# Tutorial 4: Regression Model Estimation

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## Agenda

1. Create data frames
2. Subset data frames
3. Estimate a linear model with `lm()`
4. Tips and tricks

- Prefix your objects in R (and related `TAB` tricks, i.e. arguments within function, variables within a data frame)
- `fig.height()`, `fig.width()`
- Code length <= 80 (RStudio > Tools > Options > Code)

## 1. Create data frames

```
my_dataframe <- data.frame(var1 = c(11, 12, 13),
                           var2 = c(21, 22, 23),
                           var3 = c("a", "b", "c"))
my_dataframe
```

```
##   var1 var2 var3
## 1   11   21    a
## 2   12   22    b
## 3   13   23    c
```

## 2. Subset data frames

All subsetting can be done with the following construct: `my_dataframe[?1 , ?2]`

The first question mark (`?1`) refers to which rows we want. The second question mark (`?2`) refers to which columns we want.

How to indicate to R which rows / columns we want? Multiple ways:

1. Use rows / columns index

```
my_dataframe[1, 2]
```

```
## [1] 21
```

```r
my_dataframe[1:2, 2]
```

```
## [1] 21 22
```

```r
my_dataframe[1:2, ]
```

```
##   var1 var2 var3
## 1   11   21    a
## 2   12   22    b
```

Rapid fire quiz

```r
my_dataframe[2:3, ]
my_dataframe[ , 1:2]
my_dataframe[1:2, 2:3]

my_dataframe[c(1, 3), ]
my_dataframe[c(1, 3, 2), ]
```

2. Use rows / columns name

```r
my_dataframe[ , "var2"]
```

```
## [1] 21 22 23
```

Rapid fire quiz:

```r
my_dataframe[ , c("var1", "var3")]
my_dataframe[c(2, 3), c("var1", "var3")]
```

3. Use a condition

```r
my_dataframe[c(TRUE, TRUE, FALSE), ]
```

```
##   var1 var2 var3
## 1   11   21    a
## 2   12   22    b
```

```r
my_dataframe[, c(TRUE, FALSE, TRUE)]
```

```
##   var1 var3
## 1   11    a
## 2   12    b
## 3   13    c
```

Of course this is not tenable for a large data frame. So we have this very useful trick:

```
my_dataframe[my_dataframe$var1 < 13, ]
```

```
##   var1 var2 var3
## 1   11   21    a
## 2   12   22    b
```

This works because `my_dataframe$var1 < 13` actuall returns `c(TRUE, TRUE, FALSE)` (vectorized operation in the wild!). Indeed:

```
my_dataframe$var1 < 13
```

```
## [1]  TRUE  TRUE FALSE
```

Rapid fire quiz:

```
my_dataframe[my_dataframe$var2 == 22, ]
my_dataframe[my_dataframe$var2 == 25, ]
```

4. Use a combination of condition

```
my_dataframe[my_dataframe$var1 > 10 & my_dataframe$var2 > 21, ]
```

```
##   var1 var2 var3
## 2   12   22    b
## 3   13   23    c
```

```
my_dataframe[my_dataframe$var1 > 10 | my_dataframe$var2 > 21, ]
```

```
##   var1 var2 var3
## 1   11   21    a
## 2   12   22    b
## 3   13   23    c
```

# 3. Estimate a linear model with `lm()`

In this section, I'll demo a (simplified) pipeline of steps in doing regression analysis with real data.

## Download and clean data

```
library(WDI)
```

```
## Loading required package: RJSONIO
```

```
d_2010 <- WDI(indicator = c("NY.GDP.PCAP.CD", "SP.DYN.IMRT.IN", "SH.MED.PHYS.ZS"),
              start = 2010, end = 2010, extra = TRUE)
# d_2010[d_2010$region != "Aggregates", ]
```

There are a lot of unwanted columns. What if I just want `country`, `year`, and the three variables of interest (`NY.GDP.PCAP.CD`, `SP.DYN.IMRT.IN`, `SH.MED.PHYS.ZS`)? (Hint: subsetting)

```
d_2010 <- d_2010[d_2010$region != "Aggregates",
       c("country", "year", "NY.GDP.PCAP.CD", "SP.DYN.IMRT.IN", "SH.MED.PHYS.ZS")]
```

Rename columns:

```
colnames(d_2010)
```

```
## [1] "country"        "year"           "NY.GDP.PCAP.CD" "SP.DYN.IMRT.IN"
## [5] "SH.MED.PHYS.ZS"
```

```
colnames(d_2010)[3:5] <- c('gdppc', 'infant_mortality', 'number_of_physician')
colnames(d_2010)
```

```
## [1] "country"             "year"                "gdppc"
## [4] "infant_mortality"    "number_of_physician"
```

Log gdp per capita

```
d_2010$log_gdppc <- log(d_2010$gdppc)
```

Remove missing data

```
d_2010 <- na.omit(d_2010)
```

## Build a linear model

```
lm(infant_mortality ~ log_gdppc, data = d_2010)
```

```
##
## Call:
## lm(formula = infant_mortality ~ log_gdppc, data = d_2010)
##
## Coefficients:
## (Intercept)    log_gdppc
##      134.23       -12.74
```

```
m1 <- lm(infant_mortality ~ log_gdppc, data = d_2010)
summary(m1)
```

```
##
## Call:
## lm(formula = infant_mortality ~ log_gdppc, data = d_2010)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -25.684  -8.913  -0.527   6.729  50.541
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 134.2303     6.3274   21.21   <2e-16 ***
## log_gdppc   -12.7385     0.7236  -17.60   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.1 on 141 degrees of freedom
## Multiple R-squared:  0.6873, Adjusted R-squared:  0.6851
## F-statistic: 309.9 on 1 and 141 DF,  p-value: < 2.2e-16
```

```
m2 <- lm(infant_mortality ~ log_gdppc + number_of_physician, data = d_2010)
summary(m2)
```

```
##
## Call:
## lm(formula = infant_mortality ~ log_gdppc + number_of_physician,
##     data = d_2010)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -27.343  -8.182  -1.260   5.961  50.581
##
## Coefficients:
##                     Estimate Std. Error t value Pr(>|t|)
## (Intercept)         121.1074     7.4312  16.297  < 2e-16 ***
## log_gdppc           -10.5850     0.9824 -10.774  < 2e-16 ***
## number_of_physician  -2.9102     0.9288  -3.133  0.00211 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.71 on 140 degrees of freedom
## Multiple R-squared:  0.7078, Adjusted R-squared:  0.7036
## F-statistic: 169.6 on 2 and 140 DF,  p-value: < 2.2e-16
```

## Extract result from the model

`str()` (stands for `structure`) is used to look into the structure of an object in `R`, see what it contains.

```
str(m1)
```

```
## List of 12
##  $ coefficients : Named num [1:2] 134.2 -12.7
##   ..- attr(*, "names")= chr [1:2] "(Intercept)" "log_gdppc"
```

```
##  $ residuals    : Named num [1:143] 4.16 5.94 21.51 -13.48 -15.62 ...
##   ..- attr(*, "names")= chr [1:143] "6" "7" "8" "10" ...
##  $ effects      : Named num [1:143] -293.3 230.7 21.9 -13.7 -15.7 ...
##   ..- attr(*, "names")= chr [1:143] "(Intercept)" "log_gdppc" "" "" ...
##  $ rank         : int 2
##  $ fitted.values: Named num [1:143] -1.66 1.36 53.59 28.28 31.72 ...
##   ..- attr(*, "names")= chr [1:143] "6" "7" "8" "10" ...
##  $ assign       : int [1:2] 0 1
##  $ qr           :List of 5
##   ..$ qr   : num [1:143, 1:2] -11.9583 0.0836 0.0836 0.0836 0.0836 ...
##   .. ..- attr(*, "dimnames")=List of 2
##   .. .. ..$ : chr [1:143] "6" "7" "8" "10" ...
##   .. .. ..$ : chr [1:2] "(Intercept)" "log_gdppc"
##   .. ..- attr(*, "assign")= int [1:2] 0 1
##   ..$ qraux: num [1:2] 1.08 1.09
##   ..$ pivot: int [1:2] 1 2
##   ..$ tol  : num 1e-07
##   ..$ rank : int 2
##   ..- attr(*, "class")= chr "qr"
##  $ df.residual  : int 141
##  $ xlevels      : Named list()
##  $ call         : language lm(formula = infant_mortality ~ log_gdppc, data = d_2010)
##  $ terms        :Classes 'terms', 'formula' length 3 infant_mortality ~ log_gdppc
##   .. ..- attr(*, "variables")= language list(infant_mortality, log_gdppc)
##   .. ..- attr(*, "factors")= int [1:2, 1] 0 1
##   .. .. ..- attr(*, "dimnames")=List of 2
##   .. .. .. ..$ : chr [1:2] "infant_mortality" "log_gdppc"
##   .. .. .. ..$ : chr "log_gdppc"
##   .. ..- attr(*, "term.labels")= chr "log_gdppc"
##   .. ..- attr(*, "order")= int 1
##   .. ..- attr(*, "intercept")= int 1
##   .. ..- attr(*, "response")= int 1
##   .. ..- attr(*, ".Environment")=<environment: R_GlobalEnv>
##   .. ..- attr(*, "predvars")= language list(infant_mortality, log_gdppc)
##   .. ..- attr(*, "dataClasses")= Named chr [1:2] "numeric" "numeric"
##   .. .. ..- attr(*, "names")= chr [1:2] "infant_mortality" "log_gdppc"
##  $ model        :'data.frame':   143 obs. of  2 variables:
##   ..$ infant_mortality: num [1:143] 2.5 7.3 75.1 14.8 16.1 13 3.6 4.1 33.9 6.4 ...
##   ..$ log_gdppc       : num [1:143] 10.67 10.43 6.33 8.32 8.05 ...
##   ..- attr(*, "terms")=Classes 'terms', 'formula' length 3 infant_mortality ~ log_gdppc
##   .. .. ..- attr(*, "variables")= language list(infant_mortality, log_gdppc)
##   .. .. ..- attr(*, "factors")= int [1:2, 1] 0 1
##   .. .. .. ..- attr(*, "dimnames")=List of 2
##   .. .. .. .. ..$ : chr [1:2] "infant_mortality" "log_gdppc"
##   .. .. .. .. ..$ : chr "log_gdppc"
##   .. .. ..- attr(*, "term.labels")= chr "log_gdppc"
##   .. .. ..- attr(*, "order")= int 1
##   .. .. ..- attr(*, "intercept")= int 1
##   .. .. ..- attr(*, "response")= int 1
##   .. .. ..- attr(*, ".Environment")=<environment: R_GlobalEnv>
##   .. .. ..- attr(*, "predvars")= language list(infant_mortality, log_gdppc)
##   .. .. ..- attr(*, "dataClasses")= Named chr [1:2] "numeric" "numeric"
##   .. .. .. ..- attr(*, "names")= chr [1:2] "infant_mortality" "log_gdppc"
##  - attr(*, "class")= chr "lm"
```

You can extract the coefficients

```
m1$coefficients
```

```
## (Intercept)   log_gdppc
##    134.2303    -12.7385
```

```
m1$coefficients['(Intercept)']
```

```
## (Intercept)
##    134.2303
```

```
m1$coefficients['log_gdppc']
```

```
## log_gdppc
##  -12.7385
```

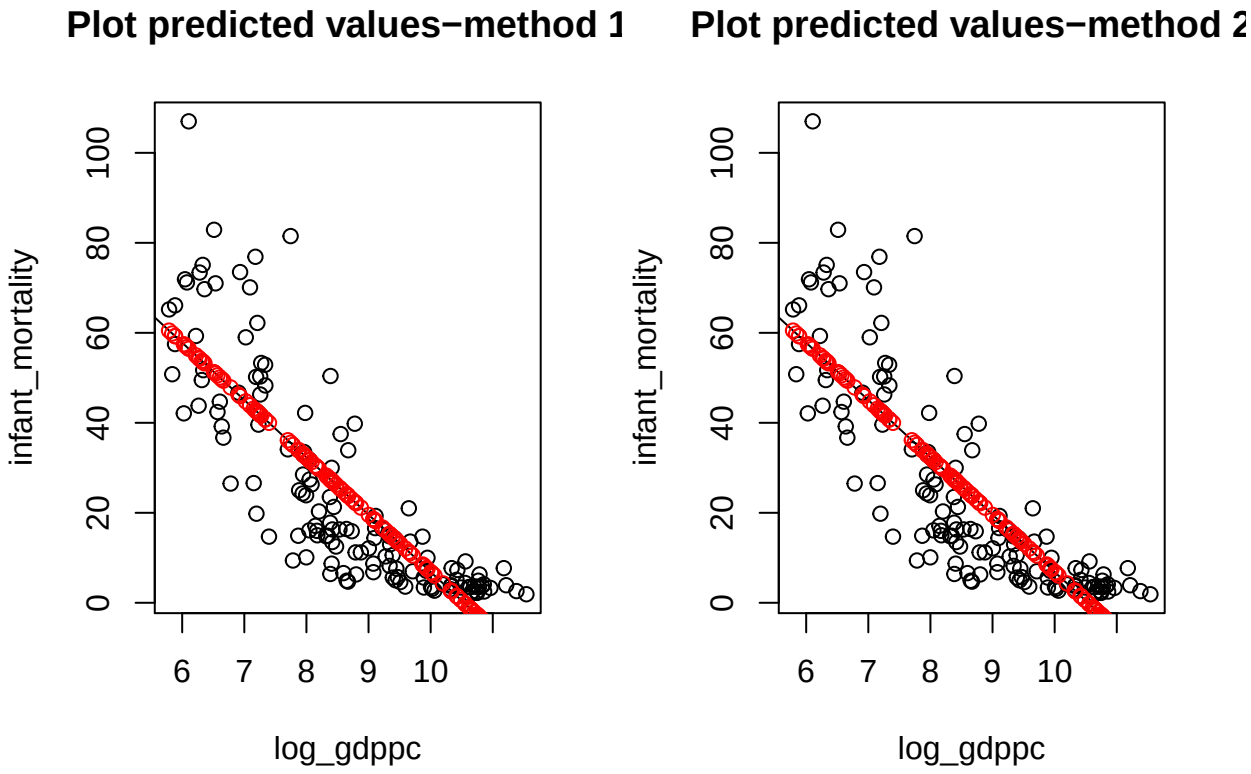
You can also generate predicted / fitted values:

```
d_2010$pred_infant_mortality1 <- predict(m1)
d_2010$pred_infant_mortality2 <- m1$coefficients['(Intercept)'] + m1$coefficients['log_gdppc'] * d_2010
```

Now we can use them for other things, e.g plotting

```
par(mfrow = c(1, 2))
plot(infant_mortality ~ log_gdppc, data = d_2010, main = "Plot predicted values-method 1")
abline(a = m1$coefficients['(Intercept)'], b = m1$coefficients['log_gdppc'])
points(d_2010$log_gdppc, d_2010$pred_infant_mortality1, col = 'red')

plot(infant_mortality ~ log_gdppc, data = d_2010, main = "Plot predicted values-method 2")
abline(a = m1$coefficients['(Intercept)'], b = m1$coefficients['log_gdppc'])
points(d_2010$log_gdppc, d_2010$pred_infant_mortality2, col = 'red')
```




### Report the model in a nice, journal-ready format

The `stargazer` library takes your model objects and generates tables in LaTeX. This package has a lot of customizing options, which you'll explore in the homework.

```
library(stargazer)
```

```
##
## Please cite as:
##
##  Hlavac, Marek (2014). stargazer: LaTeX code and ASCII text for well-formatted regression and summary
##  R package version 5.1. http://CRAN.R-project.org/package=stargazer
```

```
# LaTeX code that you can copy paste into LateX
stargazer(m1, m2)
```

```
##
## % Table created by stargazer v.5.1 by Marek Hlavac, Harvard University. E-mail: hlavac at fas.harvar
## % Date and time: Thu, Sep 17, 2015 - 10:49:54 AM
## \begin{table}[!htbp] \centering
##   \caption{}
##   \label{}
## \begin{tabular}{@{\extracolsep{5pt}}lcc}
## \\[-1.8ex]\hline
## \hline \\[-1.8ex]
##  & \multicolumn{2}{c}{\textit{Dependent variable:}} \\
## \cline{2-3}
```

```
## \\[-1.8ex] & \multicolumn{2}{c}{infant\_mortality} \\
## \\[-1.8ex] & (1) & (2)\\
## \hline \\[-1.8ex]
##  log\_gdppc & $-$12.739$^{***}$ & $-$10.585$^{***}$ \\
##   & (0.724) & (0.982) \\
##   & & \\
##  number\_of\_physician &  & $-$2.910$^{***}$ \\
##   &  & (0.929) \\
##   & & \\
##  Constant & 134.230$^{***}$ & 121.107$^{***}$ \\
##   & (6.327) & (7.431) \\
##   & & \\
## \hline \\[-1.8ex]
## Observations & 143 & 143 \\
## R$^{2}$ & 0.687 & 0.708 \\
## Adjusted R$^{2}$ & 0.685 & 0.704 \\
## Residual Std. Error & 13.102 (df = 141) & 12.711 (df = 140) \\
## F Statistic & 309.911$^{***}$ (df = 1; 141) & 169.553$^{***}$ (df = 2; 140) \\
## \hline
## \hline \\[-1.8ex]
## \textit{Note:}  & \multicolumn{2}{r}{$^{*}$p$<$0.1; $^{**}$p$<$0.05; $^{***}$p$<$0.01} \\
## \end{tabular}
## \end{table}
```

```
# If using knir, use the option results='asis'
stargazer(m1, m2)
```

% Table created by stargazer v.5.1 by Marek Hlavac, Harvard University. E-mail: hlavac at fas.harvard.edu
% Date and time: Thu, Sep 17, 2015 - 10:49:54 AM

Table 1:

| | *Dependent variable:* | |
|---|---|---|
| | infant_mortality | |
| | (1) | (2) |
| log_gdppc | $-12.739^{***}$ | $-10.585^{***}$ |
| | (0.724) | (0.982) |
| number_of_physician | | $-2.910^{***}$ |
| | | (0.929) |
| Constant | $134.230^{***}$ | $121.107^{***}$ |
| | (6.327) | (7.431) |
| Observations | 143 | 143 |
| $R^2$ | 0.687 | 0.708 |
| Adjusted $R^2$ | 0.685 | 0.704 |
| Residual Std. Error | 13.102 (df = 141) | 12.711 (df = 140) |
| F Statistic | $309.911^{***}$ (df = 1; 141) | $169.553^{***}$ (df = 2; 140) |
| *Note:* | | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 |