

Correction for Regression Assumption Violations

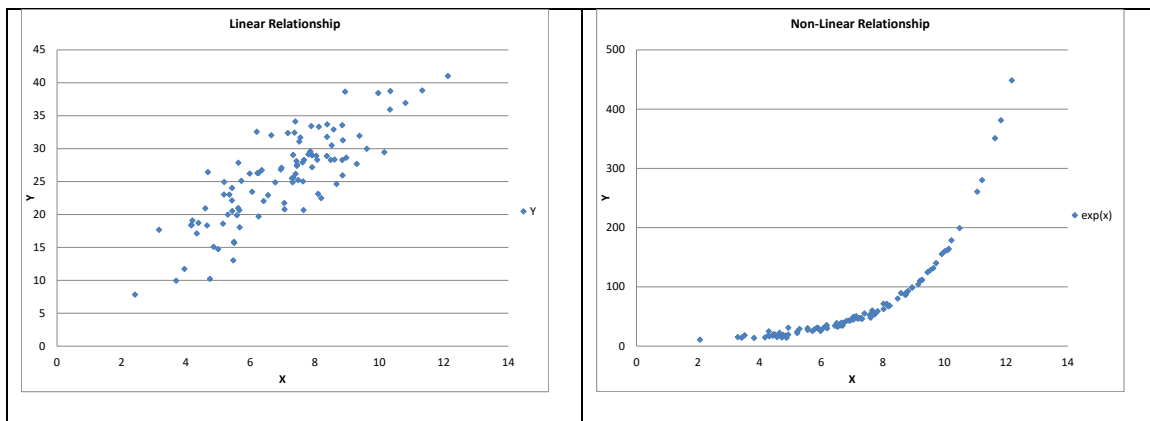
Regression Diagnostics

There are several assumptions of linear regression:

1. The relationships are linear
2. The X variables (explanatory variables) are not correlated
3. Distribution of residuals
 - a. The error terms have constant variance
 - b. The errors terms are not correlated
 - c. There are no outliers

Assumption #1: The relationship is linear (violation: non-linearity)

Let's examine each of these assumptions. In the pictures below, the left picture has data with a linear relationship, the right picture had non-linear data. Linear regression can only be used on data with a linear relationship. Transformations can be used to transform non-linear data into linear data. For example, exponential data like the data on the right can be converted into a linear relationship by taking the logarithm of both the Y and X variables.



Effects of non-linearity

If the data is not linear, and you use a linear regression, the regression will generate biased (incorrect) coefficients.

Test for Linearity

The Ramsey Regression Equation Specification Error Test (RESET) (1969) to test for linearity

Solution to non-linearity

The best solution for non-linear data is to transform the data using logarithms, squares, square roots, or inverses ($1/\text{variable}$). There are more advanced techniques which can assist in determining the correct transformation (Box-Cox for the Y variable; Box-Tidwell for the X variables).

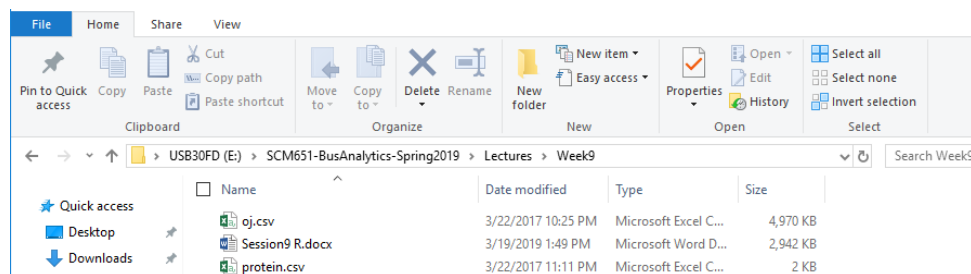
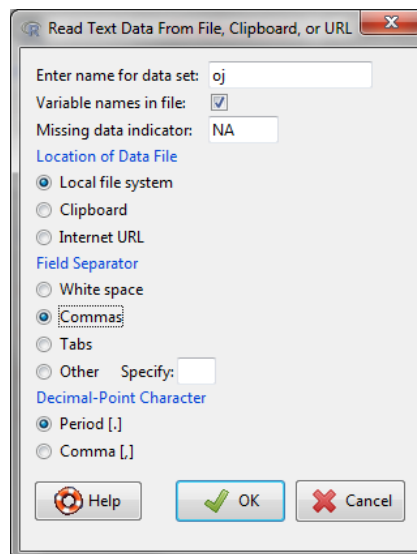
Download Datasets

Use the updated oj dataset which includes a column labeled “move”, representing sales.

Loading Data

To load data into R:

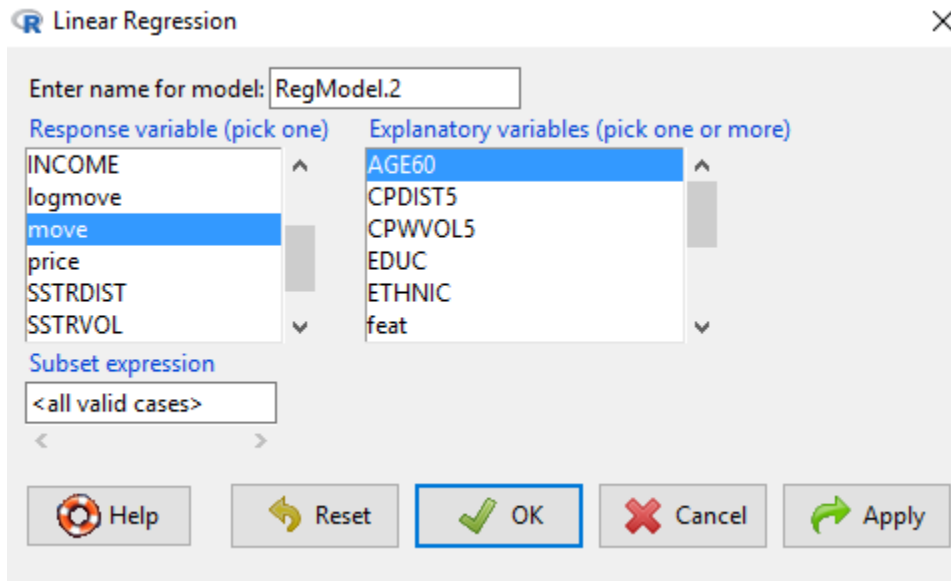
1. Click on Data at the top of the screen
2. Click on Import Data > From text file ...
3. Enter the name that you would like to use for this data set; type in oj
4. Change Field Separator to Commas, then OK
5. Click on the oj file, then Open



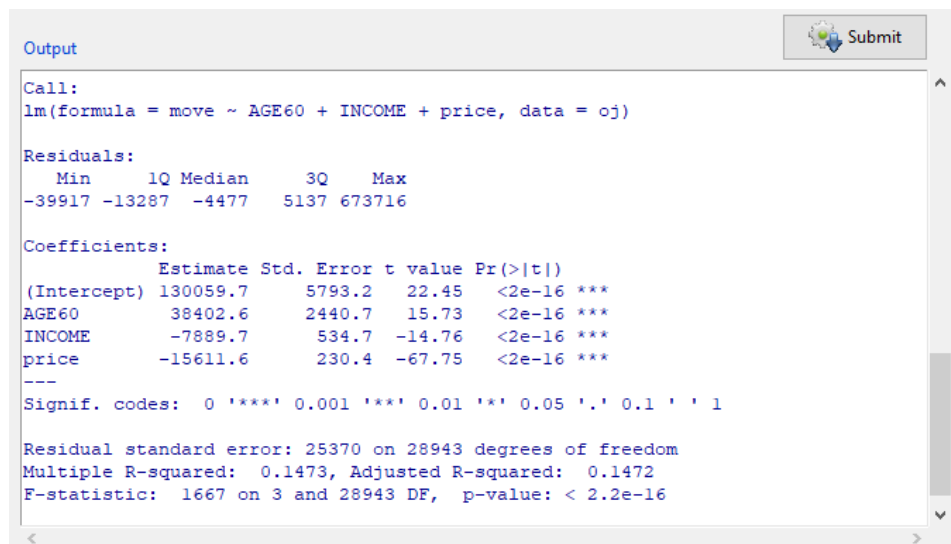
Linear Regression

Linear regression of the log of sales against age, income and price can be performed by:

1. Click on Statistics, Fit Models, Linear Regression
2. For response variable, click on move (which is the volume of products moved or sold)
3. For explanatory variables, hold down the control key and click on AGE60, INCOME, price
4. Click OK



The Linear Regression dialog box is shown. The 'Enter name for model' field contains 'RegModel.2'. The 'Response variable (pick one)' list has 'move' selected. The 'Explanatory variables (pick one or more)' list has 'AGE60', 'INCOME', and 'price' selected. The 'Subset expression' field contains '<all valid cases>'. At the bottom are buttons for Help, Reset, OK (highlighted with a blue border), Cancel, and Apply.



The Output window displays the results of the linear regression. It includes the R call, residuals, coefficients, and model fit statistics.

```
Call:
lm(formula = move ~ AGE60 + INCOME + price, data = oj)

Residuals:
    Min       1Q   Median       3Q      Max
-39917 -13287  -4477   5137 673716

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 130059.7    5793.2    22.45  <2e-16 ***
AGE60        38402.6    2440.7    15.73  <2e-16 ***
INCOME       -7889.7     534.7   -14.76  <2e-16 ***
price       -15611.6     230.4   -67.75  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

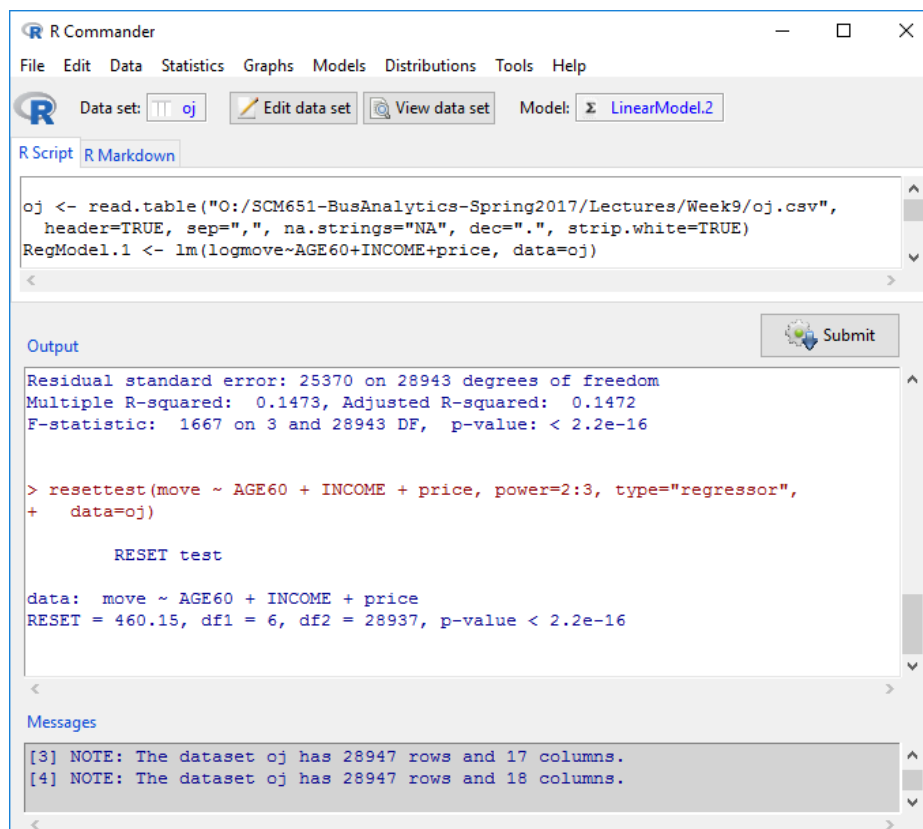
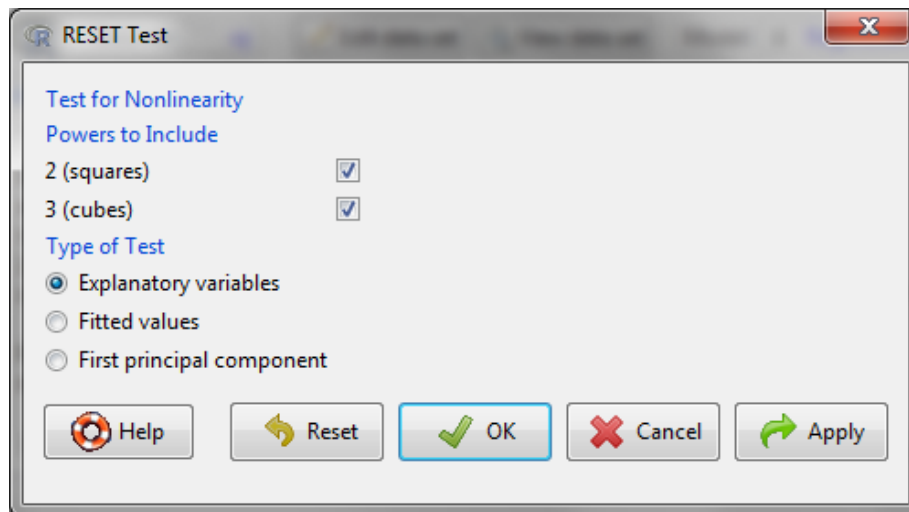
Residual standard error: 25370 on 28943 degrees of freedom
Multiple R-squared:  0.1473, Adjusted R-squared:  0.1472
F-statistic: 1667 on 3 and 28943 DF, p-value: < 2.2e-16
```

Assumption #1: Linearity

Ramsey Regression Equation Specification Error Test (RESET) (1969) to test for linearity

To test if your equation is linear:

1. Click on Models, Numerical Diagnostics, RESET test for Non-linearity
2. Click OK



3. If the p-value is less than 0.05, then there is a non-linearity problem.

Solution to Non-Linearity

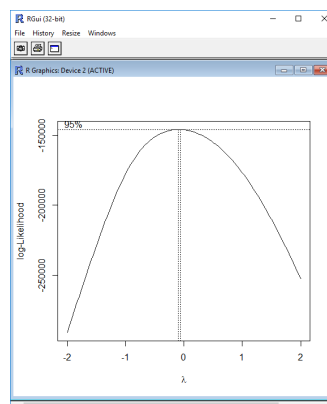
Non-linearity can result from a non-linear dependent (Y) variable or a non-linear independent (X) variable. The Box-Cox technique corrects for non-linearity in Y; the Box-Tidwell technique corrects for non-linearity in X.

Box-Cox correction for the Y-variable

When the non-linearity test indicates that your data is non-linear, first use the Box-Cox technique (George Box & D.R. Cox, 1964) to determine if the Y variable (response variable) is the problem and identify the solution. The solution is usually a transformation.

Install the Box-Cox tools set:

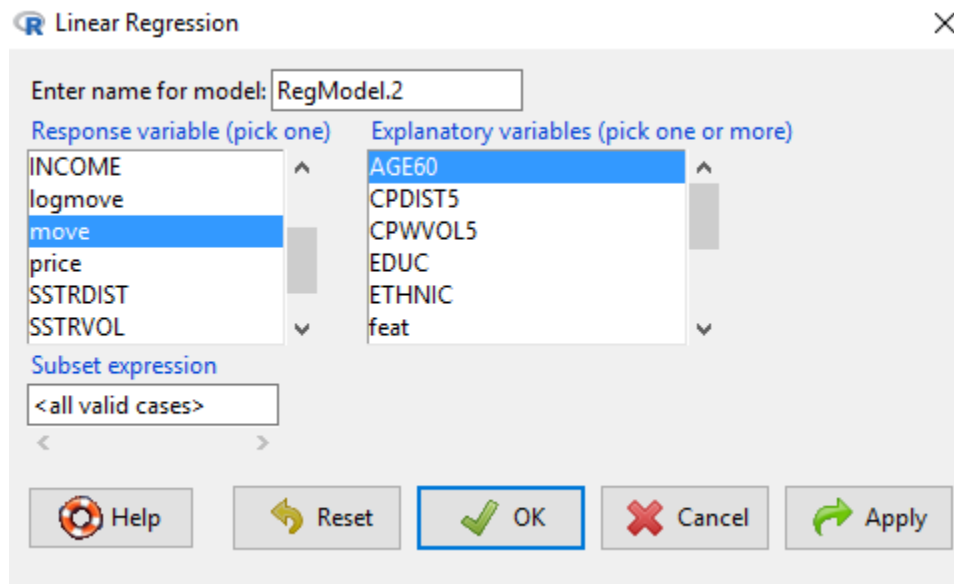
1. In the RGui screen, type:
`install.packages("MASS", dependencies=TRUE)`
2. Type `library(MASS)`
3. Type the following command
`boxcox(lm(move~AGE60+INCOME+price,data=oj),lambda=seq(-2,2,by=.1))`
4. The following components are necessary for boxcox
 - a. `boxcox` – name of command
 - b. `lm` – linear model
 - c. `move~AGE60+INCOME+price` – model formulation
 - d. `data=oj` – source of data
 - e. `lambda=seq(-2,2,by=.1)` – range of lambda and increment
5. Look on the chart for where lambda peaks; this is the maximum likelihood
6. In this example, it peaks around a lambda value of zero
7. Interpretation: lambda, in general, is the power of Y
 - a. 3 means that you should raise Y to the 3 power (Y^3)
 - b. 2 means that you should raise Y to the 2 power (Y^2)
 - c. 1 means that you should raise Y to the 1 power (Y)
 - d. $\frac{1}{2}$ means that you should raise Y to the $\frac{1}{2}$ power ($Y^{1/2}$) or \sqrt{Y}
 - e. 0 means that you should transform Y by taking the logarithm ($\log(Y)$)
 - f. $-\frac{1}{2}$ means that you should raise Y to the $-\frac{1}{2}$ power ($Y^{-1/2}$) or $1/\sqrt{Y}$
 - g. -1 means that you should transform Y by raising it to the -1 power ($1/Y$)
 - h. -2 means that you should transform Y by raising it to the -2 power ($1/Y^2$)
 - i. -3 means that you should transform Y by raising it to the -3 power ($1/Y^3$)
8. What should the transformation of our variable “move” be?



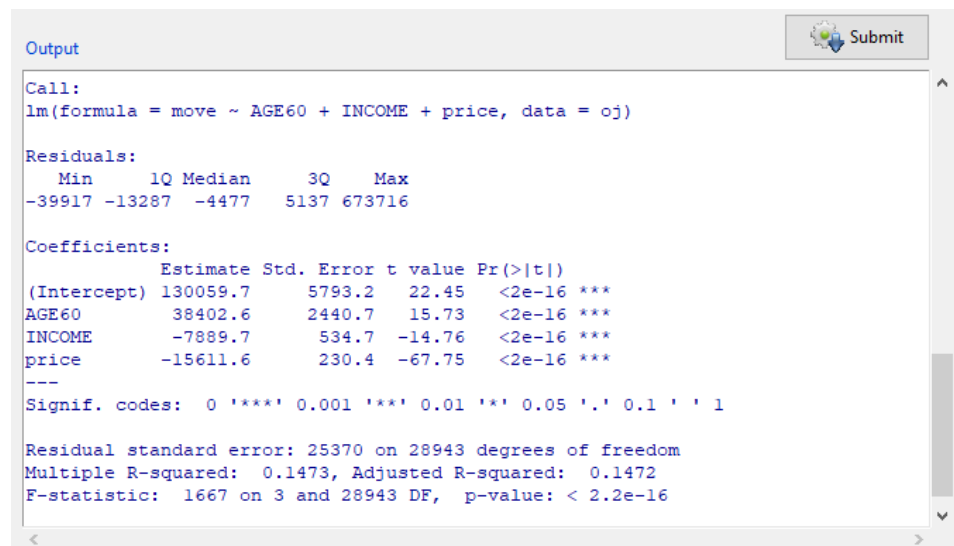
Testing the equation after correction for non-linearity in Y

Let's compare the regression results, before and after the Box-Cox correction for non-linearity in the Y-variable.

1. Click on Statistics, Fit Models, Linear Regression
2. For response variable, click on move (which is the volume of products moved or sold)
3. For explanatory variables, hold down the control key and click on AGE60, INCOME, price
4. Click OK



The image shows the 'Linear Regression' dialog box in R. The 'Enter name for model:' field contains 'RegModel.2'. The 'Response variable (pick one)' list has 'move' selected. The 'Explanatory variables (pick one or more)' list has 'AGE60', 'CPDIST5', 'CPWVOL5', 'EDUC', 'ETHNIC', and 'feat' selected. The 'Subset expression' field contains '<all valid cases>'. At the bottom, there are buttons for 'Help', 'Reset', 'OK' (highlighted with a green border), 'Cancel', and 'Apply'.



The image shows the 'Output' window in R. It displays the results of a linear regression model. The 'Call' is `lm(formula = move ~ AGE60 + INCOME + price, data = oj)`. The 'Residuals' are shown as a table with columns 'Min', '1Q', 'Median', '3Q', and 'Max'. The 'Coefficients' are shown as a table with columns 'Estimate', 'Std. Error', 't value', and 'Pr(>|t|)'. The 'Signif. codes' are shown as a table with columns '0', '***', '0.001', '***', '0.01', '***', '0.05', '***', '0.1', '***', and '1'. The 'Residual standard error' is 25370 on 28943 degrees of freedom. The 'Multiple R-squared' is 0.1473, and the 'Adjusted R-squared' is 0.1472. The 'F-statistic' is 1667 on 3 and 28943 DF, and the 'p-value' is < 2.2e-16.

```
Call:
lm(formula = move ~ AGE60 + INCOME + price, data = oj)

Residuals:
    Min       1Q   Median       3Q      Max
-39917 -13287  -4477   5137  673716

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 130059.7    5793.2    22.45  <2e-16 ***
AGE60       38402.6    2440.7    15.73  <2e-16 ***
INCOME      -7889.7     534.7   -14.76  <2e-16 ***
price      -15611.6     230.4   -67.75  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 25370 on 28943 degrees of freedom
Multiple R-squared:  0.1473, Adjusted R-squared:  0.1472
F-statistic: 1667 on 3 and 28943 DF, p-value: < 2.2e-16
```

5. The R-squared for move~AGE60+INCOME+price is 0.1472
6. Next, run the linear regression for logmove instead of move
7. Click on Statistics, Fit Models, Linear Regression
8. For response variable, click on logmove
9. For explanatory variables, hold down the control key and click on AGE60, INCOME, price
10. Click OK

Linear Regression

Enter name for model: RegModel.3

Response variable (pick one) Explanatory variables (pick one or more)

feat
 HHLARGE
 HVAL150
 INCOME
 logmove
 move

AGE60
 CPDIST5
 CPWVOL5
 EDUC
 ETHNIC
 feat

Subset expression
 <all valid cases>

Help Reset OK Cancel Apply

Output

Submit

```
lm(formula = logmove ~ AGE60 + INCOME + price, data = oj)

Residuals:
    Min       1Q   Median       3Q      Max
-4.9722 -0.5929 -0.0266  0.5846  3.5811

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 11.987186   0.208142  57.591 < 2e-16 ***
AGE60        1.709162   0.087691  19.491 < 2e-16 ***
INCOME       -0.145482   0.019211  -7.573 3.76e-14 ***
price        -0.688144   0.008279 -83.123 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9117 on 28943 degrees of freedom
Multiple R-squared:  0.2002, Adjusted R-squared:  0.2002
F-statistic: 2416 on 3 and 28943 DF, p-value: < 2.2e-16
```

11. The R-squared for logmove~AGE60+INCOME+price is 0.2002

Box-Tidwell correction for the X-variable

After correcting for any non-linearity in the Y-variable, next correct for non-linearity in the X-variable. The Box-Tidwell technique (George Box and P.W. Tidwell (1962)) corrects for non-linear independent variables.

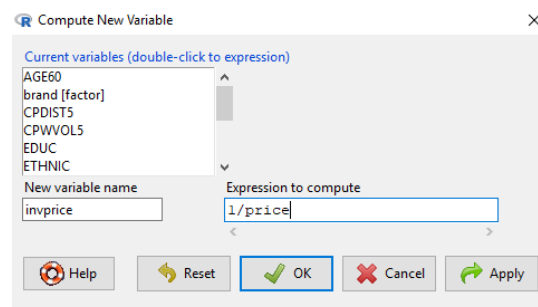
1. In the RGui screen, type:
`install.packages("car", dependencies=TRUE)`
2. Type `library(car)`
3. Type the following command
`boxTidwell(logmove~price, data=oj, tol=0.001, max.iter=25)`
4. The following components are necessary for boxcox
 - a. `boxTidwell` – name of command
 - b. `logmove~AGE60+INCOME+price` – model formulation
 - c. `data=oj` – source of data
 - d. `tol` – tolerance level, stopping threshold
 - e. `max.iter=25` – maximum number of iterations for the maximum likelihood

MLE of lambda	Score Statistic (z)	Pr(> z)
-1.0341	34.858	< 2.2e-16 ***

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

iterations = 4

5. Interpretation
 - a. 3 means that you should raise Y to the 3 power (Y^3)
 - b. 2 means that you should raise Y to the 2 power (Y^2)
 - c. 1 means that you should raise Y to the 1 power (Y)
 - d. $\frac{1}{2}$ means that you should raise Y to the $\frac{1}{2}$ power ($Y^{1/2}$) or \sqrt{Y}
 - e. 0 means that you should transform Y by taking the logarithm ($\log(Y)$)
 - f. $-\frac{1}{2}$ means that you should raise Y to the $-\frac{1}{2}$ power ($Y^{-1/2}$) or $1/\sqrt{Y}$
 - g. -1 means that you should transform Y by raising it to the -1 power ($1/Y$)
 - h. -2 means that you should transform Y by raising it to the -2 power ($1/Y^2$)
 - i. -3 means that you should transform Y by raising it to the -3 power ($1/Y^3$)
6. What should the transformation of our variable "price" be?
7. We need to create a new variable $1/X$
8. In Rcmdr, click on Data, Manage variables in active data set, Compute new variable
9. For New variable name, enter `invprice` (for inverse of price)
10. In Expression to compute, enter `1/price`
11. Click OK



12. Next, run the linear regression for $\text{logmove} \sim \text{AGE60} + \text{INCOME} + \text{invprice}$
13. Click on Statistics, Fit Models, Linear Regression
14. For response variable, click on logmove
15. For explanatory variables, hold down the control key and click on AGE60, INCOME, invprice
16. Click OK

Linear Regression X

Enter name for model:

Response variable (pick one) Explanatory variables (pick one or more)

INCOME	HVAL150
invprice	INCOME
logmove	invprice
move	logmove
price	move
SSTRDIST	price

Subset expression

R Commander _ □ X

File Edit Data Statistics Graphs Models Distributions Tools Help

Data set: **oj** Edit data set View data set Model: **RegModel.7**

R Script | R Markdown

```
readXL("O:/SCM651-BusAnalytics-Summer2019/Lectures/Session12/DistTime.xlsx",
  rownames=FALSE, header=TRUE, na="", sheet="Sheet1", stringsAsFactors=TRUE)
RegModel.5 <- lm(move~AGE60+INCOME+price, data=oj)
summary(RegModel.5)
RegModel.6 <- lm(logmove~AGE60+INCOME+price, data=oj)
summary(RegModel.6)
RegModel.7 <- lm(logmove~AGE60+INCOME+invprice, data=oj)
summary(RegModel.7)
```

Output Submit

```
Call:
lm(formula = logmove ~ AGE60 + INCOME + invprice, data = oj)

Residuals:
    Min       1Q   Median       3Q      Max
-5.4401 -0.5695 -0.0355  0.5586  3.6152

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.72274    0.20343   42.878 < 2e-16 ***
AGE60        1.65592    0.08601   19.254 < 2e-16 ***
INCOME       -0.13370    0.01884  -7.095 1.32e-12 ***
invprice      3.31092    0.03633   91.137 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8944 on 28943 degrees of freedom
Multiple R-squared:  0.2302, Adjusted R-squared:  0.2301
F-statistic: 2885 on 3 and 28943 DF, p-value: < 2.2e-16
```

Messages

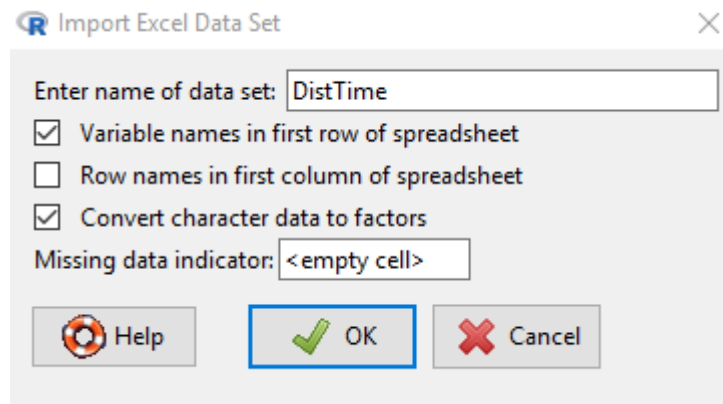
```
[11] NOTE: The dataset disttime has 6 rows and 2 columns.
[12] NOTE: The dataset oj has 28947 rows and 19 columns.
```

17. The R-squared for $\text{logmove} \sim \text{AGE60} + \text{INCOME} + \text{invprice}$ is 0.2302

Scientific Example

Datasets do not need to be large to find interesting results. Load the following data with only six observations, perform a regression of distance on time, then use Box-Cox to find the form of the equation.

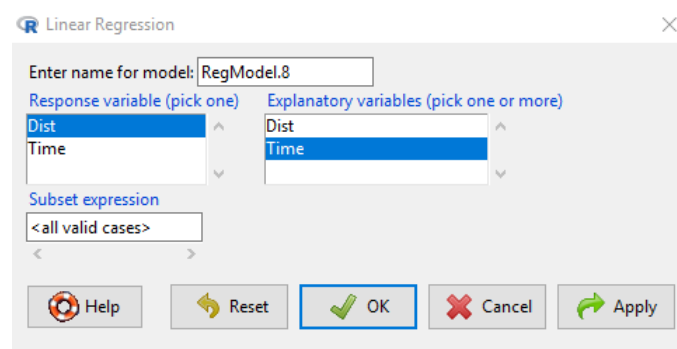
1. Click on Data at the top of the screen
2. Click on Import Data > From Excel file ...
3. Enter the name that you would like to use for this data set; type in DistTime
4. Click OK



5. Click on the DistTime file, then Open
6. Click on View data set to view the six data observations

	Dist	Time
1	0.389	87.77
2	0.724	224.70
3	1.000	365.25
4	1.524	686.95
5	5.200	4332.62
6	9.510	10759.20

7. Run the regression by clicking on Statistics, Fit models, Linear regression
8. Click on Dist for the Response variable (Y) and Time for the Explanatory variable (X)
9. Click OK



```

R Commander
File Edit Data Statistics Graphs Models Distributions Tools Help
Data set: DistTime Edit data set View data set Model: RegModel.8
R Script R Markdown

dvttest(logmove ~ AGE60 + INCOME + invprice, alternative="greater", data=o3)
bptest(logmove ~ AGE60 + INCOME + invprice, varformula = ~ fitted.values(RegModel.7), studentize=FALSE,
data=o3)
outlierTest(RegModel.7)
DistTime <- readXL("0:/SCH651-BusAnalytics-Summer2019/Lectures/Session12/DistTime.xlsx", rownames=FALSE,
header=TRUE, na="", sheet="Sheet1", stringsAsFactors=TRUE)
RegModel.8 <- lm(Dist~Time, data=DistTime)

Output
Call:
lm(formula = Dist ~ Time, data = DistTime)

Residuals:
    1      2      3      4      5      6 
-0.42428 -0.20504 -0.04787  0.20416  0.79807 -0.32504 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.73907972  0.25117128   2.943   0.0423 *
Time         0.00084541  0.00005291  15.977 0.0000897 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

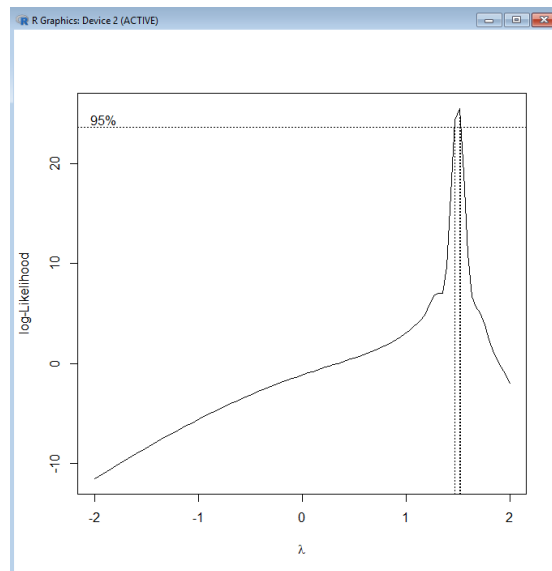
Residual standard error: 0.5021 on 4 degrees of freedom
Multiple R-squared:  0.9846, Adjusted R-squared:  0.9807
F-statistic: 255.3 on 1 and 4 DF, p-value: 0.00008972

Messages
[15] NOTE: The dataset DistTime has 6 rows and 2 columns.

```

10. Next run Box-Cox

`boxcox(lm(Dist~Time,data=DistTime),lambda=seq(-2,2,by=.1))`



11. The lambda is 1.5, or written as a fraction, $3/2$

12. The equation then is

$$\text{Dist}^{3/2} = \beta * \text{Time}$$

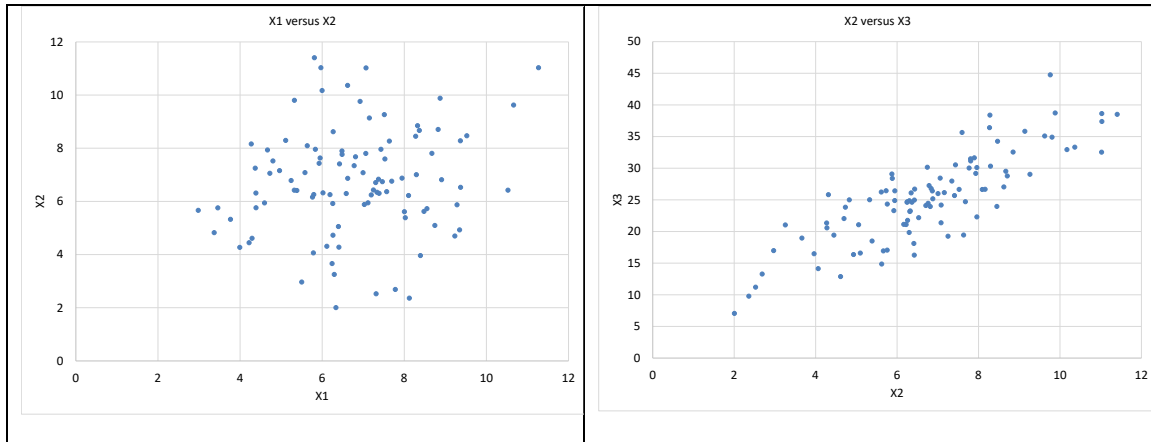
13. Taking the square of each side, we get

$$\text{Dist}^3 = \beta * \text{Time}^2$$

14. This is Kepler's Third Law of Planetary Motion (Johannes Kepler 1619)

Assumption #2: The X variable are not correlated (violation: multicollinearity)

When including more than one explanatory or independent variable (i.e., X variable) in an analysis, you must ensure that they are not related to each other. If you plot the X variables, you should see no pattern, such as the picture on the left between variables X1 and X2. If you see a relationship, such as on the right between X2 and X3, then multi-collinearity exists.



Effects of multi-collinearity

If the independent variables (x-variables) are correlated, the sign +/- will be reversed on one of the coefficients.

Test for Multi-collinearity

The Variance Inflation Factor test of correlated explanatory variables

Solution to Multi-collinearity

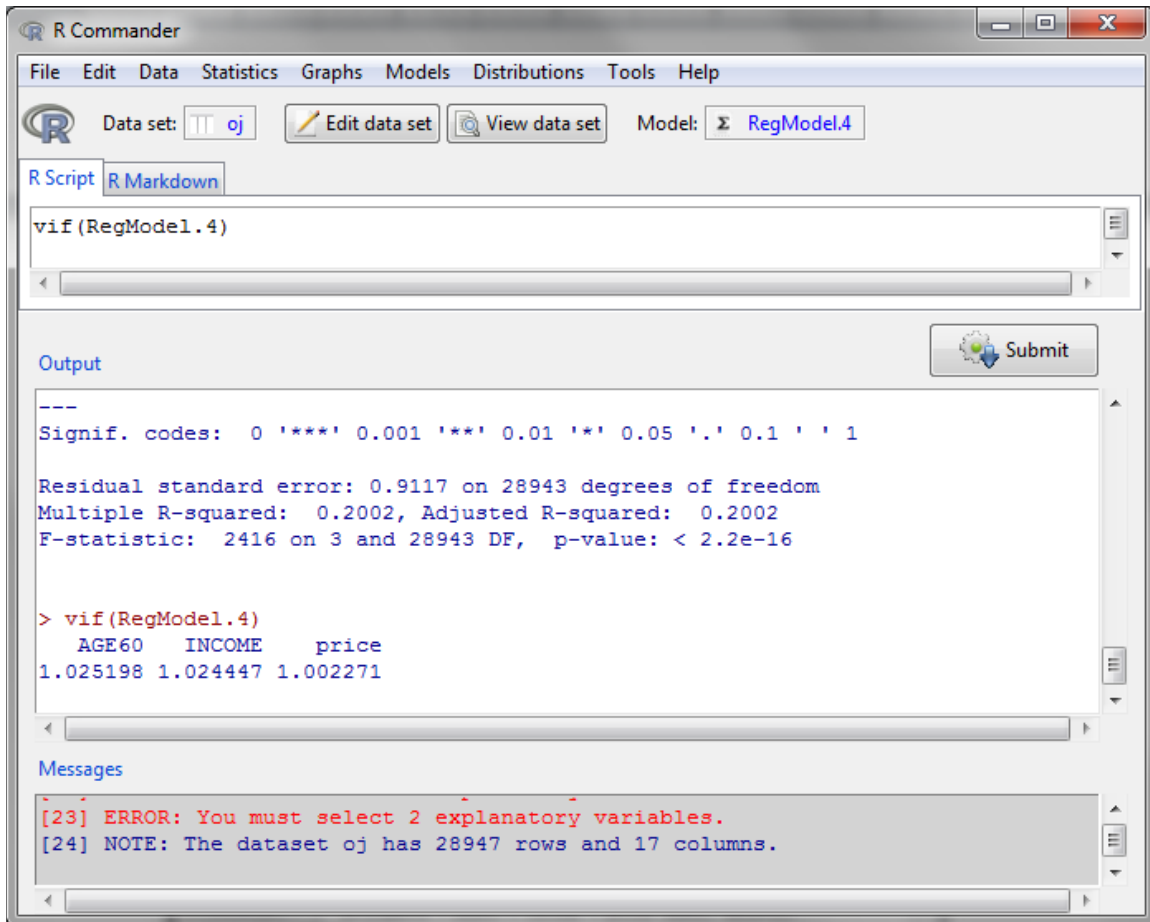
If two or more variables are collinear (highly correlated), there are three solutions:

1. Combine the variables, for example, take an average of the variables
2. Drop one of the variables
3. Use factor analysis to combine variables

Variance Inflation Factor test of correlated explanatory variables

To calculate the Variance Inflation Factor:

1. Click on Models, Numerical Diagnostics, Variance Inflation Factor



The screenshot shows the R Commander window. The 'Data set' is 'oj' and the 'Model' is 'RegModel.4'. The 'R Script' pane contains the command `vif(RegModel.4)`. The 'Output' pane displays the following text:

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9117 on 28943 degrees of freedom
Multiple R-squared:  0.2002, Adjusted R-squared:  0.2002
F-statistic: 2416 on 3 and 28943 DF, p-value: < 2.2e-16

> vif(RegModel.4)
    AGE60    INCOME    price 
1.025198 1.024447 1.002271
```

The 'Messages' pane shows the following messages:

```
[23] ERROR: You must select 2 explanatory variables.
[24] NOTE: The dataset oj has 28947 rows and 17 columns.
```

2. If the variance inflation factors are less than 10, then there is no multi-collinearity. If multi-collinearity exists, then drop variables or combine variables. Factor analysis is one technique for combining variables.

Correction for Multi-collinearity: Factor Analysis

Factor analysis identifies how many unique concepts are captured in the variables in your data.

Install

To install the modules, we need the psych library. Enter the following commands.

```
install.packages("psych",dependencies=TRUE)

library(psych)
```

Download Datasets

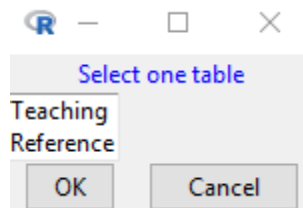
The teaching preference spreadsheet is on the G:drive in Session 13 and on BlackBoard. This data set is from Charles Zaiontz, from the website:

<http://www.real-statistics.com/multivariate-statistics/factor-analysis/factor-analysis-example/>

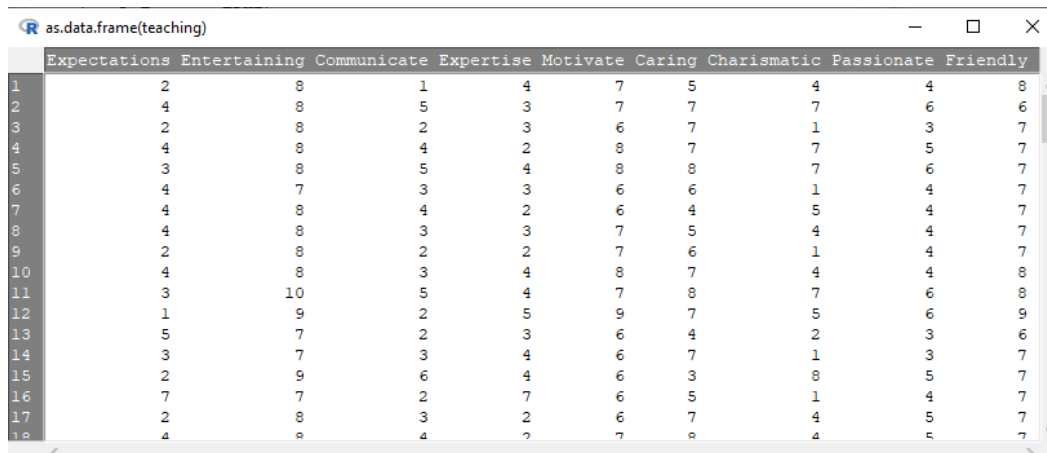
Loading Data

To load data into R:

1. Click on Data at the top of the screen
2. Click on Import Data > From Excel file ...
3. Enter the name that you would like to use for this data set; type in teaching, then OK
4. Click on the Teaching file, then Open
5. In this example, the Teaching spreadsheet has two worksheets, Teaching and Reference; click on Reference, then OK



6. In Rcmdr, click on View data



as.data.frame(teaching)

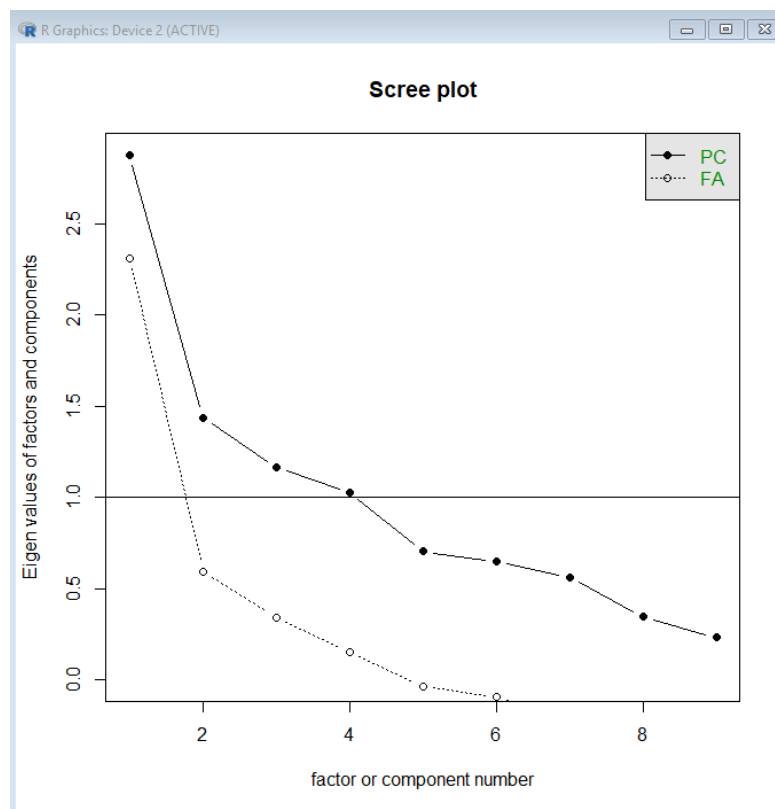
	Expectations	Entertaining	Communicate	Expertise	Motivate	Caring	Charismatic	Passionate	Friendly
1	2	8	1	4	7	5	4	4	8
2	4	8	5	3	7	7	7	6	6
3	2	8	2	3	6	7	1	3	7
4	4	8	4	2	8	7	7	5	7
5	3	8	5	4	8	8	7	6	7
6	4	7	3	3	6	6	1	4	7
7	4	8	4	2	6	4	5	4	7
8	4	8	3	3	7	5	4	4	7
9	2	8	2	2	7	6	1	4	7
10	4	8	3	4	8	7	4	4	8
11	3	10	5	4	7	8	7	6	8
12	1	9	2	5	9	7	5	6	9
13	5	7	2	3	6	4	2	3	6
14	3	7	3	4	6	7	1	3	7
15	2	9	6	4	6	3	8	5	7
16	7	7	2	7	6	5	1	4	7
17	2	8	3	2	6	7	4	5	7
18	4	8	4	2	7	8	4	5	7

7. This data represents what students feel are important characteristics for an instructor.
8. The characteristics are:

Expectations	Setting high expectations for the students
Entertaining	Entertaining
Communicate	Able to communicate effectively
Expertise	Having expertise in their subject
Motivate	Able to motivate
Caring	Caring
Charismatic	Charismatic
Passion	Having a passion for teaching
Friendly	Friendly and easy-going

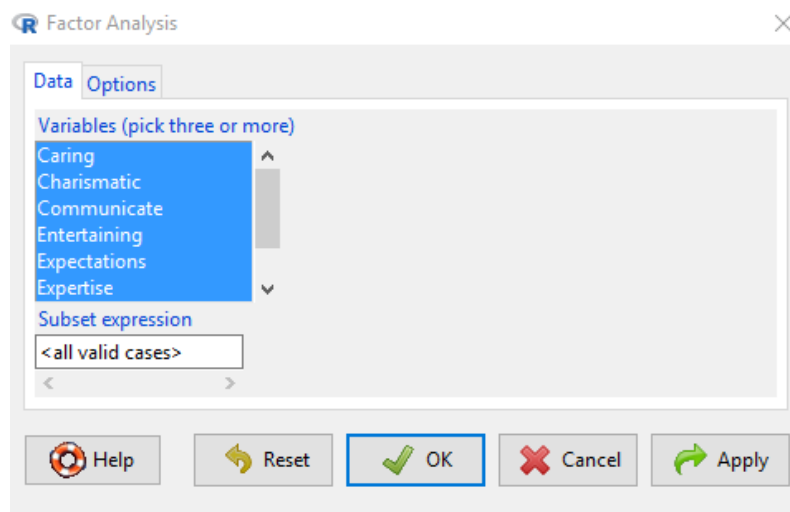
9. A screeplot will indicate how the measures above collapse into unique factors. Type the command:

```
scree(teaching)
```

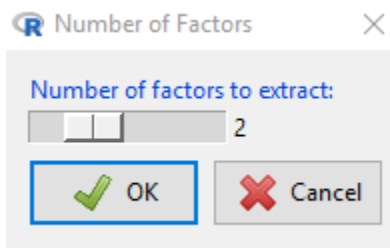


10. There are two techniques represented above, Principal Component Analysis (PC) and Factor Analysis (FA). The left side of the chart indicates Eigenvalues. The Kaiser criterion (Kaiser, 1960) recommends that the number of principal components or factors is the number of dots above the 1.0 line (eigenvalue > 1.0)
11. Now determine exactly how many factors we need.
12. Click on Statistics, Dimensional Analysis, Factor Analysis

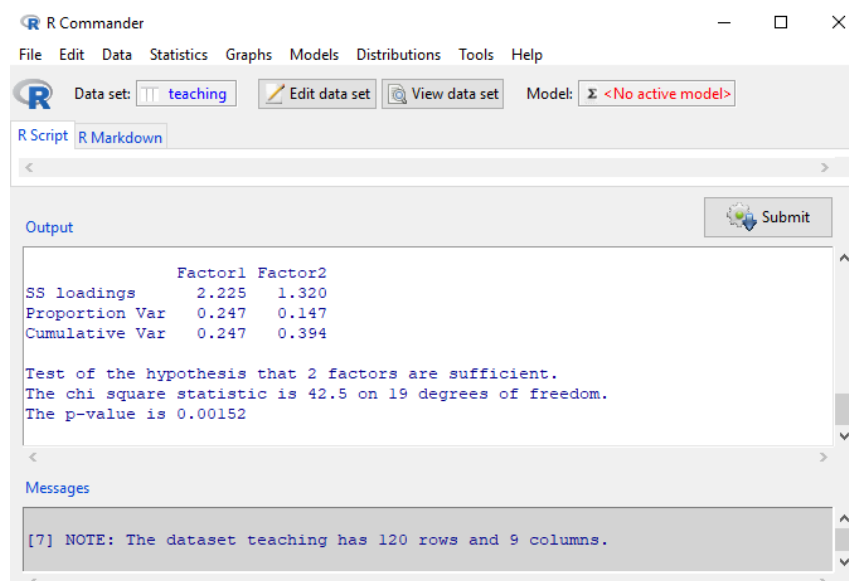
13. Highlight all the variables by holding down the control key and clicking each variable (or click on the first, hold the shift button down, then click on the last variable).



14. When asked for number of factors to extract, change to 2, then OK



15. The hypothesis is that 2 factors are sufficient. If $p < 0.05$, then 2 are not sufficient and we need to test 3 factors. In this case, $p = 0.00152$, so 2 is not sufficient



16. Click on Statistics, Dimensional Analysis, Factor Analysis, then OK
17. Change number of factors to 3, then OK

R Commander window showing the output of a Factor Analysis. The 'Data set' is 'teaching'. The 'Model' is '<No active model>'. The 'Output' pane displays the following results:

	Factor1	Factor2	Factor3
SS loadings	2.012	1.315	0.872
Proportion Var	0.224	0.146	0.097
Cumulative Var	0.224	0.370	0.466

Test of the hypothesis that 3 factors are sufficient.
The chi square statistic is 20.61 on 12 degrees of freedom.
The p-value is 0.0564

Messages pane shows: [7] NOTE: The dataset teaching has 120 rows and 9 columns.

18. Now, $p=0.0564$. Therefore, 3 factors are sufficient. This means that the original variables can be collapsed into three concepts.
19. Click on Statistics, Dimensional Analysis, Factor Analysis
20. Click on the Options tab, and check the button for Regression method, then OK
21. Set the Number of factors to extract to 3, the OK

R Commander window showing the output of a Factor Analysis. The 'Data set' is 'teaching'. The 'Model' is '<No active model>'. The 'Output' pane displays the following results:

	Factor1	Factor2	Factor3
Caring			0.437
Charismatic	0.824		0.218
Communicate	0.884		0.105
Entertaining	0.507	0.373	0.182
Expectations		-0.399	-0.225
Expertise	0.209	0.182	0.120
Friendly	0.131	0.975	-0.164
Motivate	0.266		0.538
Passionate	0.394	0.115	0.456

	Factor1	Factor2	Factor3
SS loadings	2.012	1.315	0.872
Proportion Var	0.224	0.146	0.097
Cumulative Var	0.224	0.370	0.466

Test of the hypothesis that 3 factors are sufficient.
The chi square statistic is 20.61 on 12 degrees of freedom.
The p-value is 0.0564

22. There are three factors. The numbers in the columns are loadings, which measure how much the original variable influences the factor. Which variables have a load of more than 0.500 for factor 1? Factor 2? Factor 3?
23. How would you interpret Factors 1, 2, 3?
24. In Rcmdr, click on View data; scroll to the right

25. The three new variables are F1, F2, F3, our new factors, calculated from the original variables
26. These are the variables that you would use in a regression
27. By selecting the Varimax rotation, the factors F1, F2, F3 will not be correlated, so multicollinearity in regression will not be a problem

as.data.frame(teaching)

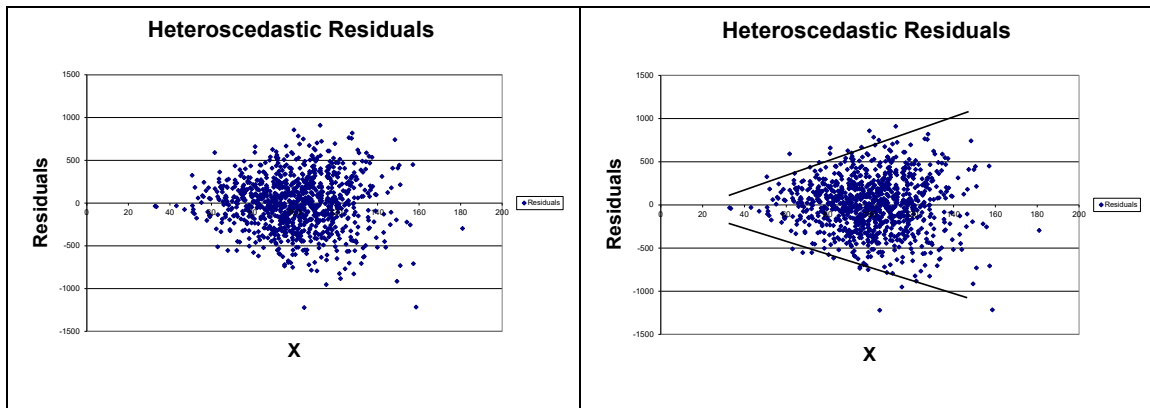
	ate	Caring	Charismatic	Passionate	Friendly		F1	F2	F3
1	7	5	4	4	8	-0.979186112	1.3314709	-0.0952331548	
2	7	7	7	6	6	0.638199552	-2.1508267	1.1183800856	
3	6	7	1	3	7	-1.211641842	-0.3836267	-0.1732023856	
4	8	7	7	5	7	0.354300389	-0.4456160	0.7441874343	
5	8	8	7	6	7	0.674046227	-0.3875633	1.3351334063	
6	6	6	1	4	7	-0.840939374	-0.5277226	-0.6827543492	
7	6	4	5	4	7	0.232887389	-0.7037285	-0.9052153492	
8	7	5	4	4	7	-0.311156035	-0.5095170	-0.1858942397	
9	7	6	1	4	7	-1.208444079	-0.3097434	0.2744069275	
10	8	7	4	4	8	-0.262721865	1.2553476	0.0632830297	
11	7	8	7	6	8	1.087519721	1.2134900	0.8288194046	
12	9	7	5	6	9	-0.360678041	3.2300026	1.3726750114	
13	6	4	2	3	6	-1.100657137	-2.2379099	-0.7741736478	
14	6	7	1	3	7	-0.919323213	-0.5028850	-0.6086545203	
15	6	3	8	5	7	1.460040232	-0.7688906	-0.3686660170	
16	6	5	1	4	7	-0.982010664	-0.5508256	-0.9338108103	
17	6	7	4	5	7	-0.438149022	-0.4046231	0.3277535562	
18	7	8	4	5	7	-0.049297354	-0.4412491	0.4509694507	
19	5	4	6	4	9	-0.140566651	2.6806387	-1.6971096907	
20	9	9	8	5	7	1.092871265	-0.4217942	1.4765586667	
21	6	3	3	6	8	0.004066874	1.0970168	-0.7124576402	
22	6	4	4	3	7	0.505367626	-0.8368609	-1.4700973383	
23	7	7	7	5	7	0.522726036	-0.4815022	0.6252276056	
24	6	5	7	4	8	0.262896501	1.0171167	-0.9518546698	
25	6	8	4	5	8	-0.662558349	1.3495923	0.2735379225	
26	8	7	9	6	7	1.392385482	-0.5428580	0.9883872577	
27	7	5	5	5	7	-0.256082157	-0.4091707	0.4363734323	
28	6	8	7	4	8	-0.635187538	1.3360781	0.2063587559	
29	7	7	1	5	7	-0.706798020	-0.3794901	0.2869615162	
30	6	5	5	5	8	-0.442950963	1.2280982	-0.2809939752	

Assumption #3a: The error terms do not have constant variance (violation: Heteroscedasticity)

The residuals (error terms) of a regression must have constant variance over a range of X values. If the size of the error terms depends on an X value, this is called heteroscedasticity.

Heteroscedasticity is often caused by performing a linear regression on non-linear data. In the charts below, there is no relationship between the X variable and the error term. On the right, the residuals or errors are heteroscedastic; the size of the error is dependent on the X value.

The picture below shows heteroscedastic residuals. Notice that the variability of the errors or residuals tends to grow larger for larger values of X. The picture on the right has lines added indicating the general growth in variability.



Effects of heteroscedasticity

If the residuals are heteroscedastic, the standard errors and p-values will be incorrect.

Test for Heteroscedasticity

Breusch-Pagan test of heteroscedasticity

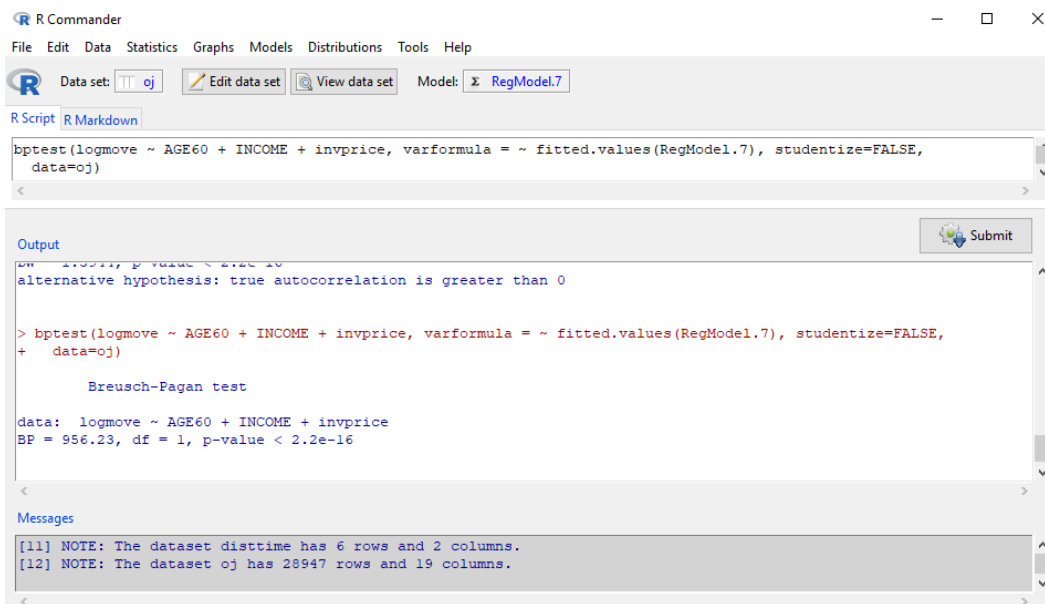
Solution to Heteroscedasticity

Heteroscedasticity is often caused by performing linear regression on non-linear data. Generally, solving non-linearity problems with transformations reduces or eliminates heteroscedasticity. If the problem is not completely resolved with a transformation, additional advanced techniques including Huber regression can correct lingering issues.

Breusch-Pagan test of heteroscedasticity

Heteroscedasticity means that the error terms are vary depending on values of the explanatory variables. To test for heteroscedasticity:

1. Click on Models, Numerical Diagnostics, Breusch-Pagan test for heteroscedasticity
2. Double click on AGE60, INCOME, invprice
3. Click on OK



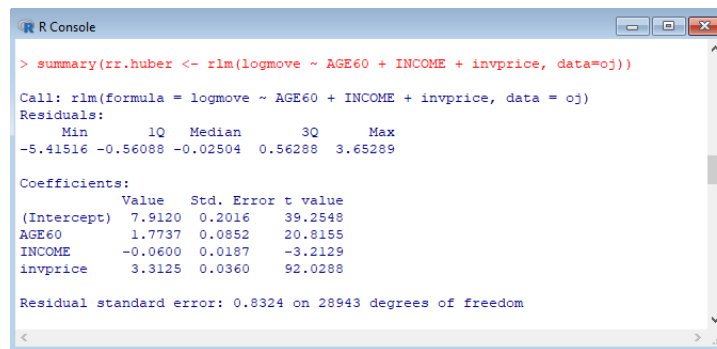
The screenshot shows the R Commander window. The 'R Script' pane contains the command: `bptest(logmove ~ AGE60 + INCOME + invprice, varformula = ~ fitted.values(RegModel.7), studentize=FALSE, data=o.j)`. The 'Output' pane shows the results of the Breusch-Pagan test: `BP = 956.23, df = 1, p-value < 2.2e-16`. The 'Messages' pane shows two notes: [11] NOTE: The dataset disttime has 6 rows and 2 columns. [12] NOTE: The dataset oj has 28947 rows and 19 columns.

4. If the p-value is less than 0.05, then there is a problem with heteroscedasticity. Generally, this is a sign that the equation is non-linear.
5. If you have already corrected for non-linearity, then more sophisticated techniques (robust Huber regression for heteroscedasticity) must be used. Install MASS if not already installed.

```
install.packages("MASS",dependencies=TRUE)
```

```
library(MASS)
```

```
summary(rr.huber <- rlm(logmove ~ AGE60 + INCOME + invprice, data=o.j))
```



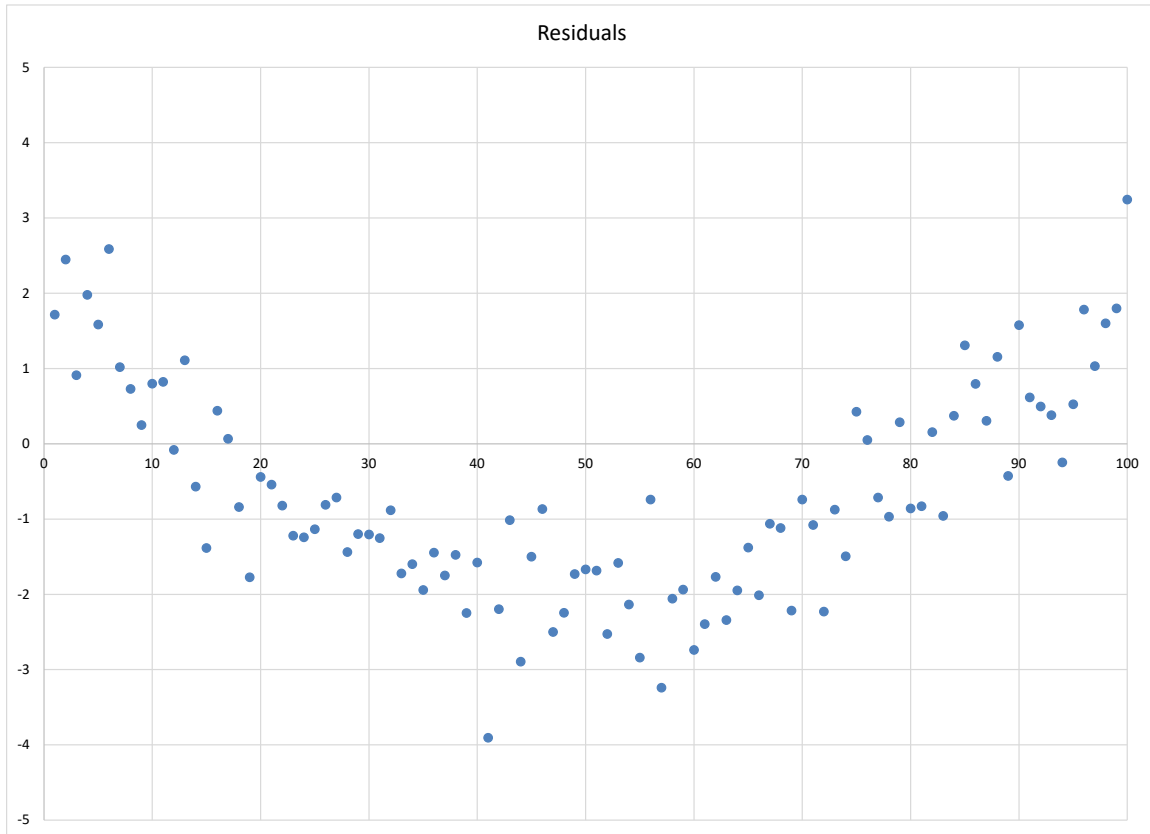
The screenshot shows the R Console output for the summary of the robust Huber regression model. The output includes the call: `Call: rlm(formula = logmove ~ AGE60 + INCOME + invprice, data = oj)`. The residuals are displayed as a table with columns: Min, 1Q, Median, 3Q, Max. The coefficients are displayed as a table with columns: Value, Std. Error, t value. The residual standard error is 0.8324 on 28943 degrees of freedom.

	Min	1Q	Median	3Q	Max
Residuals:	-5.41516	-0.56088	-0.02504	0.56288	3.65289

	Value	Std. Error	t value
(Intercept)	7.9120	0.2016	39.2548
AGE60	1.7737	0.0852	20.8155
INCOME	-0.0600	0.0187	-3.2129
invprice	3.3125	0.0360	92.0288

Assumption #3b: The residuals are not correlated (violation: Serial Correlation)

When dealing with data over time, it's possible for the error terms from one time period to be highly correlated with the previous time period. This is called serial correlation. The error terms or residuals will have a pattern that is not random, such as in the picture below.



Effects of serial correlation

If the residuals have serial correlation, the standard errors will be underestimated and the p-values will be incorrect

Test for Serial Correlation

Durbin-Watson test of serial correlation

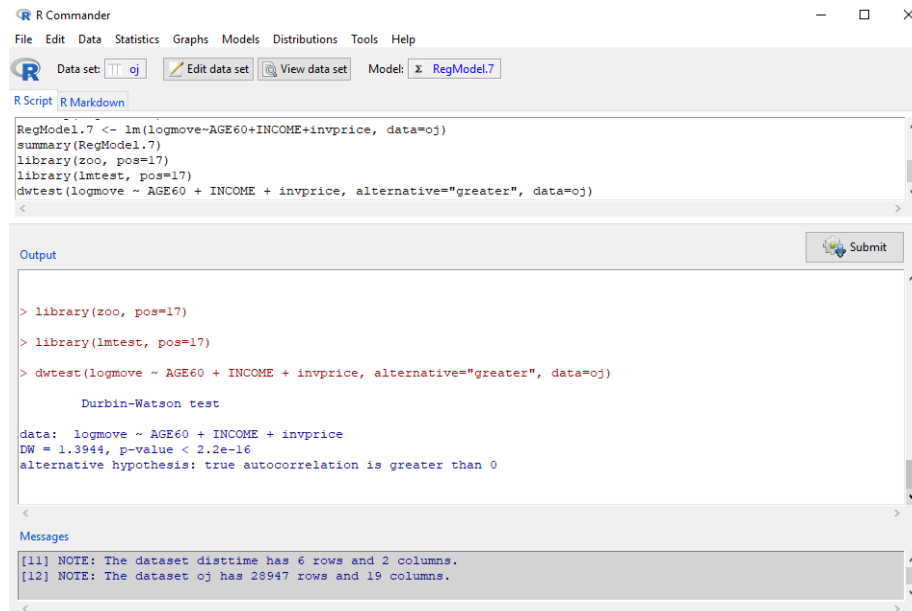
Solution to Serial Correlation

To correct for serial correlation there are a number of techniques in time series, including Prais-Winsten, rho differencing, ARCH, and Cochrane-Orcutt.

Durbin-Watson test of serial correlation

Serial correlation occurs when the errors terms are correlated. To test this,

1. Click on Models, Numerical Diagnostics, Durbin-Watson test for autocorrelation
2. Select $\rho > 0$, then OK



The screenshot shows the R Commander window. The 'R Script' pane contains the following code:

```
RegModel.7 <- lm(logmove~AGE60+INCOME+invprice, data=ojs)
summary(RegModel.7)
library(zoo, pos=17)
library(lmtest, pos=17)
dwtest(logmove ~ AGE60 + INCOME + invprice, alternative="greater", data=ojs)
```

The 'Output' pane shows the results of the Durbin-Watson test:

```
> library(zoo, pos=17)
> library(lmtest, pos=17)
> dwtest(logmove ~ AGE60 + INCOME + invprice, alternative="greater", data=ojs)

Durbin-Watson test

data: logmove ~ AGE60 + INCOME + invprice
DW = 1.3944, p-value < 2.2e-16
alternative hypothesis: true autocorrelation is greater than 0
```

The 'Messages' pane shows two notes:

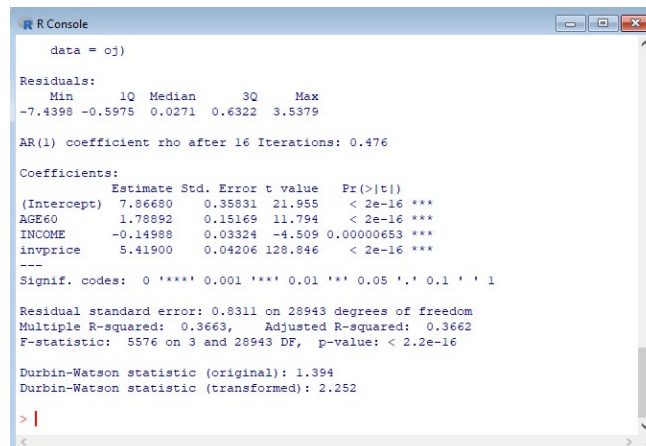
```
[11] NOTE: The dataset disttime has 6 rows and 2 columns.
[12] NOTE: The dataset ojs has 28947 rows and 19 columns.
```

3. If the p-value is less than 0.05, there is a problem with serial correlation.

Correction for Serial Correlation

There are several techniques for correction of serial correlation, including Cochrane-Orcutt (Cochrane, D.; Orcutt, G. H. (1949)), Prais-Winsten (Prais, S. J.; Winsten, C. B. (1954)) and rho differencing.

```
install.packages("prais",dependencies=TRUE)
library(prais)
pw <- prais_winsten(logmove ~ AGE60 + INCOME + invprice, data=ojs)
summary(pw)
```



The screenshot shows the R Console output for the `prais_winsten` function:

```
data = ojs)

Residuals:
    Min       1Q   Median       3Q      Max
-7.4398 -0.5975  0.0271  0.6322  3.5379

AR(1) coefficient rho after 16 iterations: 0.476

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.86680    0.35531   21.955 < 2e-16 ***
AGE60        1.78892    0.15169   11.794 < 2e-16 ***
INCOME       -0.14988    0.03324  -4.509 0.00000653 ***
invprice      5.41900    0.04206 128.846 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

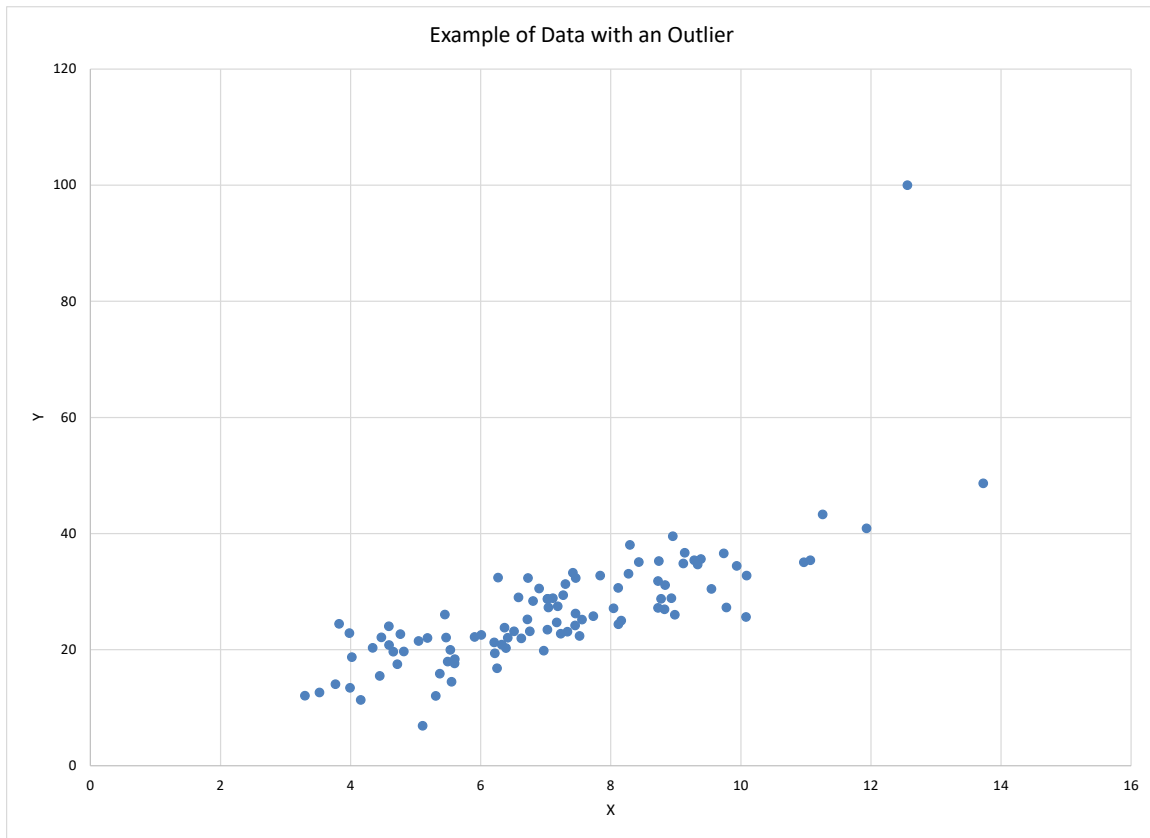
Residual standard error: 0.8311 on 28943 degrees of freedom
Multiple R-squared:  0.3663, Adjusted R-squared:  0.3662
F-statistic: 5576 on 3 and 28943 DF, p-value: < 2.2e-16

Durbin-Watson statistic (original): 1.394
Durbin-Watson statistic (transformed): 2.252

> |
```

Assumption #3c: There are no outliers (violation: Outliers)

An outlier is a data point that is significantly different from other data points. Outliers are often the result of unusual circumstances or data entry errors. The data below has an outlier.



Effect of outliers

If outliers exist in the data, the coefficients (slopes) will be incorrect.

Test for Outliers

Bonferroni outlier test

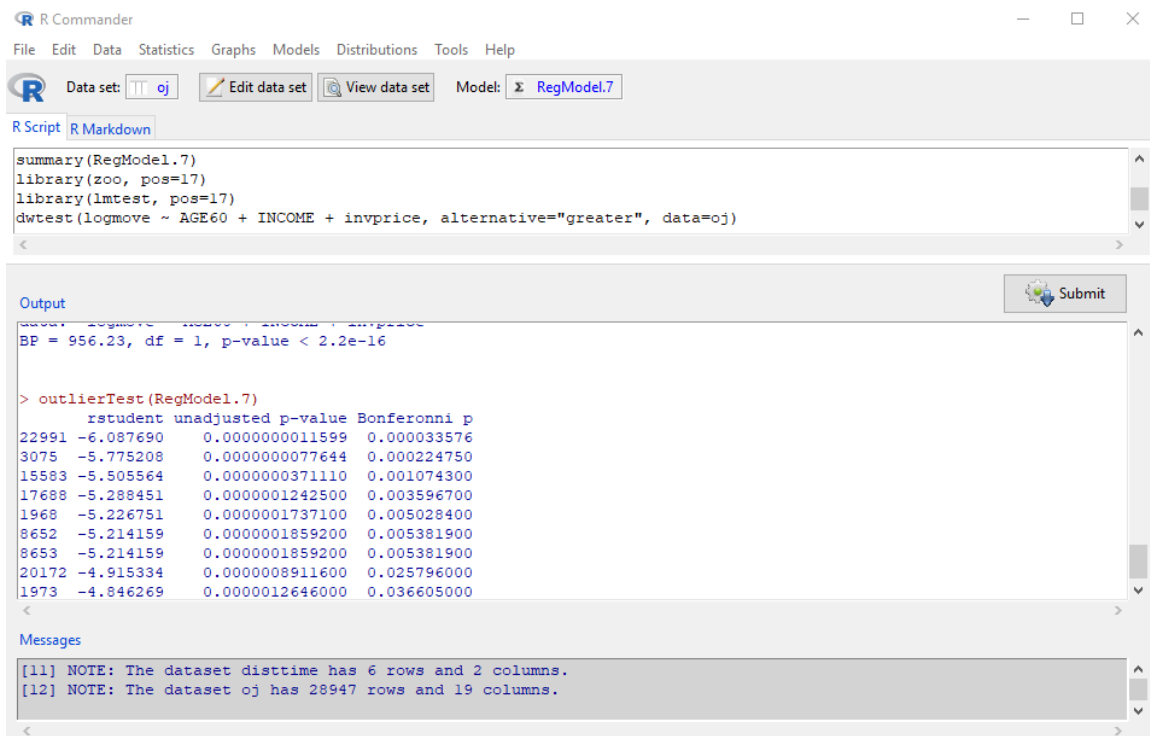
Solution to Outliers

If the data point is clearly an outlier, you can drop the bad data point, but mention in your analysis that you dropped outliers.

Bonferroni outlier test

Outliers are extreme data points that can influence the results and lead to incorrect coefficients. To identify outliers,

1. Click on Models, Numerical Diagnostics, Bonferroni outlier test



The screenshot shows the R Commander interface. The 'Data set' is 'oj' and the 'Model' is 'RegModel.7'. The R script pane contains the following code:

```
summary(RegModel.7)
library(zoo, pos=17)
library(lmtest, pos=17)
dwtest(logmove ~ AGE60 + INCOME + invprice, alternative="greater", data=oj)
```

The Output pane shows the results of the Bonferroni outlier test:

```
BP = 956.23, df = 1, p-value < 2.2e-16

> outlierTest(RegModel.7)
      rstudent unadjusted p-value Bonferonni p
22991 -6.087690   0.0000000011599  0.000033576
3075  -5.775208   0.0000000077644  0.000224750
15583 -5.505564   0.0000000371110  0.001074300
17688 -5.288451   0.0000001242500  0.003596700
1968  -5.226751   0.0000001737100  0.005028400
8652  -5.214159   0.0000001859200  0.005381900
8653  -5.214159   0.0000001859200  0.005381900
20172 -4.915334   0.0000008911600  0.025796000
1973  -4.846269   0.0000012646000  0.036605000
```

The Messages pane shows two notes:

```
[11] NOTE: The dataset disttime has 6 rows and 2 columns.
[12] NOTE: The dataset oj has 28947 rows and 19 columns.
```

2. Outliers have a Bonferonni p value < 0.05
3. In this example, there are several outliers. It is usually best to remove these data points from your data and retest the model. Always document that you removed outliers.

