qwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmrtyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnmqwertyuiopasdfghjklzxcvbnm

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| Green house gas emissions  Variation by State  4/10/2016  Daljeet Maken |

Table of Contents

[Introduction 3](#_Toc449526919)

[Methods 3](#_Toc449526920)

[Analysis and Results 3](#_Toc449526921)

[Exploratory Data Analysis / One-way Anova 3](#_Toc449526922)

[Covariate Analysis 8](#_Toc449526923)

[Unequal Slopes model 11](#_Toc449526924)

[Equal Slopes model 12](#_Toc449526925)

[Conclusion 12](#_Toc449526926)

[References 13](#_Toc449526927)

[Appendices 14](#_Toc449526928)

[Appendix A – One-Way Anova with non-transformed response variable – Tukey test comparsion results 14](#_Toc449526929)

[Appendix B – One-Way Anova with transformed response variable – Tukey test comparsion results 16](#_Toc449526930)

[Appendix B – Re-parameterizaton of ANCOVA 18](#_Toc449526931)

Green house gas emissions: Variation by State

# Introduction

The questions of interest in this study is whether the Green House Gas emission GHG varies by state and whether there is any difference among the mean scores of GHG measures.

For the test type main effect, the null hypothesis is that the mean GHG emission for all the states are the same:

The alternative hypothesis is that at least one of the state’s GHG score is different:

# Methods

This study was conducted at the Penn State University with the data from CAIT. CAIT’s Historic data allows for easy analysis and visualization of the latest available international greenhouse gas emissions data. It includes information for 186 countries, 50 U.S. states, 6 gases, multiple economic sectors, and 160 years - carbon dioxide emissions for 1850-2012 and multi-sector greenhouse gas emission for 1990-2012. For our analysis we have only used the State data and total emissions.

This is therefore an observational study with the factors as State (Fixed: since we have data for all 52 states). The independent variable is the total GHG emission. We will also evaluate if Population of the state can be used as a covariate for this analysis.

# Analysis and Results

## Exploratory Data Analysis / One-way Anova

The first step is to plot some of the states against the total GHG emissions (incl all the states makes the plot illegible)



Let’s perform a simple One-Way Anova and get the 4-way graph in Minitab:



We get the following result (detailed result in Appendix A):

Analysis of Variance

Source DF Adj SS Adj MS F-Value P-Value

State 50 18211318 364226 2588.04 0.000

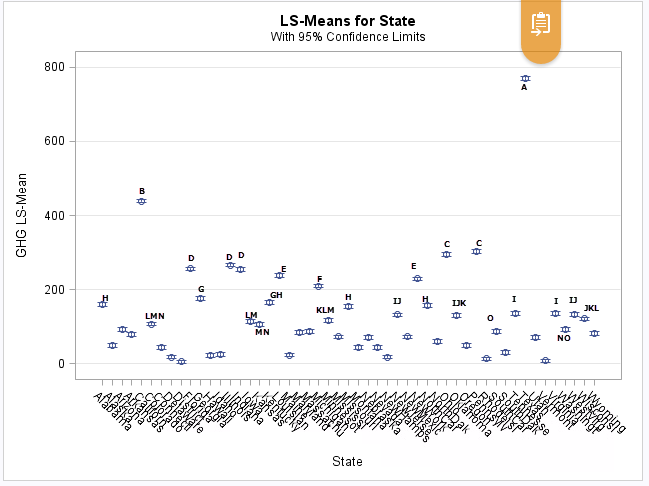
Error 1071 150726 141

Total 1121 18362045

Model Summary

S R-sq R-sq(adj) R-sq(pred)

11.8631 99.18% 99.14% 99.10%



[Labeled most of the states except the ones at bottom to maintain legibility. The complete list is in Appendix A]

This indicates that the State has a significant effect on the GHG emissions.

**Before moving further let’s take a look at the residual plots:**



We see that residuals show some fanning effect and the normality plot line is curved. So we try the Box-Cox transformation from Minitab:



We get a λ = 0.13 and therefore add a new column GHG\_trans with:

GHG\_trans = GHG^0.13

We run the Anova again and get the following plot:



It is clear that the variance distribution has improved significantly and the normality plot line is less curved than before.

The ANOVA results are:

Analysis of Variance

Source DF Adj SS Adj MS F-Value P-Value

State 50 75.3833 1.50767 3600.45 0.000

Error 1312 0.5494 0.00042

Total 1362 75.9327

This **clearly indicates that we can safely reject the null hypothesis and conclude that the means of GHG emissions are different for states**. The comparison with tukey test is in the Appendix B.

## Covariate Analysis

We will also like to analyze the possibility of using the population as a covariate. This requires that we first perform various steps to determine whether ANCOVA is suitable in the given scenario. The steps are:

**Step 1: Are all regression slopes = 0**

We carry out this step for some of the states to see the trend of data. The relevant results are below with the significant figures highlighted.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| State = Alaska | | | | | | |
| **Analysis of Variance** | | | | | | |
| **Source** | | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | | 1 | 3.39017 | 3.39017 | 0.29 | 0.5963 |
| **Error** | | 20 | 233.98464 | 11.69923 |  |  |
| **Corrected Total** | | 21 | 237.37481 |  |  |  |

|  |
| --- |
| State = Arizona |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 3932.32735 | 3932.32735 | 220.44 | <.0001 |
| **Error** | 20 | 356.76285 | 17.83814 |  |  |
| **Corrected Total** | 21 | 4289.09020 |  |  |  |

|  |
| --- |
| State = Arkansas |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 692.44318 | 692.44318 | 79.03 | <.0001 |
| **Error** | 20 | 175.23480 | 8.76174 |  |  |
| **Corrected Total** | 21 | 867.67798 |  |  |  |

|  |
| --- |
| State = Delaware |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 47.29983 | 47.29983 | 31.15 | <.0001 |
| **Error** | 20 | 30.36611 | 1.51831 |  |  |
| **Corrected Total** | 21 | 77.66594 |  |  |  |

|  |
| --- |
| State = Florida |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 11614 | 11614 | 58.95 | <.0001 |
| **Error** | 20 | 3939.91709 | 196.99585 |  |  |
| **Corrected Total** | 21 | 15554 |  |  |  |

|  |
| --- |
| State = Georgia |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 4291.46549 | 4291.46549 | 41.17 | <.0001 |
| **Error** | 20 | 2084.70167 | 104.23508 |  |  |
| **Corrected Total** | 21 | 6376.16716 |  |  |  |

|  |
| --- |
| State = Hawaii |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 8.36717 | 8.36717 | 3.04 | 0.0964 |
| **Error** | 20 | 54.98731 | 2.74937 |  |  |
| **Corrected Total** | 21 | 63.35448 |  |  |  |

|  |
| --- |
| State = Idaho |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 204.98965 | 204.98965 | 288.90 | <.0001 |
| **Error** | 20 | 14.19094 | 0.70955 |  |  |
| **Corrected Total** | 21 | 219.18058 |  |  |  |

|  |
| --- |
| State = Illinois |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 4724.17871 | 4724.17871 | 63.86 | <.0001 |
| **Error** | 20 | 1479.47564 | 73.97378 |  |  |
| **Corrected Total** | 21 | 6203.65436 |  |  |  |

|  |
| --- |
| State = Texas |

| **Analysis of Variance** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | | | | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | | | | 1 | 11169 | 11169 | 8.55 | 0.0084 |
| **Error** | | | | 20 | 26142 | 1307.10175 |  |  |
| **Corrected Total** | | | | 21 | 37311 |  |  |  |
|  |  |  |  |

|  |
| --- |
| State = Virginia |

| **Analysis of Variance** | | | | | |
| --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
| **Model** | 1 | 91.72587 | 91.72587 | 1.30 | 0.2670 |
| **Error** | 20 | 1406.71563 | 70.33578 |  |  |
| **Corrected Total** | 21 | 1498.44150 |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  |  |  |  |

**Finding:**

**We find that we can reject the null hypothesis that regression=0 for most of the states.** The highlighted values indicate that we have a significant relationship between green house gas emission and population.

**Step 2: Are the slopes equal?**

In order to check this condition we perform the

|  |
| --- |
| State = Covariance test for equal slopes |

The Mixed Procedure

| **Type 3 Tests of Fixed Effects** | | | | |
| --- | --- | --- | --- | --- |
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **State** | 50 | 1019 | 30.68 | <.0001 |
| **Pop** | 1 | 1019 | 4.32 | 0.0380 |
| **Pop\*State** | 50 | 1019 | 6.70 | <.0001 |

The results for covariate regression slopes (re-parameterization of ANCOVA)

**Finding:**

Here we see that the slope is not equal. Therefore we can’t simply remove the interaction term and compare the treatment means at the mean level of the covariate.

This is an interesting fork where we have to decide between the following options:

1. Perform the ANCOVA with unequal slopes model
2. Continue to perform the ANCOVA assuming equal slopes

### Unequal Slopes model

Now if we use different slopes, then we are acknowledging that the treatment (State) effects in subpopulations with different covariate (populations) will be different. The conditional treatment effects given X depend on X. However to get to the treatment effects in the overall population regardless of X we center the covariate population. So we add a new column PopCentered and compute as:

PopCentered = Population – Average(Population)

We get the result as:

| **Type 3 Tests of Fixed Effects** | | | | |
| --- | --- | --- | --- | --- |
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **State** | 50 | 1069 | 1280.38 | <.0001 |
| **PopCentered** | 1 | 1069 | 550.15 | <.0001 |

The detailed result is in the additional output file (output.html) under the heading title: Unequal slopes model

### Equal Slopes model

We know from theory that with real data, the assumptions of linearity and parallel slopes will never exactly hold. At best, they are only an approximation. If the slopes truly vary across the groups but we only estimate a common slope, then our estimates of the treatment effects will be biased. In practice, however, these biases tend to be small if the experiment is balanced or nearly balanced. That is, if the sample sizes n1, … ; nk within the groups are not drastically different, violations of the common-slopes assumption do not have a dramatic impact on the performance of the method, as long as the data come from a randomized experiment. Given this we have also evaluated the model with Population as covariate and got this output:

| **Type 3 Tests of Fixed Effects** | | | | |
| --- | --- | --- | --- | --- |
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **State** | 50 | 1069 | 1280.38 | <.0001 |
| **Pop** | 1 | 1069 | 550.15 | <.0001 |

The detailed result is in the additional output file (output.html) under the heading title: Equal slopes model

# Conclusion

The simple one-way ANOVA indicated that **the null hypothesis that all states have same mean GHG emissions can be rejected**. We also observed that while the covariate population relationship to response is significant it has different slopes for different states and therefore we can’t simply remove the interaction term and compare the treatment means at the mean level of the covariate. Further we performed the analysis assuming both unequal and equal slopes model and found that **the null hypothesis that all states have same mean GHG emissions can be rejected**.

# References

* Penn State University online notes
* Dataset from CAIT: http://www.wri.org/resources/data-sets/cait-historical-emissions-data-countries-us-states-unfccc
* Kutner, M & Nachtsheim C - Applied Linear Statistical Models

# Appendices

## Appendix A – One-Way Anova with non-transformed response variable – Tukey test comparsion results

Means

State N Mean StDev 95% CI

Alabama 22 160.08 9.87 (155.12, 165.04)

Alaska 22 49.353 3.362 (44.390, 54.316)

Arizona 22 92.69 14.29 ( 87.73, 97.65)

Arkansas 22 79.02 6.43 ( 74.06, 83.98)

California 22 439.05 22.75 (434.09, 444.01)

Colorado 22 106.75 15.44 (101.78, 111.71)

Connecticut 22 44.340 2.782 (39.377, 49.302)

Delaware 22 17.644 1.923 (12.681, 22.607)

DistrictOfColumbia 22 4.785 0.514 (-0.178, 9.748)

Florida 22 255.72 27.21 (250.76, 260.69)

Georgia 22 176.83 17.42 (171.87, 181.80)

Hawaii 22 22.672 1.737 (17.709, 27.634)

Idaho 22 24.834 3.231 (19.871, 29.797)

Illinois 22 266.34 17.19 (261.38, 271.30)

Indiana 22 254.09 20.90 (249.12, 259.05)

Iowa 22 113.99 10.94 (109.03, 118.96)

Kansas 22 104.93 5.45 ( 99.97, 109.89)

Kentucky 22 165.50 12.56 (160.54, 170.46)

Louisiana 22 237.88 10.80 (232.92, 242.84)

Maine 22 23.145 2.193 (18.182, 28.107)

Maryland 22 84.17 5.78 ( 79.21, 89.13)

Massachusetts 22 87.298 4.583 (82.335, 92.261)

Michigan 22 209.48 11.25 (204.52, 214.44)

Minnesota 22 116.59 8.01 (111.63, 121.55)

Mississippi 22 72.22 8.45 ( 67.26, 77.18)

Missouri 22 154.29 14.92 (149.33, 159.25)

Montana 22 44.059 3.701 (39.096, 49.022)

Nebraska 22 70.23 8.35 ( 65.27, 75.19)

Nevada 22 43.75 5.51 ( 38.79, 48.71)

NewHampshire 22 17.916 2.059 (12.954, 22.879)

NewJersey 22 131.52 6.13 (126.56, 136.48)

NewMexico 22 72.18 6.83 ( 67.22, 77.14)

NewYork 22 228.87 13.54 (223.90, 233.83)

NorthCarolina 22 157.81 15.12 (152.85, 162.78)

NorthDakota 22 58.95 5.34 ( 53.99, 63.91)

Ohio 22 295.25 13.46 (290.29, 300.21)

Oklahoma 22 130.69 8.11 (125.73, 135.65)

Oregon 22 49.266 4.179 (44.303, 54.229)

Pennsylvania 22 302.43 11.00 (297.46, 307.39)

RhodeIsland 22 12.994 1.259 ( 8.031, 17.957)

SouthCarolina 22 86.52 10.96 ( 81.56, 91.48)

SouthDakota 22 29.276 2.863 (24.313, 34.239)

Tennessee 22 135.55 10.56 (130.59, 140.51)

Texas 22 769.59 42.15 (764.63, 774.55)

Utah 22 71.13 6.02 ( 66.17, 76.09)

Vermont 22 7.6006 0.4350 (2.6378, 12.5634)

Virginia 22 136.29 8.45 (131.32, 141.25)

Washington 22 92.836 4.619 (87.873, 97.798)

WestVirginia 22 133.16 6.74 (128.19, 138.12)

Wisconsin 22 120.98 6.97 (116.01, 125.94)

Wyoming 22 81.68 5.29 ( 76.72, 86.64)

Pooled StDev = 11.8631

**Tukey Pairwise Comparisons**

Grouping Information Using the Tukey Method and 95% Confidence

State N Mean Grouping

Texas 22 769.59 A

California 22 439.05 B

Pennsylvania 22 302.43 C

Ohio 22 295.25 C

Illinois 22 266.34 D

Florida 22 255.72 D

Indiana 22 254.09 D

Louisiana 22 237.88 E

NewYork 22 228.87 E

Michigan 22 209.48 F

Georgia 22 176.83 G

Kentucky 22 165.50 G H

Alabama 22 160.08 H

NorthCarolina 22 157.81 H

Missouri 22 154.29 H

Virginia 22 136.29 I

Tennessee 22 135.55 I

WestVirginia 22 133.16 I J

NewJersey 22 131.52 I J

Oklahoma 22 130.69 I J K

Wisconsin 22 120.98 J K L

Minnesota 22 116.59 K L M

Iowa 22 113.99 L M

Colorado 22 106.75 L M N

Kansas 22 104.93 M N

Washington 22 92.836 N O

Arizona 22 92.69 N O

Massachusetts 22 87.298 O

SouthCarolina 22 86.52 O P

Maryland 22 84.17 O P Q

Wyoming 22 81.68 O P Q

Arkansas 22 79.02 O P Q

Mississippi 22 72.22 P Q R

NewMexico 22 72.18 Q R

Utah 22 71.13 Q R

Nebraska 22 70.23 Q R

NorthDakota 22 58.95 R S

Alaska 22 49.353 S T

Oregon 22 49.266 S T

Connecticut 22 44.340 T

Montana 22 44.059 T

Nevada 22 43.75 T

SouthDakota 22 29.276 U

Idaho 22 24.834 U V

Maine 22 23.145 U V

Hawaii 22 22.672 U V

NewHampshire 22 17.916 U V W

Delaware 22 17.644 U V W

RhodeIsland 22 12.994 V W

Vermont 22 7.6006 W

DistrictOfColumbia 22 4.785 W

Means that do not share a letter are significantly different.

## Appendix B – One-Way Anova with transformed response variable – Tukey test comparsion results

Means

State N Mean StDev 95% CI

Alabama 22 1.93407 0.01589 (1.92551, 1.94263)

Alaska 43 1.66006 0.01459 (1.65394, 1.66618)

Arizona 44 1.79945 0.03640 (1.79340, 1.80550)

Arkansas 44 1.76417 0.01916 (1.75812, 1.77022)

California 22 2.20528 0.01482 (2.19672, 2.21384)

Colorado 22 1.83306 0.03537 (1.82451, 1.84162)

Connecticut 22 1.63678 0.01334 (1.62822, 1.64534)

Delaware 44 1.45127 0.02188 (1.44522, 1.45732)

DistrictOfColumbia 22 1.22491 0.01753 (1.21635, 1.23347)

Florida 44 2.05464 0.02873 (2.04859, 2.06069)

Georgia 44 1.95861 0.02547 (1.95256, 1.96466)

Hawaii 44 1.49997 0.01428 (1.49391, 1.50602)

Idaho 44 1.51684 0.02625 (1.51079, 1.52289)

Illinois 44 2.06636 0.01754 (2.06031, 2.07241)

Indiana 22 2.05346 0.02230 (2.04490, 2.06201)

Iowa 22 1.85002 0.02320 (1.84146, 1.85858)

Kansas 22 1.83085 0.01254 (1.82229, 1.83940)

Kentucky 22 1.94224 0.01977 (1.93368, 1.95080)

Louisiana 22 2.03647 0.01204 (2.02791, 2.04503)

Maine 22 1.50374 0.01830 (1.49518, 1.51230)

Maryland 22 1.77894 0.01585 (1.77038, 1.78749)

Massachusetts 22 1.78757 0.01259 (1.77901, 1.79613)

Michigan 22 2.00299 0.01421 (1.99443, 2.01155)

Minnesota 22 1.85589 0.01698 (1.84733, 1.86445)

Mississippi 22 1.74297 0.02730 (1.73441, 1.75153)

Missouri 22 1.92421 0.02514 (1.91565, 1.93277)

Montana 22 1.63517 0.01764 (1.62661, 1.64373)

Nebraska 22 1.73662 0.02739 (1.72807, 1.74518)

Nevada 22 1.63287 0.02704 (1.62431, 1.64143)

NewHampshire 22 1.45421 0.02098 (1.44566, 1.46277)

NewJersey 22 1.88546 0.01151 (1.87690, 1.89402)

NewMexico 22 1.74332 0.02196 (1.73476, 1.75188)

NewYork 22 2.02610 0.01598 (2.01754, 2.03466)

NorthCarolina 22 1.92988 0.02506 (1.92132, 1.93844)

NorthDakota 22 1.69814 0.01993 (1.68958, 1.70670)

Ohio 22 2.09447 0.01252 (2.08592, 2.10303)

Oklahoma 22 1.88374 0.01526 (1.87518, 1.89230)

Oregon 22 1.65904 0.01882 (1.65048, 1.66759)

Pennsylvania 22 2.10111 0.01004 (2.09255, 2.10967)

RhodeIsland 22 1.39495 0.01800 (1.38639, 1.40351)

SouthCarolina 22 1.78415 0.03023 (1.77560, 1.79271)

SouthDakota 22 1.55030 0.02021 (1.54174, 1.55885)

Tennessee 22 1.89246 0.01959 (1.88390, 1.90102)

Texas 44 2.37215 0.01700 (2.36609, 2.37820)

Utah 22 1.74018 0.01960 (1.73162, 1.74874)

Vermont 22 1.30146 0.00975 (1.29291, 1.31002)

Virginia 44 1.89404 0.01509 (1.88799, 1.90009)

Washington 22 1.80196 0.01169 (1.79340, 1.81052)

WestVirginia 22 1.88845 0.01262 (1.87989, 1.89701)

Wisconsin 22 1.86497 0.01420 (1.85641, 1.87353)

Wyoming 22 1.77205 0.01502 (1.76349, 1.78061)

Pooled StDev = 0.0204632

**Tukey Pairwise Comparisons**

Grouping Information Using the Tukey Method and 95% Confidence

State N Mean Grouping

Texas 44 2.37215 A

California 22 2.20528 B

Pennsylvania 22 2.10111 C

Ohio 22 2.09447 C

Illinois 44 2.06636 D

Florida 44 2.05464 D E

Indiana 22 2.05346 D E

Louisiana 22 2.03647 E F

NewYork 22 2.02610 F G

Michigan 22 2.00299 G

Georgia 44 1.95861 H

Kentucky 22 1.94224 H I

Alabama 22 1.93407 I

NorthCarolina 22 1.92988 I

Missouri 22 1.92421 I

Virginia 44 1.89404 J

Tennessee 22 1.89246 J

WestVirginia 22 1.88845 J K

NewJersey 22 1.88546 J K

Oklahoma 22 1.88374 J K

Wisconsin 22 1.86497 K L

Minnesota 22 1.85589 L M

Iowa 22 1.85002 L M N

Colorado 22 1.83306 M N

Kansas 22 1.83085 N

Washington 22 1.80196 O

Arizona 44 1.79945 O

Massachusetts 22 1.78757 O P

SouthCarolina 22 1.78415 O P Q

Maryland 22 1.77894 O P Q

Wyoming 22 1.77205 P Q

Arkansas 44 1.76417 Q R

NewMexico 22 1.74332 R S

Mississippi 22 1.74297 R S

Utah 22 1.74018 S

Nebraska 22 1.73662 S

NorthDakota 22 1.69814 T

Alaska 43 1.66006 U

Oregon 22 1.65904 U V

Connecticut 22 1.63678 V W

Montana 22 1.63517 V W

Nevada 22 1.63287 W

SouthDakota 22 1.55030 X

Idaho 44 1.51684 Y

Maine 22 1.50374 Y

Hawaii 44 1.49997 Y

NewHampshire 22 1.45421 Z

Delaware 44 1.45127 Z

RhodeIsland 22 1.39495 AA

Vermont 22 1.30146 AB

DistrictOfColumbia 22 1.22491 AC

Means that do not share a letter are significantly different.

## Appendix B – Re-parameterizaton of ANCOVA

|  |
| --- |
| Reparameterizaton of ANCOVA |

The Mixed Procedure

| **Model Information** | |
| --- | --- |
| **Data Set** | WORK.GHGALLSTATEDATA |
| **Dependent Variable** | GHG |
| **Covariance Structure** | Diagonal |
| **Estimation Method** | REML |
| **Residual Variance Method** | Profile |
| **Fixed Effects SE Method** | Model-Based |
| **Degrees of Freedom Method** | Residual |

| **Class Level Information** | | |
| --- | --- | --- |
| **Class** | **Levels** | **Values** |
| **State** | 51 | Alabama Alaska Arizona Arkansas Californ Colorado Connecti Delaware District Florida Georgia Hawaii Idaho Illinois Indiana Iowa Kansas Kentucky Louisian Maine Maryland Massachu Michigan Minnesot Mississi Missouri Montana Nebraska Nevada NewHamps NewJerse NewMexic NewYork NorthCar NorthDak Ohio Oklahoma Oregon Pennsylv RhodeIsl SouthCar SouthDak Tennesse Texas Utah Vermont Virginia Washingt WestVirg Wisconsi Wyoming |

| **Dimensions** | |
| --- | --- |
| **Covariance Parameters** | 1 |
| **Columns in X** | 102 |
| **Columns in Z** | 0 |
| **Subjects** | 1 |
| **Max Obs per Subject** | 1121 |

| **Number of Observations** | |
| --- | --- |
| **Number of Observations Read** | 1121 |
| **Number of Observations Used** | 1121 |
| **Number of Observations Not Used** | 0 |

| **Covariance Parameter Estimates** | |
| --- | --- |
| **Cov Parm** | **Estimate** |
| **Residual** | 73.4258 |

| **Fit Statistics** | |
| --- | --- |
| **-2 Res Log Likelihood** | 8817.1 |
| **AIC (Smaller is Better)** | 8819.1 |
| **AICC (Smaller is Better)** | 8819.1 |
| **BIC (Smaller is Better)** | 8824.0 |

| **Solution for Fixed Effects** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Effect** | **State** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > |t|** |
| **State** | **Alabama** | 60.8223 | 37.8452 | 1019 | 1.61 | 0.1083 |
| **State** | **Alaska** | 54.9541 | 26.1305 | 1019 | 2.10 | 0.0357 |
| **State** | **Arizona** | 14.7786 | 10.8018 | 1019 | 1.37 | 0.1716 |
| **State** | **Arkansas** | -7.1765 | 28.1274 | 1019 | -0.26 | 0.7987 |
| **State** | **Californ** | 194.18 | 26.4023 | 1019 | 7.35 | <.0001 |
| **State** | **Colorado** | -8.7954 | 14.5088 | 1019 | -0.61 | 0.5445 |
| **State** | **Connecti** | 41.5944 | 62.6203 | 1019 | 0.66 | 0.5067 |
| **State** | **Delaware** | 33.5036 | 19.8443 | 1019 | 1.69 | 0.0917 |
| **State** | **District** | 16.8321 | 69.7421 | 1019 | 0.24 | 0.8093 |
| **State** | **Florida** | 60.4871 | 15.6308 | 1019 | 3.87 | 0.0001 |
| **State** | **Georgia** | 65.2592 | 14.7084 | 1019 | 4.44 | <.0001 |
| **State** | **Hawaii** | 12.1011 | 31.3665 | 1019 | 0.39 | 0.6997 |
| **State** | **Idaho** | 1.8092 | 13.9006 | 1019 | 0.13 | 0.8965 |
| **State** | **Illinois** | -167.46 | 54.1129 | 1019 | -3.09 | 0.0020 |
| **State** | **Indiana** | -38.6830 | 38.7282 | 1019 | -1.00 | 0.3181 |
| **State** | **Iowa** | -270.40 | 68.1410 | 1019 | -3.97 | <.0001 |
| **State** | **Kansas** | -0.4437 | 44.4712 | 1019 | -0.01 | 0.9920 |
| **State** | **Kentucky** | -55.1326 | 36.7752 | 1019 | -1.50 | 0.1341 |
| **State** | **Louisian** | 223.12 | 79.4912 | 1019 | 2.81 | 0.0051 |
| **State** | **Maine** | 4.8430 | 64.1443 | 1019 | 0.08 | 0.9398 |
| **State** | **Maryland** | 55.7484 | 31.2285 | 1019 | 1.79 | 0.0745 |
| **State** | **Massachu** | 180.30 | 64.2643 | 1019 | 2.81 | 0.0051 |
| **State** | **Michigan** | 57.9364 | 81.6941 | 1019 | 0.71 | 0.4784 |
| **State** | **Minnesot** | 6.1541 | 30.7490 | 1019 | 0.20 | 0.8414 |
| **State** | **Mississi** | -102.47 | 42.3079 | 1019 | -2.42 | 0.0156 |
| **State** | **Missouri** | -111.95 | 37.8369 | 1019 | -2.96 | 0.0032 |
| **State** | **Montana** | -5.6585 | 29.7431 | 1019 | -0.19 | 0.8492 |
| **State** | **Nebraska** | -116.20 | 42.3851 | 1019 | -2.74 | 0.0062 |
| **State** | **Nevada** | 29.7448 | 7.7159 | 1019 | 3.85 | 0.0001 |
| **State** | **NewHamps** | -3.5209 | 29.8632 | 1019 | -0.12 | 0.9062 |
| **State** | **NewJerse** | 76.1767 | 45.5974 | 1019 | 1.67 | 0.0951 |
| **State** | **NewMexic** | 2.8004 | 20.9696 | 1019 | 0.13 | 0.8938 |
| **State** | **NewYork** | 330.51 | 82.5289 | 1019 | 4.00 | <.0001 |
| **State** | **NorthCar** | 67.6622 | 16.2613 | 1019 | 4.16 | <.0001 |
| **State** | **NorthDak** | -153.89 | 98.5391 | 1019 | -1.56 | 0.1187 |
| **State** | **Ohio** | -53.3863 | 106.36 | 1019 | -0.50 | 0.6158 |
| **State** | **Oklahoma** | -9.7256 | 34.8051 | 1019 | -0.28 | 0.7800 |
| **State** | **Oregon** | 13.2762 | 21.0687 | 1019 | 0.63 | 0.5287 |
| **State** | **Pennsylv** | 428.39 | 99.5610 | 1019 | 4.30 | <.0001 |
| **State** | **RhodeIsl** | 11.6790 | 86.4965 | 1019 | 0.14 | 0.8926 |
| **State** | **SouthCar** | -15.3311 | 20.9489 | 1019 | -0.73 | 0.4644 |
| **State** | **SouthDak** | -29.4435 | 40.5089 | 1019 | -0.73 | 0.4675 |
| **State** | **Tennesse** | 89.9190 | 22.9445 | 1019 | 3.92 | <.0001 |
| **State** | **Texas** | 584.87 | 15.0882 | 1019 | 38.76 | <.0001 |
| **State** | **Utah** | 34.5711 | 13.1126 | 1019 | 2.64 | 0.0085 |
| **State** | **Vermont** | 3.6071 | 55.2811 | 1019 | 0.07 | 0.9480 |
| **State** | **Virginia** | 110.67 | 22.9892 | 1019 | 4.81 | <.0001 |
| **State** | **Washingt** | 92.3350 | 19.6462 | 1019 | 4.70 | <.0001 |
| **State** | **WestVirg** | 364.68 | 199.49 | 1019 | 1.83 | 0.0678 |
| **State** | **Wisconsi** | 25.3571 | 41.0048 | 1019 | 0.62 | 0.5365 |
| **State** | **Wyoming** | 22.2365 | 28.6672 | 1019 | 0.78 | 0.4381 |
| **Pop\*State** | **Alabama** | 0.000022 | 8.487E-6 | 1019 | 2.61 | 0.0091 |
| **Pop\*State** | **Alaska** | -8.77E-6 | 0.000041 | 1019 | -0.21 | 0.8299 |
| **Pop\*State** | **Arizona** | 0.000015 | 2.056E-6 | 1019 | 7.32 | <.0001 |
| **Pop\*State** | **Arkansas** | 0.000032 | 0.000011 | 1019 | 3.07 | 0.0022 |
| **Pop\*State** | **Californ** | 7.205E-6 | 0 | 1019 | Infty | <.0001 |
| **Pop\*State** | **Colorado** | 0.000027 | 3.363E-6 | 1019 | 8.03 | <.0001 |
| **Pop\*State** | **Connecti** | 8.011E-7 | 0.000018 | 1019 | 0.04 | 0.9650 |
| **Pop\*State** | **Delaware** | -0.00002 | 0.000025 | 1019 | -0.80 | 0.4224 |
| **Pop\*State** | **District** | -0.00002 | 0.000120 | 1019 | -0.17 | 0.8628 |
| **Pop\*State** | **Florida** | 0.000012 | 0 | 1019 | Infty | <.0001 |
| **Pop\*State** | **Georgia** | 0.000014 | 1.773E-6 | 1019 | 7.65 | <.0001 |
| **Pop\*State** | **Hawaii** | 8.503E-6 | 0.000025 | 1019 | 0.34 | 0.7358 |
| **Pop\*State** | **Idaho** | 0.000018 | 0.000010 | 1019 | 1.67 | 0.0951 |
| **Pop\*State** | **Illinois** | 0.000035 | 4.388E-6 | 1019 | 8.02 | <.0001 |
| **Pop\*State** | **Indiana** | 0.000048 | 6.36E-6 | 1019 | 7.57 | <.0001 |
| **Pop\*State** | **Iowa** | 0.000131 | 0.000023 | 1019 | 5.64 | <.0001 |
| **Pop\*State** | **Kansas** | 0.000039 | 0.000017 | 1019 | 2.37 | 0.0179 |
| **Pop\*State** | **Kentucky** | 0.000055 | 9.074E-6 | 1019 | 6.01 | <.0001 |
| **Pop\*State** | **Louisian** | 3.335E-6 | 0.000018 | 1019 | 0.19 | 0.8527 |
| **Pop\*State** | **Maine** | 0.000014 | 0.000050 | 1019 | 0.29 | 0.7754 |
| **Pop\*State** | **Maryland** | 5.323E-6 | 5.839E-6 | 1019 | 0.91 | 0.3622 |
| **Pop\*State** | **Massachu** | -0.00001 | 0.000010 | 1019 | -1.45 | 0.1480 |
| **Pop\*State** | **Michigan** | 0.000015 | 8.316E-6 | 1019 | 1.86 | 0.0638 |
| **Pop\*State** | **Minnesot** | 0.000022 | 6.249E-6 | 1019 | 3.60 | 0.0003 |
| **Pop\*State** | **Mississi** | 0.000062 | 0.000015 | 1019 | 4.13 | <.0001 |
| **Pop\*State** | **Missouri** | 0.000048 | 6.744E-6 | 1019 | 7.04 | <.0001 |
| **Pop\*State** | **Montana** | 0.000055 | 0.000033 | 1019 | 1.67 | 0.0943 |
| **Pop\*State** | **Nebraska** | 0.000109 | 0.000025 | 1019 | 4.40 | <.0001 |
| **Pop\*State** | **Nevada** | 6.881E-6 | 3.683E-6 | 1019 | 1.87 | 0.0620 |
| **Pop\*State** | **NewHamps** | 0.000017 | 0.000024 | 1019 | 0.72 | 0.4722 |
| **Pop\*State** | **NewJerse** | 6.605E-6 | 5.438E-6 | 1019 | 1.21 | 0.2248 |
| **Pop\*State** | **NewMexic** | 0.000038 | 0.000011 | 1019 | 3.32 | 0.0009 |
| **Pop\*State** | **NewYork** | -5.39E-6 | 4.374E-6 | 1019 | -1.23 | 0.2183 |
| **Pop\*State** | **NorthCar** | 0.000011 | 1.984E-6 | 1019 | 5.58 | <.0001 |
| **Pop\*State** | **NorthDak** | 0.000328 | 0.000152 | 1019 | 2.16 | 0.0310 |
| **Pop\*State** | **Ohio** | 0.000031 | 9.393E-6 | 1019 | 3.28 | 0.0011 |
| **Pop\*State** | **Oklahoma** | 0.000041 | 0.000010 | 1019 | 4.04 | <.0001 |
| **Pop\*State** | **Oregon** | 0.000011 | 6.135E-6 | 1019 | 1.71 | 0.0867 |
| **Pop\*State** | **Pennsylv** | -0.00001 | 8.071E-6 | 1019 | -1.27 | 0.2060 |
| **Pop\*State** | **RhodeIsl** | 1.263E-6 | 0.000083 | 1019 | 0.02 | 0.9879 |
| **Pop\*State** | **SouthCar** | 0.000025 | 5.135E-6 | 1019 | 4.88 | <.0001 |
| **Pop\*State** | **SouthDak** | 0.000077 | 0.000053 | 1019 | 1.45 | 0.1471 |
| **Pop\*State** | **Tennesse** | 8.012E-6 | 4.016E-6 | 1019 | 2.00 | 0.0463 |
| **Pop\*State** | **Texas** | 8.72E-6 | 0 | 1019 | Infty | <.0001 |
| **Pop\*State** | **Utah** | 0.000016 | 5.719E-6 | 1019 | 2.82 | 0.0050 |
| **Pop\*State** | **Vermont** | 6.607E-6 | 0.000091 | 1019 | 0.07 | 0.9424 |
| **Pop\*State** | **Virginia** | 3.578E-6 | 3.201E-6 | 1019 | 1.12 | 0.2640 |
| **Pop\*State** | **Washingt** | 8.457E-8 | 3.305E-6 | 1019 | 0.03 | 0.9796 |
| **Pop\*State** | **WestVirg** | -0.00013 | 0.000110 | 1019 | -1.16 | 0.2461 |
| **Pop\*State** | **Wisconsi** | 0.000018 | 7.632E-6 | 1019 | 2.33 | 0.0198 |
| **Pop\*State** | **Wyoming** | 0.000118 | 0.000057 | 1019 | 2.08 | 0.0380 |

| **Type 3 Tests of Fixed Effects** | | | | |
| --- | --- | --- | --- | --- |
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **State** | 51 | 1019 | 35.69 | <.0001 |
| **Pop\*State** | 51 | 1019 | 20.24 | <.0001 |

| **Contrasts** | | | | |
| --- | --- | --- | --- | --- |
| **Label** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **slopes equal hypothesis** | 1 | 1019 | 0.55 | 0.4582 |