Complying with the European Union car CO2 emission regulation

Group 1

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Executive summary:
Helping car manufacturers to Comply with the tight EU CO2 regulation

**CONTEXT**
- The European Union has implemented a strict legislation to reduce car Co2 emissions in Europe.
  - In 2015, car manufacturers fleet need to emit in average <130g of Co2/km
  - In 2020, the cap will be reduced at 95g of Co2/km
  + The EU is likely to implement a new CO2 emission calculation method that will harden the blow
- The EU regulation authorizes the creation of pools to help manufacturers reach their Co2 target.
  -> The fleet Co2 would then be calculated at the pool level and not at manufacturer level.

**PROBLEM**
Manufacturers face ambitious CO2 targets and non compliance is not an option given the level of the fine.

- 2009 avg emissions: 145g CO2/km
- 2015 Target: 130g/km
- 2020 Target: 95g/km

- “New European CO2 rules threaten car makers’ profits” – Forbes, 27 Feb 2014
- “We are not talking about (...) millions of euros. We are talking about billions” BMW CEO, July 2014

**OBJECTIVES & RESULTS**
Help the different manufacturers to minimize the fines paid to the EU

- To achieve this goal we have:
  1. Cleaned and transformed European datasets gathering car sales, emissions and detailed characteristics
  2. Forecasted the average CO2 emissions for each manufacturer for 2015 and 2020
  3. Computed the optimal pooling strategy for each manufacturer

- By applying more optimal pooling strategies, manufacturers will be able to decrease the level of the fines paid to the EU.
The EU CO2 regulation is a real challenge for car manufacturers.

### World’s most constraining targets:
- 130g CO2/km by 2015
- 95g CO2/km by 2020

### Progressive specific CO2 emission targets for each year
- Constraining targets set for 2012-14 and 2017-2020
- Calculated on the basis of the average mass of registered cars

### Tougher CO2 measurements likely to be implemented in 2017:
- On road / laboratory conditions (WPT Method)
- Potential increase of CO2 recorded: 20 to 30%

### High Penalties in case of non compliance:
- 5€ for the 1st g in excess, 15€ for the 2nd, 25€ for the 3rd
- 95€ per g of CO2 over the limit, beginning at the 4th one

### Possibility to create pools
- Avg CO2 emissions will be calculated for the pool fleet and not at the manufacturer level

### Market Reactions
- « (CO2 regulations) could prevent approximately 210k premature mortalities in urban areas in 2030 » ICCT, October 2013
- “The German Association of the Automotive Industry warned that the deal would require "enormous efforts" on the part of car makers to reach the "most severe targets in the world.”" WSJ, February 2014
- « This is an herculean task calling the best efforts of all our 40k developers. We can do it » Volkswagen Chairman, April 2014
Our 3 Steps Approach to help the car manufacturers diminish their potential fines

**DATA**
- **Identification of the Data needed:**
  - ≠ models of car sold in EU (2000-2013); number of models sold per year; main characteristics of the model sold
- **Data Research:**
  - Datasets from the EU and its member states, Car Manufacturer Annual Reports, Research Papers
- **Data Cleaning:**
  - Data formatting and outlier detection
- **Data Transformation:**
  - Pro Forma combination of the different datasets

**FORECASTING**
- **Modelisation of Car Registrations and CO2 Emissions:**
  - Identification of the variables that explain the most CO2 emissions evolution and creation of clusters of cars
- **Projection of CO2 Emissions and Number of Models sold:**
  - Forecasting of registrations and weighted average CO2 emissions using time serie analysis
- **Calculation of potential Fines:**
  - Creation of an algorithm to compute the potential fines applied to non complying manufacturers

**OPTIMIZING**
- **Compute optimal pooling strategies:**
  - Identification of three groups of manufacturers: highly probable non compliers that need to pool, highly probable compliers that can pool without too much risks, manufacturers revolving around the target
  - Identification of pooling* and depooling** possible strategies
  - Computation of financial gains from the new pooling/depooling strategies
- **Recommendations:**
  - Example of possible pooling and depooling strategy for the manufacturers that have the more to gain

*Pooling: Action of merging one or more manufacturers or pool / **Depooling: action of breaking a pool into one or more pools or manufacturers
## Identifying, Collecting, Cleaning and Transforming the Data

### MAIN BASE
European Environment Agency, Member States Datasets

- **2010-2013: Variables and rework:**
  - ≠ Pools, ≠ Brands, ≠ Unique Models, ≠ Countries
  - -> Cleaning + Pro Forma 2013
  - CO2 Emissions/Model, Mass/Model, Engine Capacity/Model, Engine Power/Model, Fuel Type/Model
  - -> Outlier Detection, Cleaning

- **2000-2009: Variables and rework:**
  - ≠ Brands, ≠ Countries
  - -> Pro Forma 2013, Pool 2013 Assignation
  - Mass Distribution per Brand, Fuel Type and Country Engine Capacity Distribution per Brand, Fuel Type and Country
  - -> Outlier Detection, Cleaning

### SANITY CHECK BASES
Manufacturer Annual Reports, Research Papers

- **Annual Reports of Car Manufacturers:**
  - Sales and sales prediction per Brand
  - -> Used to clean the main base and check the forecasts
  - Qualitative Datas
  - -> Better understanding of the impact of the regulation on each manufacturer

- **Research Papers:**
  - Historic + Forecast Sales and Specific Emissions
  - -> Used to clean the main base and check the forecasts

### Output

- **For 2010-2013:** Sales and weighted average CO2 emissions, fuel type mass and engine capacity per model, brand & 2013 pool
- **For 2000-2013:** Sales and weighted average CO2 emissions, fuel type & mass distribution per year, brand & 2013 pool
  
Sales and weighted average CO2 emissions, fuel type & engine capacity distribution per year, brand & 2013 pool
Forecasting Sales, Emissions & Fines per Brand for 2015 and 2020: The Steps

1/ Running a PCA to find the variables that explain better the CO2 emissions of a car
   • **Outcome:**
     -> Fuel Type & Engine Capacity are the best variables at our disposal to forecast emissions per manufacturer car

2/ Clustering of Sales and Weighted Average Emissions
   • **Outcome:**
     -> Creation of 6 clusters/brand as a combination of the two main fuel types (diesel & petrol) and three levels of engine capacity (high, medium and low)
     (The data were not sufficient to create useful hybrid & electric clusters for the forecasting - <5% of the sales on the period)

3/ Forecasting Sales and Weighted Average Emissions per Cluster per Brand using Time Series
   • **Method Selection**
     - Initial graphical observations of data favored using Additive models with no seasonality (Holt’s exponential modeling with zero Gamma in our case)
   • **Accuracy of the forecast**
     - Autocorrelogram: No significant autocorrelations were found between the residual lags.
     - Ljung box test: Sufficiently high p-value to not reject null hypothesis of no autocorrelation between the residuals.
     - Scatter plot of residuals: Consistent variance and near zero mean
     - Histogram of residuals: Near normal with mean zero
   • **Conclusion:** The accuracy of forecast would not improve significantly just by using another forecasting method. Therefore, we stick by this method.

4/ Computing Potential Fines for each Brand/Pool for 2015 and 2020
   • **Outcome**
     -> Creation of an algorithm that uses EU calculation method on the values forecasted by the model
If on average car manufacturers will comply with the 2015 and 2020, there’s important discrepancies between them

On Average Target will be met
- On average cars sold in 2015 will emit 117g of CO2, 13g below the authorized emissions
- In 2020, according to our forecast the average will be at 98. (However, since we didn’t take electric and hybrid cars into account due to a lack of historical datas, the real number should be lower)

But Discrepancies are important
- In 2015, 15% of the manufacturers will be above the target paying a €148.5m fine
- In 2020, 3 groups can be identified: 1 below the target, 1 far above and one revolving around it.
- The fines paid could amount to €4737m

So an optimal Pooling strategy exists
- The optimal strategy for the car manufacturers would be to constitute one unique pool.
- Smaller agreements are more plausible and could lead to a largely smaller level of fines.
- By taking out of their pools their most polluting brands, existing pools can also reduce their fines.
Result: Sales and CO2 Emissions Forecasts 2010-2020: 1/3rd of the manufacturers are likely to miss 2020 targets

CO2 emissions in g/km

EU DATAS

FORECASTS

Bubble Size: number of registrations  * Only the 11 first pools are displayed for clarity reasons

- **TATA MOTORS**
  - Em 2010: 196.12
  - Em 2015: 166.34
  - For 2020: 135.01

- **AUTOMOBILES PEUGEOT**
  - Em 2010: 131.00
  - For 2015: 105.71
  - For 2020: 78.19

- **BMW GROUP**
  - Em 2010: 143.49
  - For 2015: 119.78
  - For 2020: 106.42

- **DAIMLER AG**
  - Em 2010: 131.33
  - For 2015: 122.03
  - For 2020: 91.65

- **FIAT GROUP**
  - Em 2010: 129.06
  - For 2015: 111.20
  - For 2020: 80.60

- **FORD-WERKE GMBH**
  - Em 2010: 137.06
  - For 2015: 106.63
  - For 2020: 85.52

- **GENERAL MOTORS**
  - Em 2010: 136.25
  - For 2015: 110.31
  - For 2020: 90.04

- **NISSAN**
  - Em 2010: 145.18
  - For 2015: 123.31
  - For 2020: 104.54

- **RENAULT SA**
  - Em 2010: 139.86
  - For 2015: 115.43
  - For 2020: 97.60

- **TOYOTA-DAIHATSU GROUP**
  - Em 2010: 135.67
  - For 2015: 116.34
  - For 2020: 92.87

- **VW GROUP**
  - Em 2010: 131.33
  - For 2015: 122.50
  - For 2020: 100.46
**Singularization of High, Medium and Low Risk Players**

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Risk of Fine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 106</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| • **Low Risk of Fine**: <40% of chance to pay a fine in 2020  
  -> Total forecasted 2020 fine: €0 |
| **Medium Risk of Fine** | | |
| CO2 2015: 110 | | |
| Fine 2015: 0 | | |
| CO2 2020: 90 | | |
| Fine 2020: 0 | | |
| • **Medium Risk of Fine**: ~ 50% of chance to pay a fine in 2020  
  -> Total forecasted 2020 fine: €666m |
| **High Risk of Fine** | | |
| CO2 2015: 115 | | |
| Fine 2015: 0 | | |
| CO2 2020: 97 | | |
| Fine 2020: 555m | | |
| • **High Risk of Fine**: >60% of chance to pay a fine in 2020  
  -> Total forecasted 2020 fines: €3,385m |

**Medium Risk of Fine**

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAIMLER</td>
<td>DAIMLER</td>
<td></td>
</tr>
<tr>
<td>Mercedes-Benz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 122</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 0</td>
<td></td>
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</tr>
</tbody>
</table>

**High Risk of Fine**

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLVO</td>
<td>VOLVO</td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 125</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 108</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 67m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>KIA</td>
<td>KIA</td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUZUKI</td>
<td>SUZUKI</td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 116</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 111m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pool</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>TATA</td>
<td>TATA</td>
<td></td>
</tr>
<tr>
<td>LAND ROVER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2015: 166</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2015: 41m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 2020: 135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine 2020: 281m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5 out of the 7 pools above 2020 targets can meet them with simple pooling strategies.

### Takeway

- Two or more constructors can decide to form a pool when their aggregated weighted average fleet CO2 emission is below the EU 2020 target. *(Here two pools can merge when the intersection between them is green)*

- Nissan, Volvo, Tata, Renault and Suzuki can pool with at least 1 single pool to pass the 2020 targets.

- BMW & Hyundai can only pool in this set of possibility with the combination of Citroen & Peugeot.

- VW would need either to form a larger alliance, by grouping 2 other pools or more or to try a mix pooling depooling solution.
Other can use depooling strategies: Volkswagen example

<table>
<thead>
<tr>
<th>Current Pool</th>
<th>Main Brands</th>
<th>Current Metrics</th>
</tr>
</thead>
</table>
|               | Volkswagen  | • Current CO2 emissions: 100,1g/km  
|               | SEAT        | • Current Fine: €1.276bn          |
|               | Audi        |                               |
|               | quattro     |                               |

<table>
<thead>
<tr>
<th>New Pool 1</th>
<th>Main Brands</th>
<th>Metrics</th>
</tr>
</thead>
</table>
|               | Volkswagen  | • New CO2: 101,9g/km  
|               | SEAT        | • Current Fine: €1.276bn          |
|               | Audi        |                               |
|               | quattro     |                               |

<table>
<thead>
<tr>
<th>Current Pool</th>
<th>Main Brands</th>
<th>Current Metrics</th>
</tr>
</thead>
</table>
|               | SEAT        | • Current CO2: 94,8g/km  
|               | quattro     | • Current Fine: €0bn          |
|               | SEAT        |                               |
|               | Lamborghini |                               |
|               | SKODA       |                               |

Takeway

- By Creating two separate pools Audi can manage to save almost €300m
- BMW and Renault could use the same types of strategies
## Limits:

<table>
<thead>
<tr>
<th>Limits</th>
<th>Description</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of historical data</td>
<td>. Only 14 years of historical data for the time series analysis</td>
<td>Benchmark expert views to reach a consensus on what is the most likely to happen</td>
</tr>
<tr>
<td></td>
<td>. CO₂ emission is difficult to predict due to low data quality for 2000 / 2009</td>
<td></td>
</tr>
<tr>
<td>Few or no historical datas for electric and hybrid vehicles</td>
<td>. Impossible to forecast the sales of electric vehicles given the few numbers and irregularities of past observations</td>
<td>Use of the sole petrol and diesel vehicles for the forecasting. Upward bias on the CO₂ emission trends</td>
</tr>
<tr>
<td>Necessity of large clustering due to the low quality of the 2000-09 data</td>
<td>. Fines have been calculated on clusters rather than on each car model which makes the estimates ballpark</td>
<td>Using databases on driving behaviour will give us a better idea of effective fines to be paid</td>
</tr>
<tr>
<td>Historical Bias in the data</td>
<td>. The crisis had an impact on the buying behavior of the consumers, pushing them towards cheaper, lighter and less powerful cars</td>
<td>Downward bias on the CO₂ emission trends</td>
</tr>
<tr>
<td></td>
<td>. The EU regulation had an impact on the manufacturers, pushing them toward taking rapidly the quick wins in term of CO₂ efficiency</td>
<td></td>
</tr>
</tbody>
</table>
Based on European Data and Reports

We have discovered that:

- The most part of the manufacturers will respect the 2015 target...
- ... but will have difficulties to meet the 2020 one (projected fines paid for non compliant manufacturers amount to €4.7 bn in 2020)
- The EU will harden the regulation in 2017 (new CO2 emission calculation will be based on real driving conditions)

We have found insights by:

- Forecasting the Co2 emission thanks to fuel type and displacement based on historical data
- Using Time Series analysis to project Co2 emission and sales.

We have proposed:

- A model to estimate the most at-risk manufacturers in 2020 for not respecting the regulation (and the fines paid if so).
- Two strategies for reducing the risk to pay fines (pooling optimization & de-pooling)
  - WV could be able to reduce the cost by

Additional recommendation: Invest the saving costs to push electric cars and alternative fuel through the market
## A focus on the EU CO2 emission regulation (EC 443/2009)

### Emission targets

- Passenger cars have to comply with the following CO2 targets:
  - 130g of CO2/ km in 2015, measured with the NEDC method
  - 95g of CO2/ km in 2020, currently measured with NEDC method, but the WLTP will probably be introduced in 2017

### Specific emission targets

- Each manufacturer has a specific emission target per year. The average of the pool or of the manufacturer’s fleet is taken into account.
  - Calculated on the basis of the average mass of registered cars.
    
    \[
    \text{Specific emissions of CO2} = 130 + a \times (M - M_0)
    \]
    
    *M*: average mass of the manufacturer's fleet in kg
    *M₀*: reference mass (1372 kg)
    *a*: 0.0457

- The reference mass and coefficient *a* are calculated so that the global EU target is 130g/km. It is reviewed every 2 years.

### Phasing out

- The regulation is progressive:
  - In 2012, 65% of the best performing cars are taken into account
  - In 2013, 75%
  - In 2014, 80% and in 2015, 100% of cars concerned
A focus on the EU CO2 emission regulation (EC 443/2009)

Pooling

A flexibility is given to car manufacturers, who are allowed to regroup themselves in a pool. In that case, the pool average CO2 emission is taken into account for the calculation of CO2 emissions.

Fines

The excess emissions premium for failing to meet the specific CO2 emission target is based on the following criteria:
- the distance to the emission target in a given year (in g CO2/km)
- the number of vehicles registered by the manufacturer during that year
- the premium level as described in the table

<table>
<thead>
<tr>
<th>Excess emission</th>
<th>Fine 5</th>
<th>Fine 15</th>
<th>Fine 25</th>
<th>Fine 95</th>
<th>Nb of vehicles</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>(EE)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NV</td>
<td>(EE * 5) * NV</td>
</tr>
<tr>
<td>1 - 2</td>
<td>1</td>
<td>(EE - 1)</td>
<td>-</td>
<td>-</td>
<td>NV</td>
<td>(1 * 5 + (EE - 1) * 15) * NV</td>
</tr>
<tr>
<td>2 - 3</td>
<td>1</td>
<td>1</td>
<td>(EE - 2)</td>
<td>-</td>
<td>NV</td>
<td>(1 * 5 + 1 * 15 + (EE - 2) * 25) * NV</td>
</tr>
<tr>
<td>&gt;3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>(EE - 3)</td>
<td>NV</td>
<td>(1 * 5 + 1 * 15 + 1 * 25 + (EE - 3) * 95) * NV</td>
</tr>
</tbody>
</table>
Our car CO2 emissions are confirmed by the ICCT

In January 2014, the ICCT published a report estimating the passenger car CO2 emissions for a selected number of manufacturers in 2015 and 2020.

According to ICCT, most manufacturers will reach the 2015 target. German manufacturers are lagging a bit behind Renault-Nissan, PSA, Ford and Fiat who are very likely to reach the 2015 and 2020 targets.

The values presented in this table are calculated according to the current European CO2 emissions calculation (NEDC). The new calculation method will aim at reducing the CO2 emission gap between laboratory and on-road conditions.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Market share</th>
<th>Mass [kg]</th>
<th>CO2 [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daimler</td>
<td>5%</td>
<td>1583</td>
<td>143 140 101</td>
</tr>
<tr>
<td>BMW</td>
<td>6%</td>
<td>1563</td>
<td>138 139 100</td>
</tr>
<tr>
<td>GM</td>
<td>8%</td>
<td>1445</td>
<td>134 133 96</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>25%</td>
<td>1417</td>
<td>133 132 96</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1400</td>
<td>132 130 95</td>
</tr>
<tr>
<td>Ford</td>
<td>8%</td>
<td>1322</td>
<td>129 128 92</td>
</tr>
<tr>
<td>Renault-Nissan</td>
<td>12%</td>
<td>1329</td>
<td>128 128 93</td>
</tr>
<tr>
<td>Fiat (incl. Chrysler)</td>
<td>6%</td>
<td>1209</td>
<td>124 123 89</td>
</tr>
<tr>
<td>Toyota</td>
<td>4%</td>
<td>1325</td>
<td>122 128 92</td>
</tr>
<tr>
<td>PSA (Peugeot-Citroën)</td>
<td>12%</td>
<td>1374</td>
<td>122 130 94</td>
</tr>
</tbody>
</table>

Note: the ICCT (International Council on Clean Transportation) is a non profit organization that focuses on research and technical & scientific analysis of environmental regulations.
Source: EU CO2 emission standards for passenger cars and light-commercial vehicles
The McKinsey penalty estimation is close from ours

In a study published in February 2012, McKinsey shows that the potential fines in 2020 and 2525 are quite important, due to the ambitious target set by the EU. The level of the target acts as a real deterrent for car manufacturers. According to McKinsey, the level of the fine could even increase in the next decade in order to force all car manufacturers to comply with the EU regulation.

It is worth noting that this graph does not take into account the new CO2 calculation method (WLPT). This will increase the difficulty to reach the 2020 target and therefore will probably increase the potential penalties.

Source: Lightweight, heavy impact - McKinsey, February 2012
Analysis -2: Using only Fuel Efficiency in city (Miles per Gallon) Based on Data in FPP package of R

Strong non-linear relationship between the size of a car's carbon emission and its city-based fuel economy.

Fitted regression line from regressing the carbon footprint of cars versus their fuel economy in city driving conditions.

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | 12.525647| 0.199232   | 62.87   | <2e-16   *** |
| City           | -0.220970| 0.008878   | -24.89  | <2e-16   *** |

Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1 1

Residual standard error: 0.4703 on 132 degrees of freedom
Multiple R-squared: 0.8244,   Adjusted R-squared: 0.823
F-statistic: 619.5 on 1 and 132 DF,  p-value: < 2.2e-16

$\beta^1=-0.22$. For every extra mile per gallon, a car’s carbon emission will decrease on average by 0.22 tonnes per year.

Example: For a car with City driving fuel economy $x=30$ mpg, the average footprint forecasted is $y^*=5.90$ tons of CO2 per year. The corresponding 95% and 80% forecast intervals are $[4.95,6.84]$ and $[5.28,6.51]$ respectively (calculated using R).
Non-Linear Regression

Piecewise linear trend to fuel economy data. Plot suggests that a change in slope occurs at about 25 mpg.

The resulting fitted values are shown as the red line below.

An example of a cubic regression spline fitted to the fuel economy data is shown along side with a single knot at c1 = 25

Plots show the estimated relationship both in the original and the logarithmic scales.

Confidence Interval

<table>
<thead>
<tr>
<th></th>
<th>2.5 %</th>
<th>97.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>12.1315464</td>
<td>12.9197478</td>
</tr>
<tr>
<td>City</td>
<td>-0.2385315</td>
<td>-0.2034092</td>
</tr>
</tbody>
</table>

The interval $[-0.239, -0.203]$ contains the slope parameter, $\beta_1$, with probability 95%

The slope of the fitted regression line using a log-log functional form is non-constant.