

Lecture 1: Basic R

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Basic R

Introduction

One cannot acquire a new programming language without investing numerous hours. [R-Introduction](#) is an official manual maintained by the R core team. It was the first document that I perused painstakingly when I began to learn R in 2005. After so many years, this is still the best starting point for you to have a taste.

This lecture quickly sketches some key points of the manual, while you should carefully go over R-Introduction after today's lecture.

Help System

The help system is the first thing we must learn for a new language. In R, if we know the exact name of a function and want to check its usage, we can either call `help(function_name)` or a single question mark `?function_name`. If we do not know the exact function name, we can instead use the double question mark `??key_words`. It will provide a list of related function names from a fuzzy search.

Example: `?seq`, `??sequence`

Vector

A *vector* is a collection of elements of the same type, say, integer, logical value, real number, complex number, characters or factor. Unlike C, R does not require explicit type declaration.

`<-` assigns the value on its right-hand side to a self-defined variable name on its left-hand side. `=` is an alternative for assignment, which I prefer.

`c()` combines two or more vectors into a long vector.

Binary arithmetic operations `+`, `-`, `*` and `\` are performed element by element. So are the binary logical operations `&` `|` `!=`.

Factor is a categorical number. *Character* is text.

Missing values in R is represented as `NA` (Not Available). When some operations are not allowed, say, `log(-1)`, R returns `NaN` (Not a Number).

Vector selection is specified in square bracket `a[]` by either positive integer or logical vector.

Example

Logical vector operation.

```
# logical vectors
logi_1 = c(T,T,F)
logi_2 = c(F,T,T)

logi_12 = logi_1 & logi_2
print(logi_12)
```

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

Array and Matrix

An array is a table of numbers.

A matrix is a 2-dimensional array.

- array arithmetic: element-by-element. Caution must be exercised in binary operations involving two objects of different length. This is error-prone.
- `%%`, `solve`, `eigen`

Example

OLS estimation with one x regressor and a constant. Graduate textbook expresses the OLS in matrix form

$$\hat{\beta} = (X'X)^{-1}X'y.$$

To conduct OLS estimation in R, we literally translate the mathematical expression into code.

Step 1: We need data Y and X to run OLS. We simulate an artificial dataset.

```
# simulate data
rm(list = ls( ))
set.seed(111) # can be removed to allow the result to change

# set the parameters
n = 100
b0 = matrix(1, nrow = 2 )

# generate the data
e = rnorm(n)
X = cbind( 1, rnorm(n) )
Y = X %*% b0 + e
```

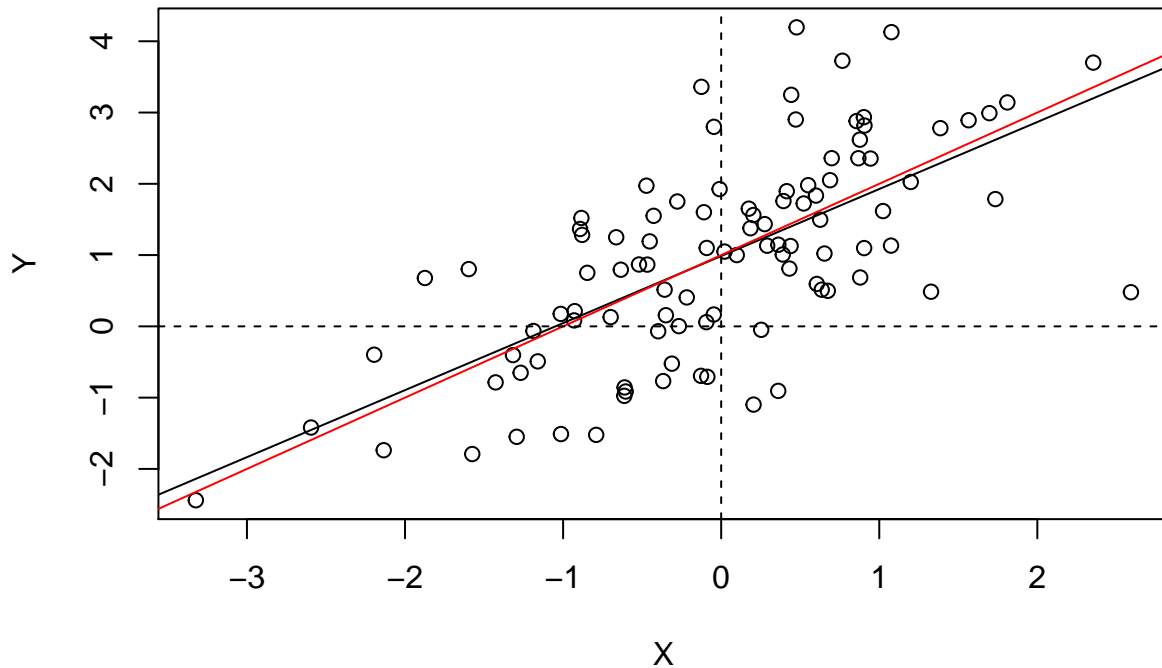
Step 2: translate the formula to code

```
# OLS estimation
bhat = solve( t(X) %*% X, t(X)%*% Y )
```

Step 3 (additional): plot the regression graph with the scatter points and the regression line. Further compare the regression line (black) with the true coefficient line (red).

```
# plot
plot( y = Y, x = X[,2], xlab = "X", ylab = "Y", main = "regression")
abline( a = bhat[1], b = bhat[2])
abline( a = b0[1], b = b0[2], col = "red")
abline( h = 0, lty = 2)
abline( v = 0, lty = 2)
```

regression



Step 4: In econometrics we are often interested in hypothesis testing. The t -statistic is widely used. To test the null $H_0 : \beta_2 = 1$, we compute the associated t -statistic. Again, this is a translation.

$$t = \frac{\hat{\beta}_2 - \beta_{02}}{\hat{\sigma}_{\hat{\beta}_2}} = \frac{\hat{\beta}_2 - \beta_{02}}{\sqrt{[(X'X)^{-1}\hat{\sigma}^2]_{22}}}.$$

where $[\cdot]_{22}$ is the (2,2)-element of a matrix.

```
# calculate the t-value
bhat2 = bhat[2] # the parameter we want to test
e_hat = Y - X %*% bhat
sigma_hat_square = sum(e_hat^2) / (n-2)
Sigma_B = solve( t(X) %*% X ) * sigma_hat_square
t_value_2 = ( bhat2 - b0[2] ) / sqrt( Sigma_B[2,2] )
print(t_value_2)
```

```
## [1] -0.5615293
```

Package

A pure clean installation of R is small, but R has an extensive ecosystem of add-on packages. This is the unique treasure for R users, and other languages like Python or MATLAB are not even close. Most packages are hosted on [CRAN](https://cran.r-project.org/). A common practice today is that statisticians upload a package to CRAN after they write or publish a paper with a new statistical method. They promote their work via CRAN, and users have easy access to the state-of-the-art methods.

A package can be installed by `install.packages("package_name")` and invoked by `library(package_name)`.

[Applied Econometrics with R](#) by Christian Kleiber and Achim Zeileis is a useful book. It also has a companion package **AER** that contains popular econometric methods such as instrumental variable regression and robust variance.

Before we can “knit” in R-studio the Rmd file to produce the pdf document you are reading at this moment, we have to install several packages such as [knitr](#) and those it depends on.

Mixed Data Types

A vector only contains one type of elements. *list* is a basket for objects of various types. It can serve as a container when a procedure returns more than one useful object. For example, when we invoke **eigen**, we are interested in both eigenvalues and eigenvectors, which are stored into **\$value** and **\$vector**, respectively.

data.frame is a two-dimensional table that stores the data, similar to a spreadsheet in Excel. A matrix is also a two-dimensional table, but it only accommodates one type of elements. Real world data can be a collection of integers, real numbers, characters, categorical numbers and so on. Data frame is the best way to organize data of mixed type in R.

Example

This is a data set in a graduate-level econometrics textbook. We load the data into memory and display the first 6 records.

```
library(AER)
```

```
## Warning: package 'zoo' was built under R version 3.4.2
```

```
## Warning: package 'sandwich' was built under R version 3.4.2
```

```
data("CreditCard")
head(CreditCard)
```

```
##   card reports      age income      share expenditure owner selfemp
## 1  yes        0 37.66667 4.5200 0.033269910 124.983300   yes    no
## 2  yes        0 33.25000 2.4200 0.005216942   9.854167    no    no
## 3  yes        0 33.66667 4.5000 0.004155556 15.000000    yes    no
## 4  yes        0 30.50000 2.5400 0.065213780 137.869200    no    no
## 5  yes        0 32.16667 9.7867 0.067050590 546.503300    yes    no
## 6  yes        0 23.25000 2.5000 0.044438400  91.996670    no    no
##   dependents months majorcards active
## 1           3     54           1     12
## 2           3     34           1     13
## 3           4     58           1      5
## 4           0     25           1      7
## 5           2     64           1      5
## 6           0     54           1      1
```

Input and Output

Raw data is often saved in ASCII file or Excel. I discourage the use of Excel spreadsheet in data analysis, because the underlying structure of an Excel file is too complicated for statistical software to read. I recommend the use of *csv* format, a plain ASCII file format.

`read.table()` or `read.csv()` imports data from an ASCII file into an R session. `write.table()` or `write.csv()` exports the data in an R session to an ASCII file.

Example

Besides loading a data file on the local hard disk, We can directly download data from internet. Here we show how to retrieve the stock daily data of *Apple Inc.* from *Yahoo Finance*, and save the dataset locally. A package called *quantmod* is used.

```
install.packages("quantmod")
```

```
## Installing package into 'C:/Users/EconUser/Documents/R/win-library/3.4'
## (as 'lib' is unspecified)

## package 'quantmod' successfully unpacked and MD5 sums checked
##
## The downloaded binary packages are in
## C:\Users\EconUser\AppData\Local\Temp\Rtmp4Ynyyr\downloaded_packages
```

```
library(quantmod)
```

```
## Loading required package: xts
## Loading required package: TTR
## Version 0.4-0 included new data defaults. See ?getSymbols.
```

```
getSymbols("AAPL",from = "2017-01-01",to = Sys.Date(),src = "yahoo")
```

```
## 'getSymbols' currently uses auto.assign=TRUE by default, but will
## use auto.assign=FALSE in 0.5-0. You will still be able to use
## 'loadSymbols' to automatically load data. getOption("getSymbols.env")
## and getOption("getSymbols.auto.assign") will still be checked for
## alternate defaults.
##
## This message is shown once per session and may be disabled by setting
## options("getSymbols.warning4.0"=FALSE). See ?getSymbols for details.
##
## WARNING: There have been significant changes to Yahoo Finance data.
## Please see the Warning section of '?getSymbols.yahoo' for details.
##
## This message is shown once per session and may be disabled by setting
## options("getSymbols.yahoo.warning"=FALSE).
## [1] "AAPL"
```

```
print(head(AAPL))
```

```
##           AAPL.Open AAPL.High AAPL.Low AAPL.Close AAPL.Volume
## 2017-01-03    118.142   118.683  117.081    116.15    28781900
## 2017-01-04    118.193   118.866  118.091    116.02    21118100
## 2017-01-05    118.264   119.223  118.152    116.61    22193600
## 2017-01-06    119.142   120.550  118.825    117.91    31751900
## 2017-01-09    120.335   121.845  120.325    118.99    33561900
## 2017-01-10    121.172   121.794  120.692    119.11    24462100
##           AAPL.Adjusted
## 2017-01-03      113.8476
## 2017-01-04      113.7202
## 2017-01-05      114.2985
## 2017-01-06      115.5727
## 2017-01-09      116.6313
## 2017-01-10      116.7489
```

```
write.csv(AAPL, file = "AAPL.csv")
```

Statistics

R is a language created by statisticians. It has elegant built-in statistical functions. **p** (probability), **d** (density for a continuous random variable, or mass for a discrete random variable), **q** (quantile), **r** (random variable generator) are used ahead of the name of a probability distribution, such as **norm** (normal), **chisq** (χ^2), **t** (t), **weibull** (Weibull), **cauchy** (Cauchy), **binomial** (binomial), **pois** (Poisson), to name a few.

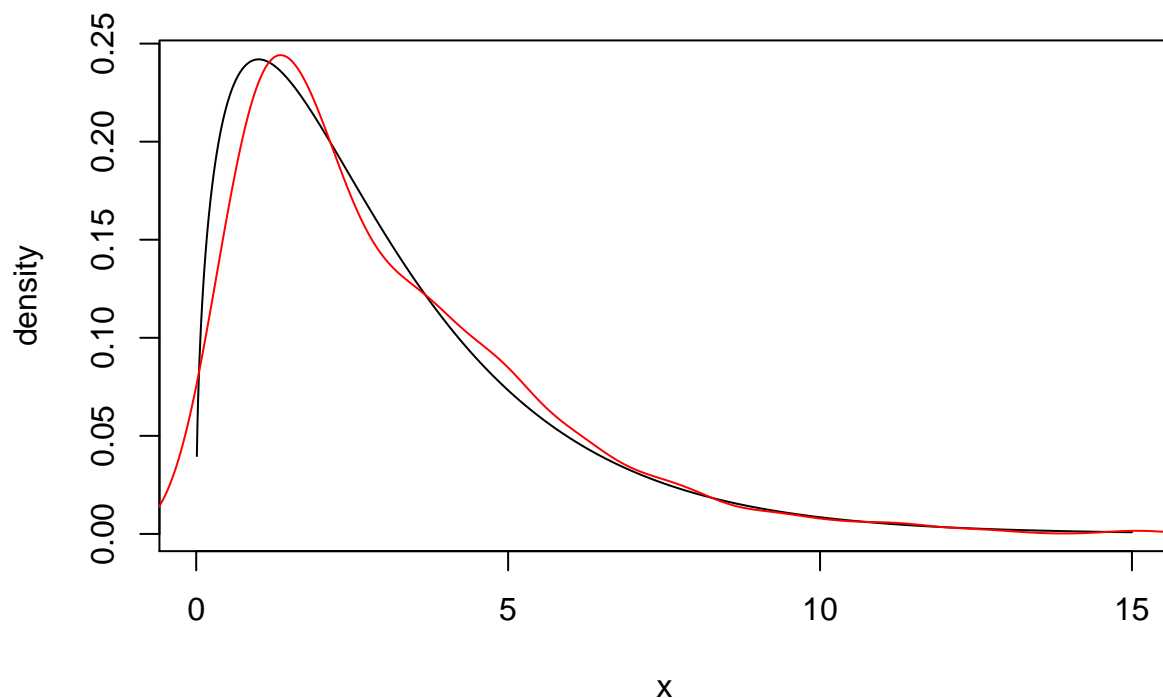
Example

This example illustrates the sampling error.

1. Plot the density of $\chi^2(3)$ over an equally spaced grid system `x_axis = seq(0.01, 15, by = 0.01)` (black line).
2. Generate 1000 observations from $\chi^2(3)$ distribution. Plot the kernel density, a nonparametric estimation of the density (red line).
3. Calculate the 95-th quantile and the empirical probability of observing a value greater than the 95-th quantile. In population, this value should be 5%. What is the number in this experiment?

```
set.seed(888)
x_axis = seq(0.01, 15, by = 0.01)

y = dchisq(x_axis, df = 3)
plot(y = y, x=x_axis, type = "l", xlab = "x", ylab = "density")
z = rchisq(1000, df = 3)
lines( density(z), col = "red")
```



```
crit = qchisq(.95, df = 3)
mean( z > crit )
## [1] 0.047
```

User-defined Function

R has numerous built-in functions. However, in practice we will almost always have some DIY functionality to be used repeatedly. It is highly recommended to encapsulate it into a user-defined function. There are important advantages:

1. In the developing stage, it allows us to focus on a small chunk of code. It cuts an overwhelmingly big project into manageable pieces.
2. A long script can have hundreds or thousands of variables. Variables defined inside a function are local. They will not be mixed up with those outside of a function. Only the input and the output of a function have interaction with the outside world.
3. If a revision is necessary, We just need to change one place. We don't have to repeat the work in every place where it is invoked.

The format of a user-defined function in R is

```
function_name = function(input) {
  expressions
  return(output)
}
```

Example

If the central limit theorem is applicable, then we can calculate the 95% two-sided asymptotic confidence interval as

$$\left(\hat{\mu} - \frac{1.96}{\sqrt{n}} \hat{\sigma}, \hat{\mu} + \frac{1.96}{\sqrt{n}} \hat{\sigma} \right)$$

from a given sample. It is an easy job, but I am not aware there is a built-in function in R to do this.

```
# construct confidence interval

CI = function(x){
  # x is a vector of random variables

  n = length(x)
  mu = mean(x)
  sig = sd(x)
  upper = mu + 1.96/sqrt(n) * sig
  lower = mu - 1.96/sqrt(n) * sig
  return( list( lower = lower, upper = upper) )
}
```

Flow Control

Flow control is common in all programming languages. `if` is used for choice, and `for` or `while` is used for loops.

Example

Calculate the empirical coverage probability of a Poisson distribution of degrees of freedom 2. We conduct this experiment for 1000 times.

```
Rep = 1000
sample_size = 100
capture = rep(0, Rep)

pts0 = Sys.time() # check time
for (i in 1:Rep){
  mu = 2
  x = rpois(sample_size, mu)
  bounds = CI(x)
  capture[i] = ( ( bounds$lower <= mu ) & (mu <= bounds$upper) )
}
mean(capture) # empirical size

## [1] 0.938

pts1 = Sys.time() - pts0 # check time elapse
print(pts1)
```

```
## Time difference of 0.04803395 secs
```

Statistical Model

Statistical models are formulated as $y \sim x$, where y on the left-hand side is the dependent variable, and x on the right-hand side is the explanatory variable. The built-in OLS function is `lm`. It is called by `lm(y~x, data = data_frame)`.

All built-in regression functions in R share the same structure. Once one type of regression is understood, it is easy to extend to other regressions.

A Linear Regression Example

Add a toy example by Zhan Gao for ECON3121D tutorial.

```
T = 100
p = 1

b0 = 1
# Generate data
x = matrix( rnorm(T*p), T, 1)
y = x %*% b0 + rnorm(T)

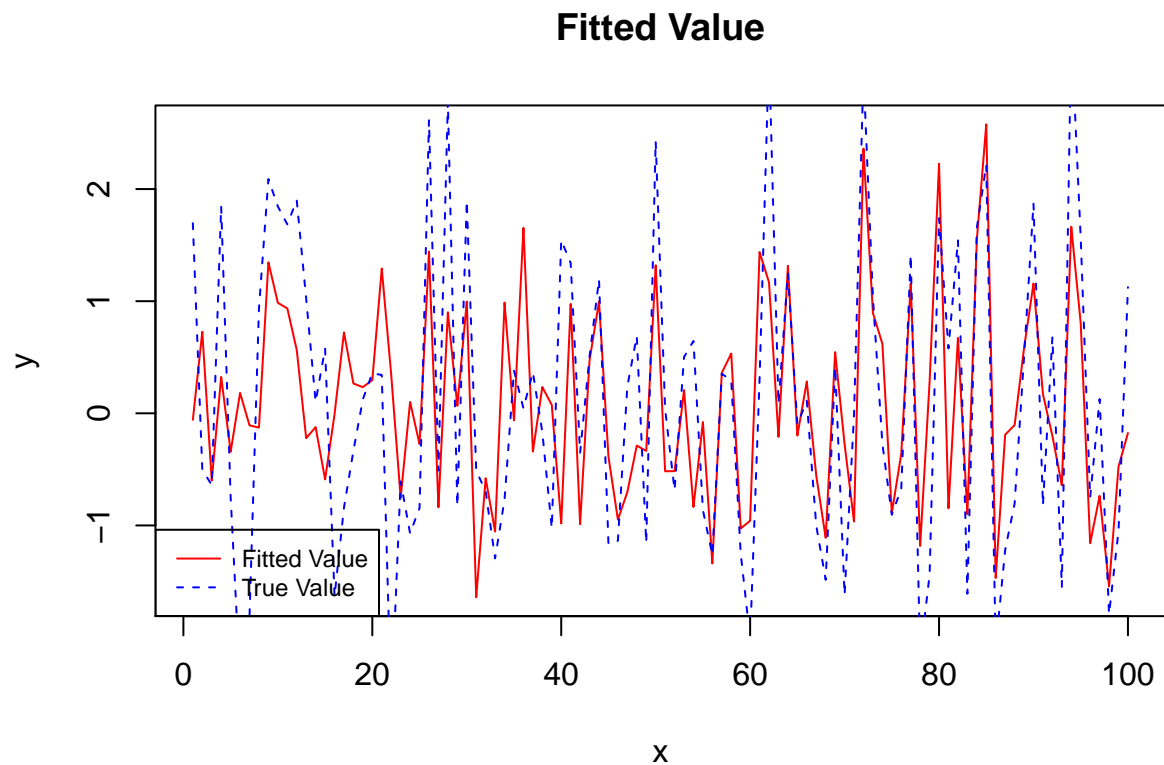
# Linear Model
result = lm(y ~ x)
summary(result)

##
## Call:
## lm(formula = y ~ x)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -2.96282 -0.70247 -0.02817  0.75194  2.52548
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.04445    0.10221   0.435   0.665
## x            0.84427    0.09604   8.791 5.06e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.021 on 98 degrees of freedom
## Multiple R-squared:  0.4409, Adjusted R-squared:  0.4352
## F-statistic: 77.29 on 1 and 98 DF,  p-value: 5.06e-14
```

The `result` object is a list containing the regression results. As shown in the results, we can easily read the estimated coefficients, t-test results, F-test results, and the R-sqaure.

We can plot the true value of y and fitted value to examine whether the regression model fit the data well.

```
plot(result$fitted.values, col = 'red', type = 'l', xlab = 'x', ylab = 'y',
     main = 'Fitted Value')
lines(y, col = 'blue', type = 'l', lty = 2)
legend('bottomleft', legend=c("Fitted Value", "True Value"),
     col=c("red", "blue"), lty=1:2, cex = 0.75)
```

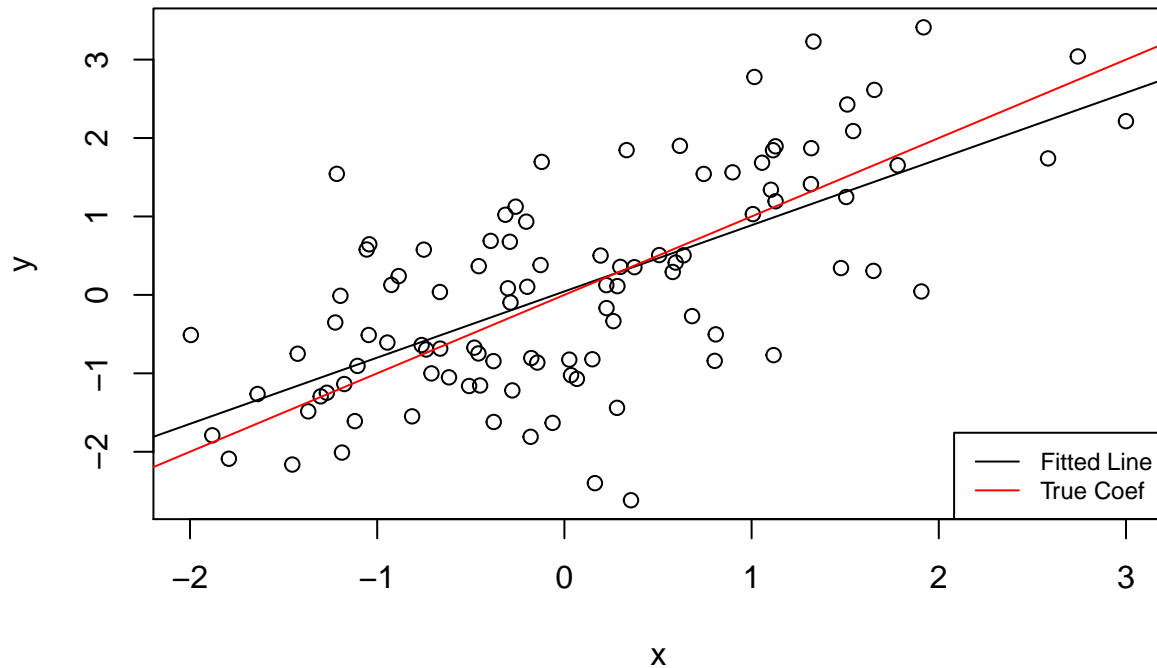


Then we plot the best fitted line.

```
plot( y = y, x = x, xlab = "x", ylab = "y", main = "Fitted Line")
abline( a= result$coefficients[1], b = result$coefficients[2])
abline( a = 0, b = b0, col = "red")

legend('bottomright', legend=c("Fitted Line", "True Coef"),
      col=c("black", "red"), lty=c(1,1), cex = 0.75)
```

Fitted Line



Another example.

```
a<-lm(women$height~women$weight)
b<-lm(women$height~women$weight+I(women$weight^2))
summary(a)
```

```
##
## Call:
## lm(formula = women$height ~ women$weight)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.83233 -0.26249  0.08314  0.34353  0.49790
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  25.723456   1.043746   24.64 2.68e-12 ***
## women$weight  0.287249   0.007588   37.85 1.09e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.44 on 13 degrees of freedom
## Multiple R-squared:  0.991, Adjusted R-squared:  0.9903
## F-statistic: 1433 on 1 and 13 DF, p-value: 1.091e-14
```

```
summary(b)
```

```
##
```

```
## Call:
## lm(formula = women$height ~ women$weight + I(women$weight^2))
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-0.105338	-0.035764	-0.004898	0.049430	0.141593

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	-1.175e+01	1.720e+00	-6.83	1.82e-05 ***
women\$weight	8.343e-01	2.502e-02	33.35	3.36e-13 ***
I(women\$weight^2)	-1.973e-03	9.014e-05	-21.89	4.84e-11 ***

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.07158 on 12 degrees of freedom
## Multiple R-squared:  0.9998, Adjusted R-squared:  0.9997
## F-statistic: 2.732e+04 on 2 and 12 DF,  p-value: < 2.2e-16
```