01
## Aftertreatment.Device.DescOxidation catalyst                                  -5.550e+00
```

```
## Aftertreatment.Device.DescSelective Catalytic Reduction                                -6.245e+00
## Aftertreatment.Device.DescThree-way catalyst                                            3.691e+01
##                                                                                       Std. Error
## (Intercept)                                                                            2.215e+01
## Model.Year.Cat2019                                                                     1.004e+00
## Model.Year.Cat2020                                                                     1.037e+00
## Model.Year.Cat2021                                                                     1.064e+00
## Model.Year.Cat2022                                                                     1.084e+00
## Test.Veh.Displacement..L.                                                              7.794e-01
## Vehicle.TypeCar                                                                        1.162e+00
## Vehicle.TypeTruck                                                                      1.419e+00
## Rated.Horsepower                                                                       5.050e-03
## X..of.Cylinders.and.Rotors                                                             5.887e-01
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  2.182e+00
## Tested.Transmission.TypeAutomatic                                                      2.224e+00
## Tested.Transmission.TypeContinuously Variable                                          2.761e+00
## Tested.Transmission.TypeManual                                                         2.266e+00
## Tested.Transmission.TypeOther                                                          2.526e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)       2.943e+00
## Tested.Transmission.TypeSemi-Automatic                                                 2.161e+00
## X..of.Gears                                                                            2.839e-01
## Transmission.Lockup.Y                                                                  1.301e+00
## Drive.System.Description2-Wheel Drive, Rear                                            1.046e+00
## Drive.System.Description4-Wheel Drive                                                  2.145e+00
## Drive.System.DescriptionAll Wheel Drive                                                1.484e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                                        5.357e+00
## Equivalent.Test.Weight..lbs..                                                          8.541e-04
## Axle.Ratio                                                                             6.160e-01
## N.V.Ratio                                                                              6.735e-02
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                       2.391e+01
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                               2.538e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                        2.722e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                     1.946e+01
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                     1.940e+01
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                  1.940e+01
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                          2.147e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                         1.924e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                2.174e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                3.134e+01
## THC..g.mi.                                                                            1.066e+01
## CO..g.mi.                                                                              9.244e-02
## RND_ADJ_FE                                                                             4.143e-02
## DT.Inertia.Work.Ratio.Rating                                                           4.075e-01
## DT.Absolute.Speed.Change.Ratg                                                          5.441e-01
## Target.Coef.A..lbf.                                                                    5.445e-02
## Target.Coef.B..lbf.mph.                                                                1.685e+00
## Target.Coef.C..lbf.mph..2.                                                             8.823e+01
## Set.Coef.A..lbf.                                                                       4.109e-02
## Set.Coef.B..lbf.mph.                                                                   1.115e+00
## Set.Coef.C..lbf.mph..2.                                                                3.147e+01
## Aftertreatment.Device.DescNOx Adsorber                                                 7.304e+00
## Aftertreatment.Device.DescOther                                                        6.098e+00
## Aftertreatment.Device.DescOxidation catalyst                                           4.094e+00
## Aftertreatment.Device.DescSelective Catalytic Reduction                                4.009e+00
## Aftertreatment.Device.DescThree-way catalyst                                           9.942e+00
##                                                                                        t value
## (Intercept)                                                                             22.990
## Model.Year.Cat2019                                                                       1.400
## Model.Year.Cat2020                                                                       3.367
## Model.Year.Cat2021                                                                       2.752
## Model.Year.Cat2022                                                                       4.437
## Test.Veh.Displacement..L.                                                                8.042
## Vehicle.TypeCar                                                                          5.578
## Vehicle.TypeTruck                                                                       -4.285
## Rated.Horsepower                                                                         7.625
## X..of.Cylinders.and.Rotors                                                              10.329
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  -3.489
## Tested.Transmission.TypeAutomatic                                                       -0.830
```

```
## Tested.Transmission.TypeContinuously Variable                                        5.206
## Tested.Transmission.TypeManual                                                      -4.834
## Tested.Transmission.TypeOther                                                       -0.546
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)     2.976
## Tested.Transmission.TypeSemi-Automatic                                              -0.410
## X..of.Gears                                                                         -4.391
## Transmission.Lockup.Y                                                               -3.100
## Drive.System.Description2-Wheel Drive, Rear                                         -6.914
## Drive.System.Description4-Wheel Drive                                               -0.587
## Drive.System.DescriptionAll Wheel Drive                                             -2.693
## Drive.System.DescriptionPart-time 4-Wheel Drive                                     -3.895
## Equivalent.Test.Weight..lbs..                                                       -8.371
## Axle.Ratio                                                                          -9.363
## N.V.Ratio                                                                           12.448
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                    -4.656
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                             1.686
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                      2.839
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                  -5.742
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                  -8.313
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               -8.766
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                       -1.422
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                      -5.491
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)              2.418
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)             -5.505
## THC..g.mi.                                                                          34.381
## CO..g.mi.                                                                           -0.020
## RND_ADJ_FE                                                                        -168.664
## DT.Inertia.Work.Ratio.Rating                                                        -2.166
## DT.Absolute.Speed.Change.Ratg                                                       -1.321
## Target.Coef.A..lbf.                                                                 10.965
## Target.Coef.B..lbf.mph.                                                             22.949
## Target.Coef.C..lbf.mph..2.                                                          17.512
## Set.Coef.A..lbf.                                                                    -5.874
## Set.Coef.B..lbf.mph.                                                                -4.678
## Set.Coef.C..lbf.mph..2.                                                              1.469
## Aftertreatment.Device.DescNOx Adsorber                                               0.061
## Aftertreatment.Device.DescOther                                                     -3.262
## Aftertreatment.Device.DescOxidation catalyst                                        -1.356
## Aftertreatment.Device.DescSelective Catalytic Reduction                             -1.558
## Aftertreatment.Device.DescThree-way catalyst                                         3.713
##                                                                                  Pr(>|t|)
## (Intercept)                                                                       < 2e-16
## Model.Year.Cat2019                                                               0.161665
## Model.Year.Cat2020                                                               0.000761
## Model.Year.Cat2021                                                               0.005927
## Model.Year.Cat2022                                                               9.18e-06
## Test.Veh.Displacement..L.                                                        9.40e-16
## Vehicle.TypeCar                                                                  2.47e-08
## Vehicle.TypeTruck                                                                1.84e-05
## Rated.Horsepower                                                                 2.56e-14
## X..of.Cylinders.and.Rotors                                                        < 2e-16
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) 0.000485
## Tested.Transmission.TypeAutomatic                                                0.406625
## Tested.Transmission.TypeContinuously Variable                                    1.96e-07
## Tested.Transmission.TypeManual                                                   1.35e-06
## Tested.Transmission.TypeOther                                                    0.584913
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles) 0.002920
## Tested.Transmission.TypeSemi-Automatic                                           0.681861
## X..of.Gears                                                                      1.13e-05
## Transmission.Lockup.Y                                                            0.001937
## Drive.System.Description2-Wheel Drive, Rear                                      4.86e-12
## Drive.System.Description4-Wheel Drive                                            0.557355
## Drive.System.DescriptionAll Wheel Drive                                          0.007082
## Drive.System.DescriptionPart-time 4-Wheel Drive                                  9.84e-05
## Equivalent.Test.Weight..lbs..                                                     < 2e-16
## Axle.Ratio                                                                        < 2e-16
## N.V.Ratio                                                                         < 2e-16
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                 3.24e-06
```

```
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                    0.091767
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                             0.004526
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                          9.49e-09
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                           < 2e-16
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                        < 2e-16
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                               0.154911
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                              4.05e-08
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                     0.015619
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                     3.75e-08
## THC..g.mi.                                                                                  < 2e-16
## CO..g.mi.                                                                                   0.983722
## RND_ADJ_FE                                                                                  < 2e-16
## DT.Inertia.Work.Ratio.Rating                                                                0.030288
## DT.Absolute.Speed.Change.Ratg                                                               0.186389
## Target.Coef.A..lbf.                                                                         < 2e-16
## Target.Coef.B..lbf.mph.                                                                     < 2e-16
## Target.Coef.C..lbf.mph..2.                                                                  < 2e-16
## Set.Coef.A..lbf.                                                                            4.32e-09
## Set.Coef.B..lbf.mph.                                                                        2.92e-06
## Set.Coef.C..lbf.mph..2.                                                                     0.141827
## Aftertreatment.Device.DescNOx Adsorber                                                      0.951701
## Aftertreatment.Device.DescOther                                                             0.001110
## Aftertreatment.Device.DescOxidation catalyst                                                0.175202
## Aftertreatment.Device.DescSelective Catalytic Reduction                                     0.119300
## Aftertreatment.Device.DescThree-way catalyst                                                0.000206
##
## (Intercept)                                                                                 ***
## Model.Year.Cat2019
## Model.Year.Cat2020                                                                          ***
## Model.Year.Cat2021                                                                          **
## Model.Year.Cat2022                                                                          ***
## Test.Veh.Displacement..L.                                                                   ***
## Vehicle.TypeCar                                                                             ***
## Vehicle.TypeTruck                                                                           ***
## Rated.Horsepower                                                                            ***
## X..of.Cylinders.and.Rotors                                                                  ***
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) ***
## Tested.Transmission.TypeAutomatic
## Tested.Transmission.TypeContinuously Variable                                               ***
## Tested.Transmission.TypeManual                                                              ***
## Tested.Transmission.TypeOther
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)          **
## Tested.Transmission.TypeSemi-Automatic
## X..of.Gears                                                                                 ***
## Transmission.Lockup.Y                                                                       **
## Drive.System.Description2-Wheel Drive, Rear                                                 ***
## Drive.System.Description4-Wheel Drive
## Drive.System.DescriptionAll Wheel Drive                                                     **
## Drive.System.DescriptionPart-time 4-Wheel Drive                                             ***
## Equivalent.Test.Weight..lbs..                                                               ***
## Axle.Ratio                                                                                  ***
## N.V.Ratio                                                                                   ***
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                            ***
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                    .
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                             **
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                          ***
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                          ***
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                       ***
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                              ***
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                     *
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                     ***
## THC..g.mi.                                                                                  ***
## CO..g.mi.
## RND_ADJ_FE                                                                                  ***
## DT.Inertia.Work.Ratio.Rating                                                                *
## DT.Absolute.Speed.Change.Ratg
## Target.Coef.A..lbf.                                                                         ***
```

```
## Target.Coef.B..lbf.mph.                                                  ***
## Target.Coef.C..lbf.mph..2.                                               ***
## Set.Coef.A..lbf.                                                         ***
## Set.Coef.B..lbf.mph.                                                     ***
## Set.Coef.C..lbf.mph..2.
## Aftertreatment.Device.DescNOx Adsorber
## Aftertreatment.Device.DescOther                                          **
## Aftertreatment.Device.DescOxidation catalyst
## Aftertreatment.Device.DescSelective Catalytic Reduction
## Aftertreatment.Device.DescThree-way catalyst                             ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 42.4 on 17186 degrees of freedom
## Multiple R-squared:  0.856,  Adjusted R-squared:  0.8555
## F-statistic:  2003 on 51 and 17186 DF,  p-value: < 2.2e-16
```

Interestingly enough, aside from a few of the initial predictors, almost all of the predictors in the model appear to be significant in predicting emissions for a car.

However, it is very possible there may be multicollinearity in the current model, which occurs when at least two of the predictor variables in a model are highly correlated and result in redundancy, skewing the results and making the model unstable.

To detect the presence of multicollinearity, we can computer the variance inflation factor (VIF) score.

```
vif(emissions.model)
```

```
##                                     GVIF Df GVIF^(1/(2*Df))
## Model.Year.Cat                  1.218965  4        1.025059
## Test.Veh.Displacement..L.       9.530381  1        3.087131
## Vehicle.Type                    3.678897  2        1.384935
## Rated.Horsepower                5.510100  1        2.347360
## X..of.Cylinders.and.Rotors     10.908181  1        3.302754
## Tested.Transmission.Type       31.997164  7        1.280879
## X..of.Gears                     5.469504  1        2.338697
## Transmission.Lockup.            3.071643  1        1.752610
## Drive.System.Description        5.494194  4        1.237337
## Equivalent.Test.Weight..lbs..   4.902283  1        2.214110
## Axle.Ratio                      1.951033  1        1.396794
## N.V.Ratio                       1.836214  1        1.355070
## Test.Fuel.Type.Description    105.350942 10        1.262211
## THC..g.mi.                      2.141612  1        1.463425
## CO..g.mi.                       1.008894  1        1.004437
## RND_ADJ_FE                      2.308121  1        1.519250
## DT.Inertia.Work.Ratio.Rating   16.359583  1        4.044698
## DT.Absolute.Speed.Change.Ratg  16.323002  1        4.040174
## Target.Coef.A..lbf.             4.191159  1        2.047232
## Target.Coef.B..lbf.mph.         2.804017  1        1.674520
## Target.Coef.C..lbf.mph..2.      3.798719  1        1.949030
## Set.Coef.A..lbf.                2.118803  1        1.455611
## Set.Coef.B..lbf.mph.            1.226191  1        1.107335
## Set.Coef.C..lbf.mph..2.         1.396493  1        1.181733
## Aftertreatment.Device.Desc     40.527500  5        1.448021
```

Typically, predictors that exceed 5 can be considered to be highly correlated with other predictors. Since there are already many significant predictors, we will be extra conservative and remove the predictors of DT.Inertia.Work.Ratio.Rating and DT.Absolute.Speed.Change.Ratg from the model.

Combining this with the predictors that did not meet the 0.05 significance level, the predictors we will be removing to create a more “tuned” model to compare to the original are:

- DT.Inertia.Work.Ratio.Rating
- DT.Absolute.Speed.Change.Ratg
- Transmission.Lockup
- CO..g.mi.

(Note that if at least one dummy variable for a categorical variable is significant, all of them will be kept as a best practice at this stage of model tuning.)

Emissions Model 2: Removing multicollinearity from model and initial insignificant terms

```
emissions.model.2 = lm(CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. + Vehicle.Type + Rated.Horsepower
+ X..of.Cylinders.and.Rotors + Tested.Transmission.Type + X..of.Gears + Drive.System.Description + Equivalent.Tes
t.Weight..lbs.. + Axle.Ratio + N.V.Ratio + Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..
lbf. + Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. + Set.Coef.B..lbf.mph. + Set.Coef.
C..lbf.mph..2. + Aftertreatment.Device.Desc, data = training.data)
```

```
summary(emissions.model.2)
```

```
##
## Call:
## lm(formula = CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. +
##     Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors +
##     Tested.Transmission.Type + X..of.Gears + Drive.System.Description +
##     Equivalent.Test.Weight..lbs.. + Axle.Ratio + N.V.Ratio +
##     Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..lbf. +
##     Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. +
##     Set.Coef.B..lbf.mph. + Set.Coef.C..lbf.mph..2. + Aftertreatment.Device.Desc,
##     data = training.data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -401.66  -23.91   -5.02   15.86  660.08
##
## Coefficients:
##                                                                                 Estimate
## (Intercept)                                                                    5.099e+02
## Model.Year.Cat2019                                                             1.613e+00
## Model.Year.Cat2020                                                             3.599e+00
## Model.Year.Cat2021                                                             3.247e+00
## Model.Year.Cat2022                                                             5.290e+00
## Test.Veh.Displacement..L.                                                      5.704e+00
## Vehicle.TypeCar                                                                6.454e+00
## Vehicle.TypeTruck                                                             -6.340e+00
## Rated.Horsepower                                                               4.075e-02
## X..of.Cylinders.and.Rotors                                                     5.967e+00
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) -7.617e+00
## Tested.Transmission.TypeAutomatic                                             -5.333e+00
## Tested.Transmission.TypeContinuously Variable                                  1.315e+01
## Tested.Transmission.TypeManual                                                -1.093e+01
## Tested.Transmission.TypeOther                                                 -1.140e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  6.532e+00
## Tested.Transmission.TypeSemi-Automatic                                        -4.814e+00
## X..of.Gears                                                                   -1.413e+00
## Drive.System.Description2-Wheel Drive, Rear                                   -6.927e+00
## Drive.System.Description4-Wheel Drive                                         -3.626e-01
## Drive.System.DescriptionAll Wheel Drive                                       -3.793e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                               -2.007e+01
## Equivalent.Test.Weight..lbs..                                                 -6.195e-03
## Axle.Ratio                                                                    -6.546e+00
## N.V.Ratio                                                                      8.439e-01
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                              -1.024e+02
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                       4.620e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                8.857e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                            -1.057e+02
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                            -1.546e+02
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)         -1.632e+02
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                 -2.431e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                -9.786e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)        6.237e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)       -1.684e+02
## THC..g.mi.                                                                     3.715e+02
## RND_ADJ_FE                                                                    -7.083e+00
## Target.Coef.A..lbf.                                                            5.449e-01
## Target.Coef.B..lbf.mph.                                                        3.675e+01
## Target.Coef.C..lbf.mph..2.                                                     1.507e+03
## Set.Coef.A..lbf.                                                              -2.512e-01
## Set.Coef.B..lbf.mph.                                                          -5.144e+00
## Set.Coef.C..lbf.mph..2.                                                        4.006e+01
## Aftertreatment.Device.DescNOx Adsorber                                         1.420e+00
## Aftertreatment.Device.DescOther                                               -2.061e+01
## Aftertreatment.Device.DescOxidation catalyst                                  -5.983e+00
## Aftertreatment.Device.DescSelective Catalytic Reduction                       -6.416e+00
## Aftertreatment.Device.DescThree-way catalyst                                   3.485e+01
##                                                                               Std. Error
## (Intercept)                                                                    2.227e+01
## Model.Year.Cat2019                                                             1.009e+00
```

```
## Model.Year.Cat2020                                                                1.041e+00
## Model.Year.Cat2021                                                                1.066e+00
## Model.Year.Cat2022                                                                1.085e+00
## Test.Veh.Displacement..L.                                                         7.804e-01
## Vehicle.TypeCar                                                                   1.168e+00
## Vehicle.TypeTruck                                                                 1.426e+00
## Rated.Horsepower                                                                  5.072e-03
## X..of.Cylinders.and.Rotors                                                        5.901e-01
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  2.186e+00
## Tested.Transmission.TypeAutomatic                                                 2.059e+00
## Tested.Transmission.TypeContinuously Variable                                     2.724e+00
## Tested.Transmission.TypeManual                                                    2.237e+00
## Tested.Transmission.TypeOther                                                     2.539e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  2.859e+00
## Tested.Transmission.TypeSemi-Automatic                                            2.000e+00
## X..of.Gears                                                                       2.805e-01
## Drive.System.Description2-Wheel Drive, Rear                                       1.051e+00
## Drive.System.Description4-Wheel Drive                                             2.156e+00
## Drive.System.DescriptionAll Wheel Drive                                           1.492e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                                   5.386e+00
## Equivalent.Test.Weight..lbs..                                                     8.526e-04
## Axle.Ratio                                                                        6.113e-01
## N.V.Ratio                                                                         6.770e-02
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                  2.403e+01
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                          2.552e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                   2.735e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                1.956e+01
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                1.950e+01
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)             1.950e+01
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                     2.158e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                    1.933e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)           2.183e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)           3.151e+01
## THC..g.mi.                                                                       1.067e+01
## RND_ADJ_FE                                                                       4.063e-02
## Target.Coef.A..lbf.                                                              5.457e-02
## Target.Coef.B..lbf.mph.                                                          1.678e+00
## Target.Coef.C..lbf.mph..2.                                                       8.853e+01
## Set.Coef.A..lbf.                                                                 4.115e-02
## Set.Coef.B..lbf.mph.                                                             1.120e+00
## Set.Coef.C..lbf.mph..2.                                                          3.165e+01
## Aftertreatment.Device.DescNOx Adsorber                                           7.344e+00
## Aftertreatment.Device.DescOther                                                  6.131e+00
## Aftertreatment.Device.DescOxidation catalyst                                     4.117e+00
## Aftertreatment.Device.DescSelective Catalytic Reduction                          4.031e+00
## Aftertreatment.Device.DescThree-way catalyst                                     9.988e+00
##                                                                                  t value
## (Intercept)                                                                       22.898
## Model.Year.Cat2019                                                                 1.598
## Model.Year.Cat2020                                                                 3.456
## Model.Year.Cat2021                                                                 3.045
## Model.Year.Cat2022                                                                 4.877
## Test.Veh.Displacement..L.                                                          7.309
## Vehicle.TypeCar                                                                    5.523
## Vehicle.TypeTruck                                                                 -4.446
## Rated.Horsepower                                                                   8.035
## X..of.Cylinders.and.Rotors                                                        10.111
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  -3.484
## Tested.Transmission.TypeAutomatic                                                 -2.590
## Tested.Transmission.TypeContinuously Variable                                      4.826
## Tested.Transmission.TypeManual                                                    -4.887
## Tested.Transmission.TypeOther                                                     -0.449
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)   2.285
## Tested.Transmission.TypeSemi-Automatic                                            -2.407
## X..of.Gears                                                                       -5.039
## Drive.System.Description2-Wheel Drive, Rear                                       -6.592
## Drive.System.Description4-Wheel Drive                                             -0.168
## Drive.System.DescriptionAll Wheel Drive                                           -2.542
```

```
## Drive.System.DescriptionPart-time 4-Wheel Drive                                        -3.726
## Equivalent.Test.Weight..lbs..                                                          -7.266
## Axle.Ratio                                                                            -10.708
## N.V.Ratio                                                                              12.464
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                       -4.261
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                1.810
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                         3.238
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                     -5.407
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                     -7.927
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                  -8.372
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                          -1.127
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                         -5.062
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                 2.857
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                -5.344
## THC..g.mi.                                                                             34.810
## RND_ADJ_FE                                                                           -174.326
## Target.Coef.A..lbf.                                                                    9.985
## Target.Coef.B..lbf.mph.                                                               21.898
## Target.Coef.C..lbf.mph..2.                                                            17.026
## Set.Coef.A..lbf.                                                                      -6.103
## Set.Coef.B..lbf.mph.                                                                  -4.592
## Set.Coef.C..lbf.mph..2.                                                                1.266
## Aftertreatment.Device.DescNOx Adsorber                                                 0.193
## Aftertreatment.Device.DescOther                                                       -3.361
## Aftertreatment.Device.DescOxidation catalyst                                          -1.453
## Aftertreatment.Device.DescSelective Catalytic Reduction                               -1.591
## Aftertreatment.Device.DescThree-way catalyst                                           3.489
##                                                                                    Pr(>|t|)
## (Intercept)                                                                         < 2e-16
## Model.Year.Cat2019                                                                 0.110063
## Model.Year.Cat2020                                                                 0.000549
## Model.Year.Cat2021                                                                 0.002329
## Model.Year.Cat2022                                                                 1.08e-06
## Test.Veh.Displacement..L.                                                          2.80e-13
## Vehicle.TypeCar                                                                    3.37e-08
## Vehicle.TypeTruck                                                                  8.79e-06
## Rated.Horsepower                                                                   9.98e-16
## X..of.Cylinders.and.Rotors                                                          < 2e-16
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) 0.000495
## Tested.Transmission.TypeAutomatic                                                  0.009617
## Tested.Transmission.TypeContinuously Variable                                      1.40e-06
## Tested.Transmission.TypeManual                                                     1.03e-06
## Tested.Transmission.TypeOther                                                      0.653423
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)   0.022339
## Tested.Transmission.TypeSemi-Automatic                                             0.016096
## X..of.Gears                                                                        4.72e-07
## Drive.System.Description2-Wheel Drive, Rear                                        4.46e-11
## Drive.System.Description4-Wheel Drive                                              0.866444
## Drive.System.DescriptionAll Wheel Drive                                            0.011019
## Drive.System.DescriptionPart-time 4-Wheel Drive                                    0.000195
## Equivalent.Test.Weight..lbs..                                                      3.85e-13
## Axle.Ratio                                                                          < 2e-16
## N.V.Ratio                                                                           < 2e-16
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                   2.05e-05
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                           0.070248
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                    0.001204
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                 6.48e-08
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                 2.37e-15
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               < 2e-16
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                      0.259942
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                     4.20e-07
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)            0.004280
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)            9.21e-08
## THC..g.mi.                                                                          < 2e-16
## RND_ADJ_FE                                                                          < 2e-16
## Target.Coef.A..lbf.                                                                 < 2e-16
## Target.Coef.B..lbf.mph.                                                             < 2e-16
## Target.Coef.C..lbf.mph..2.                                                          < 2e-16
```

```
## Set.Coef.A..lbf.                                                                1.06e-09
## Set.Coef.B..lbf.mph.                                                            4.41e-06
## Set.Coef.C..lbf.mph..2.                                                         0.205595
## Aftertreatment.Device.DescNOx Adsorber                                          0.846729
## Aftertreatment.Device.DescOther                                                 0.000780
## Aftertreatment.Device.DescOxidation catalyst                                    0.146131
## Aftertreatment.Device.DescSelective Catalytic Reduction                         0.111524
## Aftertreatment.Device.DescThree-way catalyst                                    0.000487
##
## (Intercept)                                                                     ***
## Model.Year.Cat2019
## Model.Year.Cat2020                                                              ***
## Model.Year.Cat2021                                                              **
## Model.Year.Cat2022                                                              ***
## Test.Veh.Displacement..L.                                                       ***
## Vehicle.TypeCar                                                                 ***
## Vehicle.TypeTruck                                                               ***
## Rated.Horsepower                                                                ***
## X..of.Cylinders.and.Rotors                                                      ***
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) ***
## Tested.Transmission.TypeAutomatic                                               **
## Tested.Transmission.TypeContinuously Variable                                   ***
## Tested.Transmission.TypeManual                                                  ***
## Tested.Transmission.TypeOther
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles) *
## Tested.Transmission.TypeSemi-Automatic                                          *
## X..of.Gears                                                                     ***
## Drive.System.Description2-Wheel Drive, Rear                                     ***
## Drive.System.Description4-Wheel Drive
## Drive.System.DescriptionAll Wheel Drive                                         *
## Drive.System.DescriptionPart-time 4-Wheel Drive                                 ***
## Equivalent.Test.Weight..lbs..                                                   ***
## Axle.Ratio                                                                      ***
## N.V.Ratio                                                                       ***
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                ***
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                        .
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                 **
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                              ***
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                              ***
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)           ***
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                  ***
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)         **
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)         ***
## THC..g.mi.                                                                      ***
## RND_ADJ_FE                                                                      ***
## Target.Coef.A..lbf.                                                             ***
## Target.Coef.B..lbf.mph.                                                         ***
## Target.Coef.C..lbf.mph..2.                                                      ***
## Set.Coef.A..lbf.                                                                ***
## Set.Coef.B..lbf.mph.                                                            ***
## Set.Coef.C..lbf.mph..2.
## Aftertreatment.Device.DescNOx Adsorber
## Aftertreatment.Device.DescOther                                                 ***
## Aftertreatment.Device.DescOxidation catalyst
## Aftertreatment.Device.DescSelective Catalytic Reduction
## Aftertreatment.Device.DescThree-way catalyst                                    ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 42.64 on 17190 degrees of freedom
## Multiple R-squared:  0.8543, Adjusted R-squared:  0.8539
## F-statistic:  2145 on 47 and 17190 DF,  p-value: < 2.2e-16
```

For the third and final model, we will remove the last of the insignificant variables below the 0.05 significance level, as well as those categorical variables where less than half of the dummy variables are significant. So, because of this, we will remove Set.Coef.C..lbf.mph..2.and also remove the categorical variable (and associated dummy variables) of Aftertreatment.Device.Desc.

Emissions Model 3: Removing all insignificant terms

```
emissions.model.3 = lm(CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. + Vehicle.Type + Rated.Horsepower
+ X..of.Cylinders.and.Rotors + Tested.Transmission.Type + X..of.Gears + Drive.System.Description + Equivalent.Tes
t.Weight..lbs.. + Axle.Ratio + N.V.Ratio + Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..
lbf. + Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. + Set.Coef.B..lbf.mph., data = tra
ining.data)
```

```
summary(emissions.model.3)
```

```
##
## Call:
## lm(formula = CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. +
##     Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors +
##     Tested.Transmission.Type + X..of.Gears + Drive.System.Description +
##     Equivalent.Test.Weight..lbs.. + Axle.Ratio + N.V.Ratio +
##     Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..lbf. +
##     Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. +
##     Set.Coef.B..lbf.mph., data = training.data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -401.15  -23.83   -5.08   15.86  658.98
##
## Coefficients:
##                                                                                 Estimate
## (Intercept)                                                                    5.454e+02
## Model.Year.Cat2019                                                             1.585e+00
## Model.Year.Cat2020                                                             3.593e+00
## Model.Year.Cat2021                                                             3.038e+00
## Model.Year.Cat2022                                                             4.955e+00
## Test.Veh.Displacement..L.                                                      6.016e+00
## Vehicle.TypeCar                                                                6.217e+00
## Vehicle.TypeTruck                                                             -6.496e+00
## Rated.Horsepower                                                               3.818e-02
## X..of.Cylinders.and.Rotors                                                     5.865e+00
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) -5.770e+00
## Tested.Transmission.TypeAutomatic                                             -3.771e+00
## Tested.Transmission.TypeContinuously Variable                                  1.415e+01
## Tested.Transmission.TypeManual                                                -9.368e+00
## Tested.Transmission.TypeOther                                                 -9.975e+00
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  8.109e+00
## Tested.Transmission.TypeSemi-Automatic                                        -2.917e+00
## X..of.Gears                                                                   -1.510e+00
## Drive.System.Description2-Wheel Drive, Rear                                   -6.839e+00
## Drive.System.Description4-Wheel Drive                                          5.472e-01
## Drive.System.DescriptionAll Wheel Drive                                       -3.482e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                               -1.955e+01
## Equivalent.Test.Weight..lbs..                                                 -6.083e-03
## Axle.Ratio                                                                    -6.750e+00
## N.V.Ratio                                                                      8.521e-01
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                              -1.025e+02
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                       8.073e+00
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                8.875e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                            -1.060e+02
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                            -1.545e+02
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)         -1.634e+02
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                 -6.461e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                -9.775e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)        6.343e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)       -1.681e+02
## THC..g.mi.                                                                     3.750e+02
## RND_ADJ_FE                                                                    -7.089e+00
## Target.Coef.A..lbf.                                                            5.231e-01
## Target.Coef.B..lbf.mph.                                                        3.596e+01
## Target.Coef.C..lbf.mph..2.                                                     1.525e+03
## Set.Coef.A..lbf.                                                              -2.200e-01
## Set.Coef.B..lbf.mph.                                                          -4.480e+00
##                                                                               Std. Error
## (Intercept)                                                                    2.004e+01
## Model.Year.Cat2019                                                             1.010e+00
## Model.Year.Cat2020                                                             1.042e+00
## Model.Year.Cat2021                                                             1.067e+00
## Model.Year.Cat2022                                                             1.085e+00
## Test.Veh.Displacement..L.                                                      7.799e-01
## Vehicle.TypeCar                                                                1.168e+00
## Vehicle.TypeTruck                                                              1.427e+00
## Rated.Horsepower                                                               5.067e-03
```

```
## X..of.Cylinders.and.Rotors                                                          5.905e-01
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  2.169e+00
## Tested.Transmission.TypeAutomatic                                                   2.046e+00
## Tested.Transmission.TypeContinuously Variable                                       2.715e+00
## Tested.Transmission.TypeManual                                                      2.224e+00
## Tested.Transmission.TypeOther                                                       2.543e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)    2.847e+00
## Tested.Transmission.TypeSemi-Automatic                                              1.983e+00
## X..of.Gears                                                                         2.804e-01
## Drive.System.Description2-Wheel Drive, Rear                                         1.052e+00
## Drive.System.Description4-Wheel Drive                                               2.154e+00
## Drive.System.DescriptionAll Wheel Drive                                             1.492e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                                     5.394e+00
## Equivalent.Test.Weight..lbs..                                                       8.527e-04
## Axle.Ratio                                                                          6.115e-01
## N.V.Ratio                                                                           6.779e-02
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                    2.407e+01
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                            2.368e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                     2.739e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                  1.959e+01
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                  1.953e+01
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               1.953e+01
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                       1.942e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                      1.936e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)             2.186e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)             3.156e+01
## THC..g.mi.                                                                         1.068e+01
## RND_ADJ_FE                                                                         4.068e-02
## Target.Coef.A..lbf.                                                                5.455e-02
## Target.Coef.B..lbf.mph.                                                            1.667e+00
## Target.Coef.C..lbf.mph..2.                                                         8.436e+01
## Set.Coef.A..lbf.                                                                   4.092e-02
## Set.Coef.B..lbf.mph.                                                               1.116e+00
##                                                                                    t value
## (Intercept)                                                                         27.213
## Model.Year.Cat2019                                                                   1.570
## Model.Year.Cat2020                                                                   3.450
## Model.Year.Cat2021                                                                   2.848
## Model.Year.Cat2022                                                                   4.566
## Test.Veh.Displacement..L.                                                            7.714
## Vehicle.TypeCar                                                                      5.321
## Vehicle.TypeTruck                                                                   -4.552
## Rated.Horsepower                                                                     7.535
## X..of.Cylinders.and.Rotors                                                           9.933
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  -2.660
## Tested.Transmission.TypeAutomatic                                                   -1.844
## Tested.Transmission.TypeContinuously Variable                                        5.212
## Tested.Transmission.TypeManual                                                      -4.212
## Tested.Transmission.TypeOther                                                       -0.392
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)     2.848
## Tested.Transmission.TypeSemi-Automatic                                              -1.471
## X..of.Gears                                                                         -5.386
## Drive.System.Description2-Wheel Drive, Rear                                         -6.500
## Drive.System.Description4-Wheel Drive                                                0.254
## Drive.System.DescriptionAll Wheel Drive                                             -2.334
## Drive.System.DescriptionPart-time 4-Wheel Drive                                     -3.623
## Equivalent.Test.Weight..lbs..                                                       -7.134
## Axle.Ratio                                                                         -11.039
## N.V.Ratio                                                                           12.569
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                    -4.257
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                             0.341
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                      3.240
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                  -5.413
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                  -7.912
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               -8.366
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                       -3.327
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                      -5.048
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)              2.901
```

```
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                    -5.327
## THC..g.mi.                                                                                 35.123
## RND_ADJ_FE                                                                               -174.250
## Target.Coef.A..lbf.                                                                         9.589
## Target.Coef.B..lbf.mph.                                                                    21.565
## Target.Coef.C..lbf.mph..2.                                                                 18.071
## Set.Coef.A..lbf.                                                                           -5.377
## Set.Coef.B..lbf.mph.                                                                       -4.014
##                                                                                          Pr(>|t|)
## (Intercept)                                                                               < 2e-16
## Model.Year.Cat2019                                                                       0.116502
## Model.Year.Cat2020                                                                       0.000562
## Model.Year.Cat2021                                                                       0.004406
## Model.Year.Cat2022                                                                       5.00e-06
## Test.Veh.Displacement..L.                                                                1.28e-14
## Vehicle.TypeCar                                                                          1.05e-07
## Vehicle.TypeTruck                                                                        5.35e-06
## Rated.Horsepower                                                                         5.13e-14
## X..of.Cylinders.and.Rotors                                                                < 2e-16
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) 0.007813
## Tested.Transmission.TypeAutomatic                                                        0.065256
## Tested.Transmission.TypeContinuously Variable                                            1.89e-07
## Tested.Transmission.TypeManual                                                           2.54e-05
## Tested.Transmission.TypeOther                                                            0.694906
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)         0.004406
## Tested.Transmission.TypeSemi-Automatic                                                   0.141392
## X..of.Gears                                                                              7.29e-08
## Drive.System.Description2-Wheel Drive, Rear                                              8.25e-11
## Drive.System.Description4-Wheel Drive                                                    0.799431
## Drive.System.DescriptionAll Wheel Drive                                                  0.019608
## Drive.System.DescriptionPart-time 4-Wheel Drive                                          0.000292
## Equivalent.Test.Weight..lbs..                                                            1.02e-12
## Axle.Ratio                                                                                < 2e-16
## N.V.Ratio                                                                                 < 2e-16
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                         2.09e-05
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                 0.733168
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                          0.001198
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                       6.28e-08
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                       2.69e-15
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                     < 2e-16
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                            0.000881
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                           4.52e-07
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                  0.003720
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                  1.01e-07
## THC..g.mi.                                                                                < 2e-16
## RND_ADJ_FE                                                                                < 2e-16
## Target.Coef.A..lbf.                                                                       < 2e-16
## Target.Coef.B..lbf.mph.                                                                   < 2e-16
## Target.Coef.C..lbf.mph..2.                                                                < 2e-16
## Set.Coef.A..lbf.                                                                         7.66e-08
## Set.Coef.B..lbf.mph.                                                                     6.00e-05
##
## (Intercept)                                                                              ***
## Model.Year.Cat2019
## Model.Year.Cat2020                                                                       ***
## Model.Year.Cat2021                                                                       **
## Model.Year.Cat2022                                                                       ***
## Test.Veh.Displacement..L.                                                                ***
## Vehicle.TypeCar                                                                          ***
## Vehicle.TypeTruck                                                                        ***
## Rated.Horsepower                                                                         ***
## X..of.Cylinders.and.Rotors                                                               ***
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) **
## Tested.Transmission.TypeAutomatic                                                        .
## Tested.Transmission.TypeContinuously Variable                                            ***
## Tested.Transmission.TypeManual                                                           ***
## Tested.Transmission.TypeOther
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)         **
```

```
## Tested.Transmission.TypeSemi-Automatic
## X..of.Gears                                                                  ***
## Drive.System.Description2-Wheel Drive, Rear                                  ***
## Drive.System.Description4-Wheel Drive
## Drive.System.DescriptionAll Wheel Drive                                      *
## Drive.System.DescriptionPart-time 4-Wheel Drive                              ***
## Equivalent.Test.Weight..lbs..                                                ***
## Axle.Ratio                                                                   ***
## N.V.Ratio                                                                    ***
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                             ***
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)              **
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                           ***
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                           ***
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)        ***
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                ***
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                               ***
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)      **
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)      ***
## THC..g.mi.                                                                   ***
## RND_ADJ_FE                                                                   ***
## Target.Coef.A..lbf.                                                          ***
## Target.Coef.B..lbf.mph.                                                      ***
## Target.Coef.C..lbf.mph..2.                                                   ***
## Set.Coef.A..lbf.                                                             ***
## Set.Coef.B..lbf.mph.                                                         ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 42.71 on 17196 degrees of freedom
## Multiple R-squared:  0.8538, Adjusted R-squared:  0.8534
## F-statistic:  2449 on 41 and 17196 DF,  p-value: < 2.2e-16
```

Now, the metrics of the three models can be compared to determine which one can be used to best predict a car's CO_2 emissions.

```
pred1 = emissions.model %>% predict(testing.data)
p1 = data.frame(
  RMSE = RMSE(pred1, testing.data$CO2..g.mi.),
  R2 = R2(pred1, testing.data$CO2..g.mi.)
)
pred2 = emissions.model.2 %>% predict(testing.data)
p2 = data.frame(
  RMSE = RMSE(pred2, testing.data$CO2..g.mi.),
  R2 = R2(pred2, testing.data$CO2..g.mi.)
)
pred3 = emissions.model.3 %>% predict(testing.data)
p3 = data.frame(
  RMSE = RMSE(pred3, testing.data$CO2..g.mi.),
  R2 = R2(pred3, testing.data$CO2..g.mi.)
)
```

```
combined = rbind(p1, p2, p3)

combined = cbind(combined, c(summary(emissions.model)$fstatistic[1], summary(emissions.model.2)$fstatistic[1], su
mmary(emissions.model.3)$fstatistic[1]))

combined=cbind(combined, c(summary(emissions.model)$adj.r.squared, summary(emissions.model.2)$adj.r.squared, summ
ary(emissions.model.3)$adj.r.squared))

combined=cbind(combined,c(summary(emissions.model)$sigma,summary(emissions.model.2)$sigma, summary(emissions.mode
l.3)$sigma))

combined=cbind(combined, c("Model 1", "Model 2", "Model 3"))
colnames(combined)[c(3,4,5,6)] = c("F-Statistic", "Adj R2", "RSE", "Model Name")
```

```
library(kableExtra)
```

```
## Warning in !is.null(rmarkdown::metadata$output) && rmarkdown::metadata$output
## %in% : 'length(x) = 2 > 1' in coercion to 'logical(1)'
```

```
##
## Attaching package: 'kableExtra'
```

```
## The following object is masked from 'package:dplyr':
##
##     group_rows
```

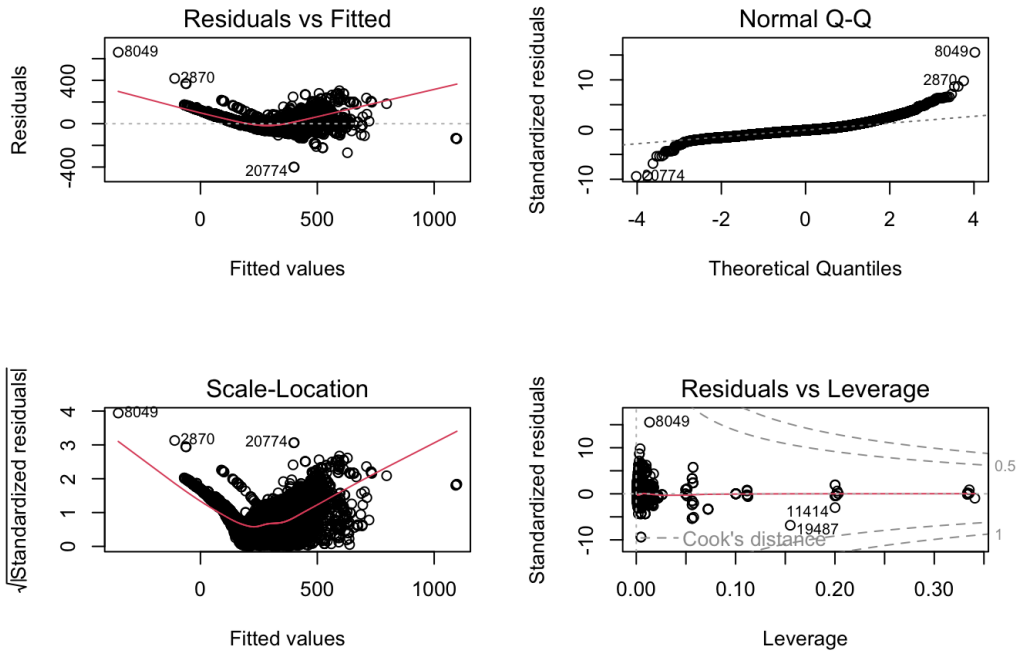
```
combined %>%
  kbl() %>%
  kable_classic(full_width = F, html_font = "Cambria")
```

RMSE	R2	F-Statistic	Adj R2	RSE	Model Name
67.19786	0.6954633	2002.677	0.8555428	42.40103	Model 1
67.93032	0.6903372	2144.816	0.8539192	42.63865	Model 2
67.94107	0.6903654	2449.245	0.8534456	42.70771	Model 3

Overall, the models seem to perform relatively equally, with Adjusted R^2 scores around 85% for all models. However, because Model 3 has the least number of predictor terms in the model, and knowing that the addition of predictor terms inflates the R^2, we can say that Model 3 is the best predictor of a car's emissions.

Lastly, we want to check for any outliers or high leverage points in the chosen model.

```
par(mfrow=c(2,2))
plot(emissions.model.3)
```



Looking at the plots above, particularly the Residuals vs Fitted and the Scale-Location plots, we can see that linearity appears to be violated. Due to the parabola shape of the data, it is possible that quadratic regression could be a better fit for this data.

To see if a quadratic term could improve this model, we will add single squared regression term to the predictor variables.

Because the predictor with the highest influence on the model (largest F-statistic) is RND_ADJ_FE, or Miles per Gallon, with an F-statistic of -174.250, we will add a quadratic term for this predictor to see if it improves the model.

```
nonelectric$RND_ADJ_FE_2 = nonelectric$RND_ADJ_FE^2
```

```
set.seed(101)

training.samples = nonelectric$CO2..g.mi. %>%
  createDataPartition(p = 0.8, list = FALSE)

training.data = nonelectric[training.samples,]
testing.data = nonelectric[-training.samples, ]
```

Emissions Model 4: Quadratic Regression Model

```
emissions.model.4 = lm(CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. + Vehicle.Type + Rated.Horsepower
+ X..of.Cylinders.and.Rotors + Tested.Transmission.Type + X..of.Gears + Drive.System.Description + Equivalent.Tes
t.Weight..lbs.. + Axle.Ratio + N.V.Ratio + Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..
lbf. + Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. + Set.Coef.B..lbf.mph. + RND_ADJ_F
E_2, data = training.data)
```

```
summary(emissions.model.4)
```

```
##
## Call:
## lm(formula = CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. +
##     Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors +
##     Tested.Transmission.Type + X..of.Gears + Drive.System.Description +
##     Equivalent.Test.Weight..lbs.. + Axle.Ratio + N.V.Ratio +
##     Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..lbf. +
##     Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. +
##     Set.Coef.B..lbf.mph. + RND_ADJ_FE_2, data = training.data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -641.54  -11.26   -1.61   10.92  244.82
##
## Coefficients:
##                                                                                  Estimate
## (Intercept)                                                                     8.568e+02
## Model.Year.Cat2019                                                              5.260e-01
## Model.Year.Cat2020                                                              1.715e+00
## Model.Year.Cat2021                                                              7.048e-01
## Model.Year.Cat2022                                                              1.855e+00
## Test.Veh.Displacement..L.                                                       3.074e+00
## Vehicle.TypeCar                                                                -6.975e-01
## Vehicle.TypeTruck                                                              -5.158e+00
## Rated.Horsepower                                                                3.217e-02
## X..of.Cylinders.and.Rotors                                                      1.751e+00
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  4.313e+00
## Tested.Transmission.TypeAutomatic                                               7.911e+00
## Tested.Transmission.TypeContinuously Variable                                   1.028e+01
## Tested.Transmission.TypeManual                                                  4.536e+00
## Tested.Transmission.TypeOther                                                   1.105e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  1.243e+01
## Tested.Transmission.TypeSemi-Automatic                                          9.087e+00
## X..of.Gears                                                                    -7.366e-01
## Drive.System.Description2-Wheel Drive, Rear                                    -8.034e+00
## Drive.System.Description4-Wheel Drive                                          -7.545e+00
## Drive.System.DescriptionAll Wheel Drive                                        -7.647e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                                -1.764e+01
## Equivalent.Test.Weight..lbs..                                                  -4.306e-03
## Axle.Ratio                                                                     -1.095e+00
## N.V.Ratio                                                                       4.163e-01
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                               -1.075e+02
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                       -3.731e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                 1.618e+02
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                             -1.263e+02
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                             -1.380e+02
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)          -2.192e+02
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                  -7.364e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                 -1.126e+02
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)         8.883e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)        -1.751e+02
## THC..g.mi.                                                                      2.095e+02
## RND_ADJ_FE                                                                     -2.140e+01
## Target.Coef.A..lbf.                                                             3.796e-01
## Target.Coef.B..lbf.mph.                                                         1.446e+01
## Target.Coef.C..lbf.mph..2.                                                      6.247e+02
## Set.Coef.A..lbf.                                                               -1.826e-01
## Set.Coef.B..lbf.mph.                                                           -6.985e-01
## RND_ADJ_FE_2                                                                    1.777e-01
##                                                                                Std. Error
## (Intercept)                                                                     1.209e+01
## Model.Year.Cat2019                                                              6.028e-01
## Model.Year.Cat2020                                                              6.216e-01
## Model.Year.Cat2021                                                              6.368e-01
## Model.Year.Cat2022                                                              6.477e-01
## Test.Veh.Displacement..L.                                                       4.657e-01
## Vehicle.TypeCar                                                                 6.984e-01
## Vehicle.TypeTruck                                                               8.517e-01
```

```
## Rated.Horsepower                                                                3.024e-03
## X..of.Cylinders.and.Rotors                                                      3.531e-01
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  1.296e+00
## Tested.Transmission.TypeAutomatic                                               1.223e+00
## Tested.Transmission.TypeContinuously Variable                                   1.621e+00
## Tested.Transmission.TypeManual                                                  1.330e+00
## Tested.Transmission.TypeOther                                                   1.518e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  1.699e+00
## Tested.Transmission.TypeSemi-Automatic                                          1.186e+00
## X..of.Gears                                                                     1.674e-01
## Drive.System.Description2-Wheel Drive, Rear                                     6.279e-01
## Drive.System.Description4-Wheel Drive                                           1.286e+00
## Drive.System.DescriptionAll Wheel Drive                                         8.905e-01
## Drive.System.DescriptionPart-time 4-Wheel Drive                                 3.219e+00
## Equivalent.Test.Weight..lbs..                                                   5.089e-04
## Axle.Ratio                                                                      3.663e-01
## N.V.Ratio                                                                       4.053e-02
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                1.437e+01
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                        1.413e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                 1.635e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                              1.169e+01
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                              1.165e+01
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)           1.166e+01
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                   1.159e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                  1.156e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)         1.305e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)         1.883e+01
## THC..g.mi.                                                                     6.440e+00
## RND_ADJ_FE                                                                     8.473e-02
## Target.Coef.A..lbf.                                                            3.256e-02
## Target.Coef.B..lbf.mph.                                                        1.002e+00
## Target.Coef.C..lbf.mph..2.                                                     5.060e+01
## Set.Coef.A..lbf.                                                               2.442e-02
## Set.Coef.B..lbf.mph.                                                           6.664e-01
## RND_ADJ_FE_2                                                                   1.007e-03
##                                                                                t value
## (Intercept)                                                                     70.860
## Model.Year.Cat2019                                                               0.873
## Model.Year.Cat2020                                                               2.758
## Model.Year.Cat2021                                                               1.107
## Model.Year.Cat2022                                                               2.864
## Test.Veh.Displacement..L.                                                        6.601
## Vehicle.TypeCar                                                                 -0.999
## Vehicle.TypeTruck                                                               -6.056
## Rated.Horsepower                                                                10.640
## X..of.Cylinders.and.Rotors                                                       4.959
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)   3.329
## Tested.Transmission.TypeAutomatic                                                6.470
## Tested.Transmission.TypeContinuously Variable                                    6.346
## Tested.Transmission.TypeManual                                                   3.412
## Tested.Transmission.TypeOther                                                    0.728
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)   7.317
## Tested.Transmission.TypeSemi-Automatic                                           7.665
## X..of.Gears                                                                     -4.401
## Drive.System.Description2-Wheel Drive, Rear                                    -12.795
## Drive.System.Description4-Wheel Drive                                           -5.867
## Drive.System.DescriptionAll Wheel Drive                                         -8.588
## Drive.System.DescriptionPart-time 4-Wheel Drive                                 -5.479
## Equivalent.Test.Weight..lbs..                                                   -8.461
## Axle.Ratio                                                                      -2.988
## N.V.Ratio                                                                       10.271
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                -7.484
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                        -2.640
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                  9.891
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                             -10.805
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                             -11.843
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)          -18.798
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                   -6.353
```

```
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                                  -9.740
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                          6.808
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                         -9.296
## THC..g.mi.                                                                                      32.537
## RND_ADJ_FE                                                                                    -252.592
## Target.Coef.A..lbf.                                                                             11.657
## Target.Coef.B..lbf.mph.                                                                         14.421
## Target.Coef.C..lbf.mph..2.                                                                      12.344
## Set.Coef.A..lbf.                                                                                -7.478
## Set.Coef.B..lbf.mph.                                                                            -1.048
## RND_ADJ_FE_2                                                                                   176.325
##                                                                                               Pr(>|t|)
## (Intercept)                                                                                    < 2e-16
## Model.Year.Cat2019                                                                            0.382908
## Model.Year.Cat2020                                                                            0.005820
## Model.Year.Cat2021                                                                            0.268368
## Model.Year.Cat2022                                                                            0.004192
## Test.Veh.Displacement..L.                                                                     4.20e-11
## Vehicle.TypeCar                                                                               0.317984
## Vehicle.TypeTruck                                                                             1.42e-09
## Rated.Horsepower                                                                               < 2e-16
## X..of.Cylinders.and.Rotors                                                                    7.16e-07
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)     0.000874
## Tested.Transmission.TypeAutomatic                                                             1.00e-10
## Tested.Transmission.TypeContinuously Variable                                                 2.27e-10
## Tested.Transmission.TypeManual                                                                0.000648
## Tested.Transmission.TypeOther                                                                 0.466720
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)              2.65e-13
## Tested.Transmission.TypeSemi-Automatic                                                        1.89e-14
## X..of.Gears                                                                                   1.08e-05
## Drive.System.Description2-Wheel Drive, Rear                                                    < 2e-16
## Drive.System.Description4-Wheel Drive                                                         4.52e-09
## Drive.System.DescriptionAll Wheel Drive                                                        < 2e-16
## Drive.System.DescriptionPart-time 4-Wheel Drive                                               4.34e-08
## Equivalent.Test.Weight..lbs..                                                                  < 2e-16
## Axle.Ratio                                                                                    0.002809
## N.V.Ratio                                                                                      < 2e-16
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                              7.54e-14
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                      0.008301
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                                < 2e-16
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                             < 2e-16
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                             < 2e-16
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                          < 2e-16
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                                 2.16e-10
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                                 < 2e-16
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                       1.02e-11
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                        < 2e-16
## THC..g.mi.                                                                                     < 2e-16
## RND_ADJ_FE                                                                                     < 2e-16
## Target.Coef.A..lbf.                                                                            < 2e-16
## Target.Coef.B..lbf.mph.                                                                        < 2e-16
## Target.Coef.C..lbf.mph..2.                                                                     < 2e-16
## Set.Coef.A..lbf.                                                                              7.88e-14
## Set.Coef.B..lbf.mph.                                                                          0.294588
## RND_ADJ_FE_2                                                                                   < 2e-16
##
## (Intercept)                                                                                   ***
## Model.Year.Cat2019
## Model.Year.Cat2020                                                                            **
## Model.Year.Cat2021
## Model.Year.Cat2022                                                                            **
## Test.Veh.Displacement..L.                                                                     ***
## Vehicle.TypeCar
## Vehicle.TypeTruck                                                                             ***
## Rated.Horsepower                                                                              ***
## X..of.Cylinders.and.Rotors                                                                    ***
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)     ***
## Tested.Transmission.TypeAutomatic                                                             ***
```

```
## Tested.Transmission.TypeContinuously Variable                                    ***
## Tested.Transmission.TypeManual                                                   ***
## Tested.Transmission.TypeOther
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles) ***
## Tested.Transmission.TypeSemi-Automatic                                           ***
## X..of.Gears                                                                      ***
## Drive.System.Description2-Wheel Drive, Rear                                      ***
## Drive.System.Description4-Wheel Drive                                            ***
## Drive.System.DescriptionAll Wheel Drive                                          ***
## Drive.System.DescriptionPart-time 4-Wheel Drive                                  ***
## Equivalent.Test.Weight..lbs..                                                    ***
## Axle.Ratio                                                                       **
## N.V.Ratio                                                                        ***
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                 ***
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                         **
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                  ***
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                               ***
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                               ***
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)            ***
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                    ***
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                   ***
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)          ***
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)          ***
## THC..g.mi.                                                                       ***
## RND_ADJ_FE                                                                       ***
## Target.Coef.A..lbf.                                                              ***
## Target.Coef.B..lbf.mph.                                                          ***
## Target.Coef.C..lbf.mph..2.                                                       ***
## Set.Coef.A..lbf.                                                                 ***
## Set.Coef.B..lbf.mph.
## RND_ADJ_FE_2                                                                     ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 25.49 on 17195 degrees of freedom
## Multiple R-squared:  0.9479, Adjusted R-squared:  0.9478
## F-statistic:  7454 on 42 and 17195 DF,  p-value: < 2.2e-16
```

```
pred4 = emissions.model.4 %>% predict(testing.data)
p4 = data.frame(
  RMSE = RMSE(pred4, testing.data$CO2..g.mi.),
  R2 = R2(pred4, testing.data$CO2..g.mi.)
)
```

```
combined = rbind(p1, p2, p3, p4)

combined = cbind(combined, c(summary(emissions.model)$fstatistic[1], summary(emissions.model.2)$fstatistic[1], su
mmary(emissions.model.3)$fstatistic[1], summary(emissions.model.4)$fstatistic[1]))

combined=cbind(combined, c(summary(emissions.model)$adj.r.squared, summary(emissions.model.2)$adj.r.squared, summ
ary(emissions.model.3)$adj.r.squared, summary(emissions.model.4)$adj.r.squared))

combined=cbind(combined,c(summary(emissions.model)$sigma,summary(emissions.model.2)$sigma, summary(emissions.mode
l.3)$sigma, summary(emissions.model.4)$sigma))

combined=cbind(combined, c("Model 1", "Model 2", "Model 3", "Model 4"))
colnames(combined)[c(3,4,5,6)] = c("F-Statistic", "Adj R2", "RSE", "Model Name")
```

```
library(kableExtra)
combined %>%
  kbl() %>%
  kable_classic(full_width = F, html_font = "Cambria")
```

RMSE	R2	F-Statistic	Adj R2	RSE	Model Name
67.19786	0.6954633	2002.677	0.8555428	42.40103	Model 1
67.93032	0.6903372	2144.816	0.8539192	42.63865	Model 2

RMSE	R2	F-Statistic	Adj R2	RSE	Model Name
67.94107	0.6903654	2449.245	0.8534456	42.70771	Model 3
390.62920	0.0712754	7453.846	0.9478072	25.48660	Model 4

Results

As we can see in the model results, Model 4 appears to be a huge improvement in every way on the previous Model 3. However, when looking at the RMSE for Model 4, we can see that it is extremely large, suggesting that this quadratic regression is badly overfitting, and therefore is not a good predictor.

Therefore, the best model is still the multiple linear regression model of Model 3.

```
summary(emissions.model.3)
```

```
##
## Call:
## lm(formula = CO2..g.mi. ~ Model.Year.Cat + Test.Veh.Displacement..L. +
##     Vehicle.Type + Rated.Horsepower + X..of.Cylinders.and.Rotors +
##     Tested.Transmission.Type + X..of.Gears + Drive.System.Description +
##     Equivalent.Test.Weight..lbs.. + Axle.Ratio + N.V.Ratio +
##     Test.Fuel.Type.Description + THC..g.mi. + RND_ADJ_FE + Target.Coef.A..lbf. +
##     Target.Coef.B..lbf.mph. + Target.Coef.C..lbf.mph..2. + Set.Coef.A..lbf. +
##     Set.Coef.B..lbf.mph., data = training.data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -401.15  -23.83   -5.08   15.86  658.98
##
## Coefficients:
##                                                                                 Estimate
## (Intercept)                                                                    5.454e+02
## Model.Year.Cat2019                                                             1.585e+00
## Model.Year.Cat2020                                                             3.593e+00
## Model.Year.Cat2021                                                             3.038e+00
## Model.Year.Cat2022                                                             4.955e+00
## Test.Veh.Displacement..L.                                                      6.016e+00
## Vehicle.TypeCar                                                                6.217e+00
## Vehicle.TypeTruck                                                             -6.496e+00
## Rated.Horsepower                                                               3.818e-02
## X..of.Cylinders.and.Rotors                                                     5.865e+00
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) -5.770e+00
## Tested.Transmission.TypeAutomatic                                             -3.771e+00
## Tested.Transmission.TypeContinuously Variable                                  1.415e+01
## Tested.Transmission.TypeManual                                                -9.368e+00
## Tested.Transmission.TypeOther                                                 -9.975e+00
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)  8.109e+00
## Tested.Transmission.TypeSemi-Automatic                                        -2.917e+00
## X..of.Gears                                                                   -1.510e+00
## Drive.System.Description2-Wheel Drive, Rear                                   -6.839e+00
## Drive.System.Description4-Wheel Drive                                          5.472e-01
## Drive.System.DescriptionAll Wheel Drive                                       -3.482e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                               -1.955e+01
## Equivalent.Test.Weight..lbs..                                                 -6.083e-03
## Axle.Ratio                                                                    -6.750e+00
## N.V.Ratio                                                                      8.521e-01
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                              -1.025e+02
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                       8.073e+00
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                8.875e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                            -1.060e+02
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                            -1.545e+02
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)         -1.634e+02
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                 -6.461e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                -9.775e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)        6.343e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)       -1.681e+02
## THC..g.mi.                                                                     3.750e+02
## RND_ADJ_FE                                                                    -7.089e+00
## Target.Coef.A..lbf.                                                            5.231e-01
## Target.Coef.B..lbf.mph.                                                        3.596e+01
## Target.Coef.C..lbf.mph..2.                                                     1.525e+03
## Set.Coef.A..lbf.                                                              -2.200e-01
## Set.Coef.B..lbf.mph.                                                          -4.480e+00
##                                                                              Std. Error
## (Intercept)                                                                    2.004e+01
## Model.Year.Cat2019                                                             1.010e+00
## Model.Year.Cat2020                                                             1.042e+00
## Model.Year.Cat2021                                                             1.067e+00
## Model.Year.Cat2022                                                             1.085e+00
## Test.Veh.Displacement..L.                                                      7.799e-01
## Vehicle.TypeCar                                                                1.168e+00
## Vehicle.TypeTruck                                                              1.427e+00
## Rated.Horsepower                                                               5.067e-03
```

```
## X..of.Cylinders.and.Rotors                                                          5.905e-01
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  2.169e+00
## Tested.Transmission.TypeAutomatic                                                   2.046e+00
## Tested.Transmission.TypeContinuously Variable                                       2.715e+00
## Tested.Transmission.TypeManual                                                      2.224e+00
## Tested.Transmission.TypeOther                                                       2.543e+01
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)    2.847e+00
## Tested.Transmission.TypeSemi-Automatic                                              1.983e+00
## X..of.Gears                                                                         2.804e-01
## Drive.System.Description2-Wheel Drive, Rear                                         1.052e+00
## Drive.System.Description4-Wheel Drive                                               2.154e+00
## Drive.System.DescriptionAll Wheel Drive                                             1.492e+00
## Drive.System.DescriptionPart-time 4-Wheel Drive                                     5.394e+00
## Equivalent.Test.Weight..lbs..                                                       8.527e-04
## Axle.Ratio                                                                          6.115e-01
## N.V.Ratio                                                                           6.779e-02
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                    2.407e+01
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                            2.368e+01
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                     2.739e+01
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                  1.959e+01
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                  1.953e+01
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               1.953e+01
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                       1.942e+01
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                      1.936e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)             2.186e+01
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)             3.156e+01
## THC..g.mi.                                                                         1.068e+01
## RND_ADJ_FE                                                                         4.068e-02
## Target.Coef.A..lbf.                                                                5.455e-02
## Target.Coef.B..lbf.mph.                                                            1.667e+00
## Target.Coef.C..lbf.mph..2.                                                         8.436e+01
## Set.Coef.A..lbf.                                                                   4.092e-02
## Set.Coef.B..lbf.mph.                                                               1.116e+00
##                                                                                    t value
## (Intercept)                                                                         27.213
## Model.Year.Cat2019                                                                   1.570
## Model.Year.Cat2020                                                                   3.450
## Model.Year.Cat2021                                                                   2.848
## Model.Year.Cat2022                                                                   4.566
## Test.Veh.Displacement..L.                                                            7.714
## Vehicle.TypeCar                                                                      5.321
## Vehicle.TypeTruck                                                                   -4.552
## Rated.Horsepower                                                                     7.535
## X..of.Cylinders.and.Rotors                                                           9.933
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles)  -2.660
## Tested.Transmission.TypeAutomatic                                                   -1.844
## Tested.Transmission.TypeContinuously Variable                                        5.212
## Tested.Transmission.TypeManual                                                      -4.212
## Tested.Transmission.TypeOther                                                       -0.392
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)     2.848
## Tested.Transmission.TypeSemi-Automatic                                              -1.471
## X..of.Gears                                                                         -5.386
## Drive.System.Description2-Wheel Drive, Rear                                         -6.500
## Drive.System.Description4-Wheel Drive                                                0.254
## Drive.System.DescriptionAll Wheel Drive                                             -2.334
## Drive.System.DescriptionPart-time 4-Wheel Drive                                     -3.623
## Equivalent.Test.Weight..lbs..                                                       -7.134
## Axle.Ratio                                                                         -11.039
## N.V.Ratio                                                                           12.569
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                    -4.257
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                             0.341
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                      3.240
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                  -5.413
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                  -7.912
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)               -8.366
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                       -3.327
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                      -5.048
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)              2.901
```

```
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                    -5.327
## THC..g.mi.                                                                                 35.123
## RND_ADJ_FE                                                                               -174.250
## Target.Coef.A..lbf.                                                                         9.589
## Target.Coef.B..lbf.mph.                                                                    21.565
## Target.Coef.C..lbf.mph..2.                                                                 18.071
## Set.Coef.A..lbf.                                                                           -5.377
## Set.Coef.B..lbf.mph.                                                                       -4.014
##                                                                                          Pr(>|t|)
## (Intercept)                                                                               < 2e-16
## Model.Year.Cat2019                                                                       0.116502
## Model.Year.Cat2020                                                                       0.000562
## Model.Year.Cat2021                                                                       0.004406
## Model.Year.Cat2022                                                                       5.00e-06
## Test.Veh.Displacement..L.                                                                1.28e-14
## Vehicle.TypeCar                                                                          1.05e-07
## Vehicle.TypeTruck                                                                        5.35e-06
## Rated.Horsepower                                                                         5.13e-14
## X..of.Cylinders.and.Rotors                                                                < 2e-16
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) 0.007813
## Tested.Transmission.TypeAutomatic                                                        0.065256
## Tested.Transmission.TypeContinuously Variable                                            1.89e-07
## Tested.Transmission.TypeManual                                                           2.54e-05
## Tested.Transmission.TypeOther                                                            0.694906
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)         0.004406
## Tested.Transmission.TypeSemi-Automatic                                                   0.141392
## X..of.Gears                                                                              7.29e-08
## Drive.System.Description2-Wheel Drive, Rear                                              8.25e-11
## Drive.System.Description4-Wheel Drive                                                    0.799431
## Drive.System.DescriptionAll Wheel Drive                                                  0.019608
## Drive.System.DescriptionPart-time 4-Wheel Drive                                          0.000292
## Equivalent.Test.Weight..lbs..                                                            1.02e-12
## Axle.Ratio                                                                                < 2e-16
## N.V.Ratio                                                                                 < 2e-16
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                                         2.09e-05
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur                                 0.733168
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)                          0.001198
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                                       6.28e-08
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                                       2.69e-15
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)                     < 2e-16
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                            0.000881
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                                           4.52e-07
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)                  0.003720
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)                  1.01e-07
## THC..g.mi.                                                                                < 2e-16
## RND_ADJ_FE                                                                                < 2e-16
## Target.Coef.A..lbf.                                                                       < 2e-16
## Target.Coef.B..lbf.mph.                                                                   < 2e-16
## Target.Coef.C..lbf.mph..2.                                                                < 2e-16
## Set.Coef.A..lbf.                                                                         7.66e-08
## Set.Coef.B..lbf.mph.                                                                     6.00e-05
##
## (Intercept)                                                                              ***
## Model.Year.Cat2019
## Model.Year.Cat2020                                                                       ***
## Model.Year.Cat2021                                                                       **
## Model.Year.Cat2022                                                                       ***
## Test.Veh.Displacement..L.                                                                ***
## Vehicle.TypeCar                                                                          ***
## Vehicle.TypeTruck                                                                        ***
## Rated.Horsepower                                                                         ***
## X..of.Cylinders.and.Rotors                                                               ***
## Tested.Transmission.TypeAutomated Manual- Selectable (e.g. Automated Manual with paddles) **
## Tested.Transmission.TypeAutomatic                                                        .
## Tested.Transmission.TypeContinuously Variable                                            ***
## Tested.Transmission.TypeManual                                                           ***
## Tested.Transmission.TypeOther
## Tested.Transmission.TypeSelectable Continuously Variable (e.g. CVT with paddles)         **
```

```
## Tested.Transmission.TypeSemi-Automatic
## X..of.Gears                                                                  ***
## Drive.System.Description2-Wheel Drive, Rear                                  ***
## Drive.System.Description4-Wheel Drive
## Drive.System.DescriptionAll Wheel Drive                                      *
## Drive.System.DescriptionPart-time 4-Wheel Drive                              ***
## Equivalent.Test.Weight..lbs..                                                ***
## Axle.Ratio                                                                   ***
## N.V.Ratio                                                                    ***
## Test.Fuel.Type.DescriptionCARB Phase II Gasoline                             ***
## Test.Fuel.Type.DescriptionCold CO Diesel 7-15 ppm Sulfur
## Test.Fuel.Type.DescriptionCold CO E10 Premium Gasoline (Tier 3)              **
## Test.Fuel.Type.DescriptionCold CO Premium (Tier 2)                           ***
## Test.Fuel.Type.DescriptionCold CO Regular (Tier 2)                           ***
## Test.Fuel.Type.DescriptionE85 (85% Ethanol 15% EPA Unleaded Gasoline)        ***
## Test.Fuel.Type.DescriptionFederal Cert Diesel 7-15 PPM Sulfur                ***
## Test.Fuel.Type.DescriptionTier 2 Cert Gasoline                               ***
## Test.Fuel.Type.DescriptionTier 3 E10 Premium Gasoline (9 RVP @Low Alt.)      **
## Test.Fuel.Type.DescriptionTier 3 E10 Regular Gasoline (9 RVP @Low Alt.)      ***
## THC..g.mi.                                                                   ***
## RND_ADJ_FE                                                                   ***
## Target.Coef.A..lbf.                                                          ***
## Target.Coef.B..lbf.mph.                                                      ***
## Target.Coef.C..lbf.mph..2.                                                   ***
## Set.Coef.A..lbf.                                                             ***
## Set.Coef.B..lbf.mph.                                                         ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 42.71 on 17196 degrees of freedom
## Multiple R-squared:  0.8538, Adjusted R-squared:  0.8534
## F-statistic:  2449 on 41 and 17196 DF,  p-value: < 2.2e-16
```

Looking again at the summary of Emissions Model 3, we can see that the top 3 predictors that hold the most weight in predicting a car's CO_2 based on respective t-values are:

1. Miles per Gallon (RND_ADJ_FE): -174.25

As the number of miles per gallon a car is able to achieve increases, its CO_2 emissions go down.

2. Total hydrocarbon emissions (THC..g.mi.): 35.12

3. Electric Dynamometer Coefficient/mph (Target.Coef.B..lbf.mph.): 21.90

(This is the measure of force, speed, and power required to operate the car being measured)

As the total hydrocarbon emissions and the electric dynamometer coefficient increase, the CO_2 emissions produced by a car will also increase.